Species Profiles for Pacific Island Agroforestry
www.traditionaltree.org

April 2006
ver. 2.1

Artocarpus altilis (breadfruit)

Moraceae (mulberry family)

beta **(Vanuatu);** ***bia, bulo, nimbalu*** **(Solomon Islands); breadfruit (English);** ***kapiak*** **(Papua New Guinea);** ***kuru*** **(Cook Islands);** ***meduu*** **(Palau);** ***mei*** **(*****mai*****) (Federated States of Micronesia, Kiribati, Marshalls, Marquesas, Tonga, Tuvalu);** ***mos*** **(Kosrae);** ***'ulu*** **(Hawai'i, Samoa, Rotuma, Tuvalu);** ***'uru*** **(Society Islands);** ***uto, buco*** **(Fiji)**

Diane Ragone

IN BRIEF

Distribution Pantropical, very widely distributed.

Size Commonly found at 12–15 m (40–50 ft).

Habitat Grows best in tropical lowlands below 650 m (2160 ft) with rainfall of 1500–3000 mm (60–120 in).

Vegetation Associated with a wide variety of cultivated plants.

Soils Deep, fertile, well drained soils are preferred; some varieties are adapted to coral atolls.

Growth rate Fast growing in favorable conditions, growing 0.5–1.5 m (1.5–5 ft) per year.

Main agroforestry uses Soil stabilization, overstory, homegardens.

Main products Staple food, medicinal, lightweight wood.

Yields 160–500 kg (350–1100 lb) fruit per tree per year in intensive cultivation.

Intercropping Interplanted with small fruit trees or short-term fruit and vegetable crops.

Invasive potential Very little potential for invasiveness.

PHOTO: D. RAGONE

A young breadfruit tree.

INTRODUCTION

Breadfruit has long been an important staple crop and a primary component of traditional agroforestry systems in Oceania, where numerous varieties are grown. The fruit can be cooked and eaten at all stages of maturity, is high in carbohydrates, and is a good source of minerals and vitamins. In addition to producing abundant, nutritious, tasty fruits, this multipurpose tree provides medicine, construction materials, and animal feed. The attractive, evergreen trees grow to heights of 15 to 21 m (48 to 70 ft) or more and the trunks may be as large as 2 m (6.6 ft) in diameter at the base. The trees begin bearing in 3–5 years and are productive for many decades. They are easy to propagate, require little attention and input of labor or materials, and can be grown under a wide range of ecological conditions. Most breadfruit is produced for subsistence purposes and small quantities are available for sale in town markets as fresh fruit or chips. There is interest in establishing small-scale orchards to provide fresh fruits and chips for export from Pacific islands to New Zealand, the United States, and Canada.

Breadfruit is a beautiful and prolific tree, and an essential component of traditional Pacific island agriculture. PHOTO: J. WISEMAN

DISTRIBUTION

Native range

The wild, seeded, ancestral form of breadfruit, *Artocarpus camansi* Blanco, or breadnut, is native to New Guinea, and possibly the Moluccas (Indonesia) and Philippines. Breadfruit, both seeded and seedless forms, does not naturally occur in the Pacific islands, although long-abandoned plantings are sometimes mistaken for wild trees. It was first domesticated in the western Pacific and spread by humans throughout the region beginning 3000 years ago.

Current distribution

Breadfruit is cultivated on most Pacific islands, with the exception of New Zealand and Easter Island. It is now pantropical in distribution. In the late 1700s several seedless varieties were introduced to Jamaica and St. Vincent from Tahiti, and a Tongan variety was introduced to Martinique and Cayenne via Mauritius. These Polynesian varieties were then spread throughout the Caribbean and to Central and South America, Africa, India, Southeast Asia, Madagascar, the Maldives, the Seychelles, Indonesia, Sri Lanka, and northern Australia. Breadfruit is also found in south Florida.

BOTANICAL DESCRIPTION

Preferred scientific name

Artocarpus altilis (Parkinson) Fosberg

Family

Moraceae

Non-preferred scientific names

Artocarpus camansi
A. mariannensis
A. communis
A. incisa

Common names

Pacific islands

beta (Vanuatu)
bia, bulo, nimbalu (Solomon Islands)
breadfruit (English)
kapiak (Papua New Guinea)
kuru (Cook Islands)
meduu (Palau)
mei (mai) (Federated States of Micronesia, Kiribati, Marshalls, Marquesas, Tonga, Tuvalu)

mos (Kosrae)
'ulu (Hawai'i, Samoa, Rotuma, Tuvalu)
'uru (Society Islands)
uto, buco (Fiji)

Other regions

árbol a pan (Spanish)
l'arbre à pan (French)
rimas (Philippines)
sukun (Indonesia)

Size

Trees can reach heights of 21 m (70 ft) or more at maturity, more commonly around 12–15 m (40–50 ft). The trunk may be large as 2 m (6.6 ft) in diameter, occasionally growing to a height of 4 m or more (13 ft) before branching. A white milky latex is present in all parts of the tree.

Form

Single-trunked tree with spreading, evergreen canopy.

Flowers

Monoecious with male and female flowers on the same tree and the male inflorescence appearing first. Male flowers are club-shaped, up to 5 cm (2 in) in diameter and 45 cm (18 in) long. Thousands of tiny flowers with two anthers are attached to a central, spongy core. Female inflorescences consist of 1500–2000 reduced flowers attached to a spongy core. The flowers fuse together and develop into the fleshy, edible portion of the fruit. It is cross-pollinated, but pollination is not required for the fruit to form.

Leaves

Leaves are alternate, broadly obovate to broadly ovate, almost entire, with only slight lobing to deeply pinnately lobed, with sinuses up to 2/3 or more of the distance from margin to midrib, with up to six pairs of lobes and a large apical tip. Blade is generally smooth, glossy, dark green with green or yellow-green veins, and few to many white to reddish-white hairs on the midrib and veins. Leaves on new shoots and root suckers are generally larger and more hirsute than leaves on mature branches. Size is variable depending on the variety, ranging from 15–60 cm (6–24 in) long.

Fruit

Fruits are variable in shape, size, and surface texture. They are usually round, oval, or oblong ranging from 9 to 20 cm (3.6–8 in) wide and more than 30 cm (12 in) long, weighing 0.25–6 kg (0.5–13 lb). The tough skin is composed of five- to seven-sided disks, each the surface of an individual flower. Two strap-shaped, reflexed stigmas protrude from center of the disk and often leave a small distinctive scar when they blacken and wither. The skin texture varies from smoothly to slightly bumpy or spiny. The color is light green, yellowish-green, or yellow when mature, although one unusual variety ('Afara' from the Society Islands) has pinkish or orange-brown skin. The skin is usually stained with dried latex exudations at maturity. The flesh is creamy white or pale yellow and contains none to many seeds, depending upon the variety. Fruits are typically mature and ready to harvest and eat as a starchy staple in 15–19 weeks. Ripe fruits have a yellow or yellow-brown skin and soft, sweet, creamy flesh that can be eaten raw but rarely is in the Pacific

The leaves and fruit are found in an amazing diversity of shapes, sizes, and shades of color. PHOTOS: D. RAGONE

 

Look-a-likes *A. camansi* (left) and *A. mariannensis* (right). PHOTOS: D. RAGONE

Seeds

Throughout the Pacific, breadfruit exhibits great morphological variability, ranging from true seedless varieties to those with several small aborted seeds, or one to a few viable seeds, to varieties with numerous viable seeds. Seeded types are most common in the southwestern Pacific. Seedless varieties are most common in Micronesia and the eastern islands of Polynesia. All of the breadfruit varieties elsewhere in the tropics are seedless.

Seeds are thin-walled, subglobose or obovoid, irregularly compressed, 1–2 cm (0.4–0.8 in) thick, and embedded in the pulp. The outer seed coat is usually shiny dark brown with a light brown inner seed coat. Seeds have little or no endosperm and no period of dormancy; they germinate immediately and are unable to withstand desiccation. Seeds are distributed by flying foxes, where they occur. Seeds are rarely used for propagation.

How to distinguish from similar species

Artocarpus camansi (breadnut, camansi) has oblong, very spiny fruits with little pulp and numerous large, light-brown seeds and large, shallowly dissected leaves with 4–6 pairs of lobes. *Artocarpus mariannensis* (dugdug, chebiei) has small, cylindrical or kidney-shaped, dark-green fruits with yellow flesh and dark-brown seeds, and small, entire to shallowly 1–3-lobed leaves.

GENETICS

Variability of species

Breadfruit is genetically diverse, especially the seeded forms in the western Pacific and hybrids (with *Artocarpus mariannensis*) in Micronesia. Numerous Polynesian triploid varieties are genetically identical but morphologically distinct. These Polynesian triploids tend to not thrive under atoll conditions, while both seeded and seedless hybrid varieties are best adapted to these conditions.

Known varieties

There are hundreds of named varieties in the Pacific islands that are perpetuated clonally by vegetative propagation. Some varieties have a wide distribution, such as 'Maopo' in Samoa and Tonga (known as 'Rare autia' in Society Islands, 'Mei aukape' in Marquesas, 'Uto lolo' in Fiji, 'Morava' in Cook Islands, and 'Sra fon' in Kosrae). Others are localized to specific islands.

'Maopo' has an almost entire leaf with shallow lobes at the tip. The seedless fruits are oval or broad ovoid with pale white or creamy flesh, 16–26 cm (6.4–10.4 in) long and 16–18 cm (6.4–7.2 in) wide, weighing 2–3.5 kg (4.4–7.7 lb), averaging 2.4 kg (5.2 lb). The trees reach heights of 15 m (50 ft) or taller, and the timber is used for house building in Samoa.

'Ma'afala' is common throughout Polynesia and has been introduced to Pohnpei, Kosrae, and Tuvalu. It is generally a smaller tree up to 10 m (33 ft) tall with a spreading canopy. The small leaves are moderately dissected with three to five pairs of lobes. The small fruits are oval or oblong with white flesh, 12–16 cm (4.8–5.4 in) long and 10–13 cm (4–5.4 in) wide, weighing 0.6–1 kg (1.3–2.2 lb), averaging 0.75 kg (1.6 lb), with none to few seeds.

'Puou' is common throughout Polynesia. It is generally a smaller tree up to 10 m (33 ft) tall with a dense, spreading canopy. The large leaves are dull, shallowly dissected with 4–6 pairs of lobes. The fruits are round, 12–20 cm (4.8–8 in) long and 11–17 cm (4.4–6.8 in) wide, weighing 1.2–2.4 kg (2.4–4.8 lb), averaging 1.5 kg (3.3 lb) with a long, stout stalk up to 10 cm (4 in) and a distinctive raised "neck." The pale white or creamy flesh has none to few seeds.

'Mein iwe' ('Mos n wa', 'Motinwae', 'Mejenwe') is an important variety in the the FSM, the Marshall Islands, and Kiribati. The deeply dissected leaves have 3–4 pairs of lobes. The round to oval fruits with white flesh are seedless, 12–21 cm (4.8–8.4 in) long and 12–16 cm (4.8–6.4 in) wide, and weigh 0.8–2.2 kg (1.7–4.8 lb), averaging 1.6 kg (3.5 lb).

ASSOCIATED PLANT SPECIES

Breadfruit is an aboriginal introduction in the Pacific islands and occurs only in cultivation throughout the area. It is grown around homes in villages and towns and is an important component of agroforestry systems, especially on the high islands of the FSM. It is associated with other staple crops such as taro (*Colocasia esculenta*), yam (*Dioscorea* spp.), banana, as well as Tahitian chestnut (*Inocarpus fagifer*), noni (*Morinda citrifolia,* Indian mulberry), coconut, kava (*Piper methysticum*), cacao, coffee, and various fruit trees such as citrus and papaya. Understory plants include Polynesian arrowroot (*Tacca leotopetaloides*) and *Curcuma australasiatica* (in Pohnpei).

ENVIRONMENTAL PREFERENCES AND TOLERANCES

Climate

Breadfruit has a wide range of adaptability to ecological conditions. It grows best in equatorial lowlands below 600–650 m (2000–2160 ft) but is found at elevations up to 1550 m (5100 ft). The latitudinal limits are approximately 17°N and S; but maritime climates extend that range to the Tropics of Cancer and Capricorn.

Elevation range

0–1550 m (5100 ft)

Left: Young farmer Fa'aaliga in American Samoa with the large-fruited 'Aveloloa tala'. PHOTO: C. ELEVITCH. **Top and bottom right: Varieties 'Maopo' and 'Mein padahk'.** PHOTOS: D. RAGONE.

Breadfruit is compatible with many other cultivated crops such as banana and taro, as shown here. In the lower left corner are young *Flueggea flexuosa* and coconut seedlings, which will grow to overtop the breadfruit. American Samoa. PHOTO: C. ELEVITCH

Mean annual rainfall

1500–3000 mm (60–120 in), but trees can yield regularly on Pacific atolls that receive 1000 mm (40 in)

Rainfall pattern

It prefers climates with summer rains.

Dry season duration (consecutive months with <40 mm [1.6 in] rainfall)

0–3 months

Mean annual temperature

15–40°C (59–104°F), does best at 21–32°C (70–90°F)

Mean maximum temperature of hottest month

32–38°C (90–100°F)

Mean minimum temperature of coldest month

16–18°C (61–64°F)

Minimum temperature tolerated

5–10°C (41–50°F)

Soils

Deep, fertile, well drained soils are preferred, although some varieties are adapted to the shallow sandy soils of coral atolls.

Soil texture

Breadfruit prefers light and medium soils (sands, sandy loams, loams, and sandy clay loams).

Soil drainage

It requires freely draining soils.

Soil acidity

Neutral to alkaline soils (pH 7.4–6.1)

Special soil tolerances

Breadfruit tolerates saline soils, as well as coralline soils and atolls.

Tolerances

Drought

Breadfruit can withstand drought for a few months but will prematurely drop its fruits.

Full sun

The tree does best in full sun and forms the overstory canopy in traditional mixed agroforests.

Shade

Young trees prefer 20–50% shade when young but can be grown in full sun.

Fire

It can sprout back from the roots after a small fire, but the trunk and branches are not fire-tolerant.

Frost

It is damaged by frost, which causes it to lose all fruits and leaves, and some branch die-back may occur.

Waterlogging

It can tolerate waterlogged soils for only very brief periods.

Salt spray

It can tolerate some salt spray for brief periods, but the leaves will turn yellow and fall.

Wind

The branches break and shed in heavy winds, especially with a heavy fruit load, but new shoots and branches quickly regrow.

Abilities

Breadfruit produces numerous root shoots when roots are cut or damaged. It quickly regrows new shoots and branches after wind damage or when topped to facilitate harvest. Even large trees 1 m (3.3 ft) or greater in diameter will regenerate and produce fruits again in as soon as 2 years after severe pruning.

GROWTH AND DEVELOPMENT

Growth rate

Breadfruit is fast growing in favorable conditions, growing 0.5–1.5 m (1.7–4.8 ft) per year and to a diameter of close to 1 m (3.3 ft) in the first 10–12 years. Small branches often die back at the tip after fruiting, but new shoots and branches continue to develop throughout the life of the tree.

Flowering and fruiting

Breadfruit bears seasonally, with most varieties producing one or two crops per year. The main crop typically occurs during the hot, rainy, summer months, followed by a smaller crop 3–4 months later. Trees grown from seed begin flowering and produce fruit in 6–10 years, or sooner. Vegetatively propagated trees start fruiting in 3–6 years.

Yields

Yields are extremely variable, ranging from less than 100 to more than 700 fruits per tree, depending on the variety, age, and condition of the tree. Average yields are 150–200 fruits per tree. A study of Pohnpeian varieties recorded:

Variety	Number of fruits	Average yield
‘Mein iwe’	30–268	141
‘Mein padahk’	26–557	219
‘Mei uhwp’	10–615	218

Rooting habit

Roots are spreading and grow on or slightly below the surface of the ground. Some varieties, especially *A. altilis* × *A. mariannensis* hybrids, develop extensive buttress roots.

Reaction to competition

Breadfruit does well interplanted with a wide array of plants, and more than 120 useful species have been documented in traditional breadfruit agroforests on Pohnpei. Vines such as *Merremia peltata*, if left unchecked, can smother and eventually kill the trees.

Root shoot growing from surface roots. Root shoots help breadfruit trees survive wind damage and are a primary source for propagation material. PHOTO: D. RAGONE

Diseases and pests

It is relatively free of diseases and pests, although mealybugs can be a problem locally. *Phellinus noxius*, a root rot, and fruit rots caused by *Phytophthora*, *Colletotrichum* (anthracnose), and *Rhizopus* can be a problem. Fruit flies infest ripe fruits on the tree and ground. Tree decline and dieback have been a problem throughout the Pacific and Caribbean islands, especially on atolls. No pathological cause has been identified. It is considered to be the result of storm damage, drought, aging of the trees, and salinity. Proper husbandry practices, such as removing dead and dying branches and mulching, are essential to maintaining the health and vigor of the trees.

PROPAGATION

Breadfruit is easy to propagate from root shoots or root cuttings, by air-layering branches, or from seeds. Breadfruit can also be grafted using various techniques. Stem cuttings are not used. Seeds are rarely grown because they do not develop true to type. Vegetative propagation is a must for seedless varieties, and root shoots or root cuttings are the preferred methods for both seeded and seedless varieties.

Propagation by root shoots and root cuttings

It is best to collect root shoots and root cuttings after the fruiting season is over and when the tree is in an active vegetative stage, producing new leaves. This generally coincides with the end of the dry season, and root shoots/cuttings should be collected as the rainy season commences. This is the period when carbohydrate stores in the roots are at their highest levels.

Collection and handling of propagating material

Root shoots

The use of root shoots to propagate breadfruit is the traditional method in the Pacific, and some varieties, such as 'Puou', produce numerous root shoots. Collect healthy shoots when they are at least 20–25 cm (8–10 in) tall and the stem has become woody and is producing lobed leaves. Shoots up to 1 m (3.3 ft) tall can be used. Remove by cutting the attached root 10–15 cm (4–6 in) on either side of the shoot and carefully lifting out the shoot and any attached root system. Use a sharp machete or clippers to sever the shoot from the parent tree and to facilitate wound healing. It is difficult to avoid damaging the shoot's root system when the shoot is removed, so root shoots need to be grown under nursery conditions before outplanting. The success rate of directly transplanting shoots to another location is low, around 25%. Trim off the leaves and cut the tip at a 45 degree angle at a height of 15–30 cm (6–12 in; see photo). Trimming the tip makes the root shoot more manageable, and the apical shoot tends to die back anyway. Plant in organic, well drained media in a 1–2 gallon (10-20 cm) pot. Keep shaded (up to 60% shade) and moist, but not wet, and misting is recommended. It should never be allowed to dry out. Depending on the size of the shoot, it will need to be grown under nursery conditions for 3–6 months before outplanting. The percentage of successful rooting and shoot growth ranges from 50 to 90%.

Root cuttings

Root shoots are not always available from a desired variety, and root cuttings can be used to mass-propagate breadfruit. Collect roots from healthy, vigorous trees. Carefully excavate roots that are growing just beneath the surface of the soil. Do not use surface roots because these tend to dry out and have a lower success rate. Look for roots with small rounded bumps on the surface—these adventitious buds will develop into new shoots. Roots 1.5–6 cm (0.6–2.4 in) in diameter can be used, and 3–4 cm (1.4–1.8 in) is suggested for best results. Removing roots larger than 6 cm (2.4 in) can be detrimental to the tree, damaging the root system, and because the wounded area will heal more slowly. Use a sharp machete or clippers to sever the root and facilitate wound healing. The remaining attached root will often develop a root shoot at the cut end.

Cut roots into 15–25 cm (6–10 in) sections. It is best to wash and scrub the roots to remove soil. Discard any pieces that are damaged or misshapen. Treatment with fungicide is recommended to prevent growth of pathogens that cause root rots. Hormone treatment is not required but standard hormone mixes can be used according to the manufactur-

Root shoots and root cuttings, both pictured here in nursery containers, are the primary means of propagating breadfruit.
PHOTO: D. RAGONE

ers recommendation.

Place the roots in a propagating bed, flats, or individual pots. Space roots 10–15 cm (4–6 in) in a row and 15–20 cm (6–8 in) between rows in beds or flats. Use well drained potting media or clean, washed silica sand. Do not use beach sand because it is too saline and alkaline. Cuttings are placed either horizontal (covered with media) or at an angle, but not upright, with a small upper portion of the root exposed.

Root cuttings should be kept shaded (up to 60% shade) and moist, but not wet; misting is recommended. The roots should never be allowed to dry out. The percentage of rooting ranges from 75 to 85%. Shoots begin to develop from adventitious buds after 3–4 weeks. When shoots are 20–25 cm (8–10 in) tall with their own root system—usually in 4–6 months—carefully uproot and transplant into 2–3 gallon (20–30 cm) pots. Use a well drained medium. If adding fertilizer (such as balanced 8–8–8) use only sparingly, less than half the manufacturers' recommendations. Keep plants in partial shade and weed-free. Grow to a size of 0.6–1.6 m (24–64 in) in 6–9 months.

Propagation by air-layering

It is best to air-layer branches at the beginning of the rainy season when the tree is in an active vegetative stage, producing new shoots and leaves, and before fruits appear. Select newly developed shoots, and do not use the ends of branches that have previously flowered or fruited. Branches 2–4 cm (0.8–1.6 in) are prepared for air-layering by removing a strip of bark 3–5 cm (1.4–2 in) wide around the circumference of the branch. Use a sharp knife and be careful not to cut into the wood. Rooting hormone is not required but if used, follow the manufacturer's recommendations. Wrap moistened sphagnum moss, or other organic media, around this area and hold it in place with a piece of plastic, aluminum foil, burlap, or copra bag tied around the branch. Up to 50% of air-layers will not root but instead form a ring of hardened callus along the end of the cut. Also, the branches are brittle and may snap off in high winds. They can be braced with bamboo splints placed over the wrapped air-layer. After 2–4 months, new roots will develop and grow through the medium. Remove the air-layer by cutting the branch directly below the roots. Place in a 1–2 gallon (10-20 cm) pot in a well drained medium until the plant has an established root system (about a year). The tip of the branch often dies and the air-layer will fail to take unless a new shoot develops from buds lower on the branch.

Although a less common means of propagation than root suckers and root cuttings, air-layering of breadfruit also works well. Air-layers are shown here wrapped in aluminum foil to reduce evaporation and keep them cool. PHOTO: C. ELEVITCH

Establishment in the nursery

Young breadfruit plants grow best in partial shade, so full-sun hardening is often not necessary. However, if plants are to be planted in full sun, gradually move to full-sun conditions in the nursery to harden them to the site conditions, at about 2 months. Young plants should never be allowed to dry out or be exposed to strong wind.

Outplanting

Outplant when the plants have reached the desired size. Because of their large surface area it is best to reduce the size of the leaves to reduce transpiration. Carefully remove 1/2 to 2/3 of the lower leaves. Do not remove or damage the growing point of the plant where new leaves develop. Protect from wind and excessive heat during transport. Dig a hole the same depth of the container and twice as wide as the container. Add a small amount of fertilizer, such as 8–8–8 slow-release fertilizer, to the bottom of the hole and cover with soil. To prevent injury to the delicate root system, carefully cut off the container rather than pulling the plant out. Place the breadfruit tree in the hole, add soil no higher than the level of the plant in the pot, top-dress with compost, and water well. Close to 100% success rate can be expected.

Young plants prefer partial shade. It is best to plant at the onset of the rainy season, but if the weather is dry, irrigate for the first 1–3 months of establishment. Once established, breadfruit trees can withstand a dry season of 3–4 months, although it prefers moist conditions. Mulching young plants is beneficial by helping keep the soil moist and adding a steady supply of nutrients. It also helps control weeds

Breadfruit remains a common tree in homegardens in much of the Pacific, such as pictured above in Apia, Samoa. PHOTO: C. ELEVITCH

around the root system. Use of herbicides to control weeds around the base of the tree can damage the tree if it comes in contact with the surface roots or young trunk. Young trees need to be protected from cattle, goats, horses, and pigs that will eat the bark and tender shoots.

DISADVANTAGES

Potential for invasiveness

Breadfruit has no potential for invasiveness. Most of the varieties are seedless and can only be propagated vegetatively, requiring humans to distribute and spread this species. Breadfruit does produce root shoots, so clonal offsprings spread a limited distance from the original tree. Since seeds lose viability quickly, the seeded varieties are not readily spread.

Susceptibility to pests/pathogens

Breadfruit is a relatively trouble-free plant to grow, with its disease and pest problems localized. The major problem is fruit rots caused by *Phytophthora*, *Colletotrichum* (anthracnose), and *Rhizopus*. *Phellinus noxius* root rot can be a problem; it spreads through root contact, especially when the tree is planted in areas of native forest that have been recently cleared.

Host to crop pests/pathogens

Fruit flies are attracted to ripe fruits on the tree and ground and infest many fruit crops.

Other disadvantages or design considerations

The spreading surface roots can interfere with other plants and are easily hit and damaged by mowers or other equipment.

AGROFORESTRY/ENVIRONMENTAL PRACTICES

Mulch/organic matter

The large leaves of this evergreen species provide abundant mulch for the tree and other plants growing beneath the canopy.

Soil stabilization

Breadfruit is often grown on steep hillsides, especially on the high islands of Micronesia, where it is the canopy species in traditional agroforestry systems.

Crop shade/overstory

Breadfruit can be interplanted with a wide range of crops and plants such as yams, bananas, medicinal plants, aroids, gingers, Indian mulberry, kava, etc.

Homegardens

Breadfruit is well suited for homegardens, providing beneficial shade and numerous nutritious fruits.

Animal fodder

All parts—flesh, peel, core, and seeds—of both mature and ripe fruits are edible and are fed to pigs and other livestock. The leaves are also edible.

Native animal/bird food

Breadfruit is an important food source for flying foxes, native doves, and other birds in the Pacific islands.

Host plant trellising

Breadfruit is used as a trellis tree for yam (*Dioscorea* spp.), especially in Pohnpei.

Bee forage

Honeybees visit male inflorescences and collect pollen, especially from fertile, seeded varieties. Bees also collect latex that oozes from the fruit surface.

Ornamental

Breadfruit is an attractive, evergreen tree with large, striking leaves.

USES AND PRODUCTS

Staple food

Breadfruit produces abundant nutritious fruits that are typically consumed as a starchy staple when firm and mature. The fruits are high in carbohydrates and a good source of vitamins and minerals. Breadfruit is canned in brine and sold in the Caribbean and speciality markets in the United States, Europe, and Canada.

Nut/seed

Seeds are high in protein and low in fat and a good source of vitamins and minerals. They are cooked in the fruits and eaten throughout the Pacific islands, but rarely in Polynesia.

Medicinal

All parts are used medicinally in the Pacific and Caribbean, especially the latex, leaf tips, and inner bark. The latex is massaged into the skin to treat broken bones and sprains and is bandaged on the spine to relieve sciatica. It is commonly used to treat skin ailments and fungus diseases such as "thrush," which is also treated with crushed leaves. Diluted latex is taken internally to treat diarrhea, stomachaches, and dysentery. The sap from the crushed stems of leaves is used to treat ear infections or sore eyes. The root is astringent and used as a purgative; when macerated it is used as a poultice for skin ailments. The bark is also used to treat headaches in several islands. In the West Indies the yellowing leaf is brewed into tea and taken to reduce high blood pressure and relieve asthma. The tea is also thought to control diabetes.

Timber

The wood is lightweight, flexible, and may resist termites. Taller varieties such as 'Maopo' and 'Aveloloa' are preferred for house building in Samoa.

Fuelwood

Breadfruit is used as firewood throughout the Pacific, but generally older, less productive trees are utilized.

Craft wood/tools

The wood is easy to work and carve into statues, bowls, and other objects.

Canoe/boat/raft making

The light-weight timber is used throughout the Pacific islands to make small one- or two-person canoes.

Fiber/weaving/clothing

The inner bark is used to make bark cloth (tapa), but this formerly widespread custom is now only practiced in the Marquesas.

Rope/cordage/string

The inner bast was traditionally used to make strong cordage used for fishing and animal harnesses in Samoa, Micronesia, and the Philippines.

Wrapping/parcelization

The large, flexible leaves are used throughout the Pacific to wrap foods for cooking in earth ovens.

Resin/gum/glue/latex

The sticky white latex is used as a chewing gum and as an adhesive. It was widely used to caulk canoes and as birdlime (to catch birds).

Toxin/insecticide/fish poison

Dried male flowers can be burned to repel mosquitoes and other flying insects.

URBAN AND COMMERCIAL FORESTRY

The stately and attractive breadfruit tree is a familiar landscape tree in the Pacific islands. Widely planted throughout the region, breadfruit provides comfortable shade, delicious and nutritious fruits, timber, and other useful products. A common element in home landscapes, breadfruit trees are typically grown around and near homes so the fruits can be easily and quickly harvested. A few magnificent specimen trees can be found in parks and other public places. Unfortunately, in large metropolitan areas such as Honolulu, many beautiful old trees have disappeared from the urban landscape in recent years—cut down to make room for larger homes and buildings, and to open view planes.

A large tree cut back to open a view plane. PHOTO: C. ELEVITCH

Size in an urban environment

Trees can reach heights of 18 m (60 ft) or more but are typically 12–15 m (40–50 ft). Some varieties are relatively short-statured, reaching average heights of 9 m (30 ft). The canopy is generally about two-thirds of the height.

Rate of growth in a landscape

It is moderately fast growing in favorable conditions, growing 0.5–1.5 m (1.5–5 ft) per year.

Root system

Roots are spreading, grow on or slightly below the surface of the ground, and can form raised buttresses. Surface roots are easily hit and damaged by mowers or other equipment.

Products commonly used in a Pacific island household

Primarily grown for food, the nutritious, starchy fruits are usually consumed when mature. The mature fruit must be cooked when still green and firm, but it can be eaten raw when soft and ripe. These multipurpose trees have a lightweight, easy-to-work timber well suited for carvings and handicrafts, canoes, and house construction. Leaves, buds, latex, and bark all have medicinal uses. The sticky sap is widely used for glue and as a traditional caulk.

Light requirements

Young trees can be grown in 20–50% shade when young but develop a more compact, dense canopy when grown in full sun.

Water/soil requirements

Newly planted trees may require daily watering during dry periods until established, but mature trees normally tolerate dry conditions and do not require irrigation. Breadfruit prefers light and medium soils (sands, sandy loams, loams, and sandy clay loams) and requires good drainage.

Life span

Trees begin bearing in 3–5 years and are productive for many decades.

Varieties favored for use in a homegardens

Shorter-statured, more compact varieties such as 'Puou' or 'Ma'afala' from Polynesia or the Micronesian variety 'Mei uhwp' are ideal for homegardens.

Seasonality of leaf flush, flowering, fruiting

Male flowers and fruits develop at the tips of branches, with the male flowers occurring first. The fruiting season typically coincides with the wet, rainy summer months, but a smaller flush may occur about 5 months later for some varieties. New leaves are produced year-round, with a heavy flush after a period of rest that follows the end of the fruiting season.

Use as living fence, hedge or visual/noise barrier

Because of its stature and dense foliage when grown in the open, breadfruit is well suited as a specimen or shade tree that can serve as a visual screen when sited correctly.

Birds/wildlife

Birds and honeybees are attracted to the fruits and/or male flowers.

Maintenance requirements

Mulching with fallen breadfruit leaves and other organic material is beneficial. This relatively low-maintenance species can be fertilized once a year with a balanced NPK fertilizer, but trees can produce abundantly and thrive for years without supplemental fertilizer. Small tip branches often die back after fruiting and should be pruned and removed to maintain the long-term health of the tree.

Special considerations regarding leaf, branch, and fruit drop

Some fruits may drop prematurely, but most fruits develop and should be harvested when mature. High, out-of-reach fruits will ripen and fall to the ground throughout the fruiting period. Heavily laden branches may break off the tree during strong winds.

Nuisance issues

Soft, ripe fruits that remain on the ground after falling draw clouds of fruit flies and quickly begin to rot into a gooey, unsightly mass.

Author with breadfruit tree bearing nicely 28 months after planting. PHOTO: J. WISEMAN

Hazards

Since some breadfruit varieties have fruits that weigh up to 5.5 kg (12 lb), trees should not be planted close to sidewalks or other public areas where falling fruits could hit and injure a passing pedestrian or trip passers-by.

Common pest problems

The tree is relatively pest free. The main problems with breadfruit are fruit flies and fruit rots from fungal diseases. Vigilance in harvesting and disposing of fruits affected by fungal disease is the easiest way to limit problems. House yard or farm pigs readily "pig out" on damaged and ripe fruits, solving disposal problems for the homeowner while benefiting from a nutritious foodstuff.

Other comments about this species in urban environments

Breadfruit trees are an essential component of homegardens and should be more widely planted throughout the islands. They are not as well suited as street or park trees. Soft, ripe fruits can make a mess of sidewalks, streets, or parked cars, and the sticky latex could adhere to and damage the finish of vehicles.

COMMERCIAL PRODUCTS

Breadfruit is grown primarily as a subsistence crop throughout the Pacific islands and other regions where it is cultivated. It is available in village and town markets for local consumption. Breadfruit is produced and sold locally as chips in Fiji, Samoa, Guam, Hawai'i, and other islands. Fresh mature fruits, treated for fruit flies by hot forced air, are being exported to New Zealand from Fiji and Samoa. The fruits are harvested from small plantings and backyard trees. There are no orchards in the Pacific islands with the exception of a farm in Hawai'i with more than 180 trees on approximately 2.5 ha (6 acres).

Spacing

Trees should be planted 12–14 m (40–46 ft) apart under orchard conditions, although in the Caribbean trees are often spaced 8–12 m (27–40 ft).

Management objectives and design considerations

Breadfruit is traditionally grown in integrated mixed agroforestry systems. Little information is available about managing breadfruit for commercial production. It is best to keep trees mulched. Provide a complete fertilizer at the beginning and end of the fruiting season to maintain the health and vigor of trees, especially trees that are 10 or more years old. Pruning should be limited to the removal of dead branches, but trees are often topped to make it easier to reach and harvest fruits. However, the new shoots and branches are brittle and readily break.

Yields

Under orchard conditions, yield estimates range from 16 to 50 mt per ha (7–23 t/ac) of fruit based on 100 trees/ha (40 trees/ac). Approximately 5.5 mt per ha (2.4 t/ac) are produced in a traditional mixed agroforestry system on Pohnpei.

Processing

Breadfruit is generally picked and consumed when mature but not yet ripe. Careful harvesting is essential for maintaining fruit quality. Fruits that fall to the ground may be bruised and soften sooner than those that are gently handled. Fruits quickly ripen in just 1–3 days after harvest. Shelf life can be extended by careful harvesting and pre-cooling fruits with chipped ice in the field and during transport. Covering fruits with water can also delay ripening for a few days.

Markets

Breadfruit is usually available for sale in markets throughout the Pacific and Caribbean islands. An estimated 100–300 tons of breadfruit is sold in Samoa annually, with 60–130 tons sold in the Fugalei Market in Apia.

INTERPLANTING/FARM APPLICATIONS

Breadfruit trees provide shade, mulch, and a beneficial microclimate. They are generally planted as part of a homegarden or mixed agroforestry system with a wide array of useful plants. Widely spaced trees in an orchard can be interplanted with small fruit trees, such as citrus, and a leguminous cover crop. Short-term fruit crops, such as pineapple, banana, and papaya, or field and vegetable crops including taro, tomato, and eggplant, can also be grown between breadfruit trees. A leguminous cover crop should replace these intercrops when they begin to interfere with orchard operations. Some interplanting systems include:

One of the great staples of Pacific island cultures, breadfruit is shown here for sale together with two other staples, sweetpotato and cooking banana. PHOTO: C. ELEVITCH

Example 1

Location

Federated States of Micronesia (Pohnpei).

Description

Breadfruit is typically grown with yam (*Dioscorea* spp.). The vines climb trellises of *Hibiscus tiliaceus* and grow into the canopy of the tree during the non-fruiting period and are dormant when the fruits are harvested. This allows the fruits to be picked without damaging the yam vines.

Example 2

Location

American Samoa.

Description

Breadfruit is grown in a mixed planting with taro, cassava, bananas, citrus, and cacao.

PUBLIC ASSISTANCE AND AGROFORESTRY EXTENSION

Extension offices for agroforestry and forestry in the Pacific: http://www.traditionaltree.org/extension.html

The Cooperative Extension Service (CES) of the University of Hawai'i can assist landowners with questions relating to tree crops.

University of Hawai'i at Mānoa
College of Tropical Agriculture and Human Resources
Cooperative Extension Service
Komohana Agricultural Complex
875 Komohana St., Hilo, HI 96720
Tel: 808-959-9155; Fax: 808-959-3101
Web: http://www2.ctahr.hawaii.edu/

GERMPLASM RESOURCES

The National Tropical Botanical Garden can provide selected varieties from an extensive breadfruit germplasm collection.

The USDA Clonal Germplasm Repository, Waiakea, Hawai'i, can provide selected breadfruit varieties.

The National Tropical Botanical Garden's Kahanu Garden, Maui, Hawai'i, has the largest collection of breadfruit varieties in the world. PHOTO: D. RAGONE

INTERNET

The Breadfruit Institute: <http://www.breadfruit.org>.

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Traditional Tree Initiative—Species Profiles for Pacific Island Agroforestry (www.traditionaltree.org)

Artocarpus altilis (breadfruit)

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Acknowledgments: The author and publisher thank Dale Evans, Kent Lighter, John Parrotta, and Art Whistler for their input. Photo contributions by Jim Wiseman are greatly appreciated.

Recommended citation: Ragone, D. 2006. *Artocarpus altilis* (breadfruit), ver. 2.1. In: Elevitch, C.R. (ed.). Species Profiles for Pacific Island Agroforestry. Permanent Agriculture Resources (PAR), Hōlualoa, Hawai'i. <http://www.traditionaltree.org>.

Sponsors: Publication was made possible by generous support of the United States Department of Agriculture Western Region Sustainable Agriculture Research and Education (USDA-WSARE**)** Program; SPC/GTZ Pacific-German Regional Forestry Project; USDA Natural Resources Conservation Service (USDA NRCS); Kaulunani, an Urban Forestry Program of the DLNR Division of Forestry and Wildlife and the USDA Forest Service; State of Hawai'i Department of Land & Natural Resources Division of Forestry & Wildlife; USDA Forest Service Forest Lands Enhancement Program; and Muriel and Kent Lighter. This material is based upon work supported by the Cooperative State Research, Education, and Extension Service, U.S. Department of Agriculture, and Agricultural Experiment Station, Utah State University, under Cooperative Agreement 2002-47001-01327.

Series editor: Craig R. Elevitch

Publisher: Permanent Agriculture Resources (PAR**)**, PO Box 428, Hōlualoa, Hawai'i 96725, USA; Tel: 808-324-4427; Fax: 808-324-4129; E-mail: par@agroforestry.net; Web: <http://www.agroforestry.net>. This institution is an equal opportunity provider.

Species Profiles for Pacific Island Agroforestry
www.traditionaltree.org

April 2006
ver. 2.1

Artocarpus camansi (breadnut)

Moraceae (mulberry family)

breadnut (English), *castaña* (Spanish), *chataignier* (French), *kapiak* (New Guinea), *dulugian*, *kamansi, kolo, pakau, ugod* (Philippines), *kelur*, *kulor*, *kulur, kuror* (Malaya, Java), *mei kakano* (Marquesas), *pana de pepitas* (Puerto Rico)

Diane Ragone

IN BRIEF

Distribution Currently found throughout the tropics, including some Pacific islands.

Size Medium tree 15 m (50 ft) or more in height at maturity.

Habitat Grows best in equatorial lowlands below 600–650 m (1970–2130 ft) and rainfall of 1300–3800 mm (50–150 in) but is widely adaptable.

Vegetation In native range, an important component of the vegetation associated with lowland mixed alluvial forests; in cultivation, associated with a wide variety of domesticated plants.

Soils Deep, fertile, well drained soils are preferred.

Growth rate Moderately fast growing in favorable conditions, growing 0.5–1.5 m (1.5–5 ft) per year.

Main agroforestry uses Overstory, homegardens.

Main products Staple food, wood for crafts.

Yields Mature trees can yield 600–800 fruits per season.

Intercropping Interplanted with small fruit trees or short-term fruit and vegetable crops.

Invasive potential It has little potential for invasiveness.

Young breadnut tree.

INTRODUCTION

Breadnut (*Artocarpus camansi*) is native to New Guinea and possibly the Moluccas (Indonesia) and the Philippines. In New Guinea, it is a dominant member of alluvial forests in lowland areas and is one of the first species to appear on the tops of frequently flooded banks of rivers. The trees grow widely scattered in the forest and are dispersed by birds, flying foxes, and arboreal mammals that feed on the flesh and drop the large seeds. *Artocarpus camansi* has often been considered to be a form of seeded breadfruit, *A. altilis*. Breadfruit, however, is a separate species that originated from its wild seeded ancestor, breadnut. Pacific islanders did not distribute it through the region, probably because the seeds are short-lived and would be difficult to transport long distances. A few trees, all fairly recent introductions, can be found in New Caledonia, Pohnpei, the Marquesas, Tahiti, Palau, and Hawai'i. While breadnut is uncommon in the Pacific islands, it has long been cultivated and used in other tropical regions. Beginning in the late 1700s the British and French spread breadnut throughout the tropics. The oblong, spiny fruits have little pulp and are primarily grown for their large, nutritious seeds, although immature fruits, seeds and all, are thinly sliced and cooked as a vegetable, especially in the Philippines. The seeds are high in protein and relatively low in fat. They are boiled or roasted and are similar to chestnuts in texture and flavor.

DISTRIBUTION

Native range

This wild seeded ancestor of breadfruit (*Artocarpus altilis*) is native to New Guinea and possibly the Moluccas (Indonesia) and the Philippines. It is distributed throughout its natural range by flying foxes (fruit bats) and arboreal mammals.

Current distribution

Breadnut is widespread throughout the lowlands of New Guinea where it occurs naturally, and it is also found in cultivation in homegardens. It is now found only in cultivation in the Philippines, where it is typically grown as a backyard tree. It is infrequently grown in the Pacific islands outside of its native range. A few trees can be found in New Caledonia, Pohnpei, the Marquesas, Tahiti, Palau, and Hawai'i, mainly introduced by immigrants from the Philippines in recent years. It is currently not found on any of the Pacific atolls. While breadnut is still underutilized

A mature breadnut tree can produce as many as 600–800 fruits per year. PHOTO: D. RAGONE in Oceania it has long been grown and used in other tropical regions. Beginning in the late 1700s the British and French spread breadnut throughout the tropics, and it is now widespread in the Caribbean—where it is especially popular in Trinidad, Tobago, and Guyana—Central and South America, Southeast Asia, and parts of Africa, especially coastal West Africa.

BOTANICAL DESCRIPTION

Preferred scientific name and author

Artocarpus camansi Blanco

Family

Moraceae (mulberry family)

Non-preferred scientific names

These names for other *Artocarpus* species have been used incorrectly for *A. camansi*:

Artocarpus altilis
A. communis
A. incisa

Common names

breadnut (English)
castaña (Spanish)
chataignier (French)
kapiak (New Guinea)
kamansi, dulugian, pakau, kolo, ugod (Philippines)
kulur, kelur, *kulor, kuror* (Malaya, Java)
mei kakano (Marquesas)
pana de pepitas (Puerto Rico)

Size

Trees grow to heights of 10–15 m (33–50 ft) or taller with a trunk 1 m (3.3 ft) or larger in diameter, often growing to a height of 5 m (16 ft) before branching. A sticky, white, milky latex is present in all parts of the tree. Canopy diameter generally measures about half of the tree height.

Form

It is a single-trunked tree with a spreading evergreen canopy. The tree typically forms buttresses at the base of the trunk. It has a more open branching structure than breadfruit (*A. altilis*) or dugdug (*A. mariannensis*).

Flowering

Flowering is monoecious with male and female flowers on the same tree at the ends of branches, with the male inflorescence appearing first. Male flowers are club-shaped, up to 3 cm (1.2 in) in diameter and 25–35 cm (10–14 in) long or longer. Thousands of tiny flowers with two anthers are attached to a central spongy core. Female inflorescences consist of 1500–2000 reduced flowers attached to a spongy core. Unlike breadfruit, the individual flowers do not fuse together along their length.

Buttress roots and trunk of breadnut. PHOTO: D. RAGONE

Leaves

Leaves are alternate, large, 40–60 cm (16–24 in) long, moderately dissected with 4–6 pairs of lobes and sinuses cut half way to the midrib. New leaves on young trees can be 76 or more cm (30 in) long. They are densely pubescent, with many white or reddish-white hairs on upper and lower veins, lower leaf surface, and petiole. Blade is dull green with green veins. Two large green stipules enclose the bud, turning yellow before dehiscing.

Fruit

The fruit is a large fleshy syncarp, oval or ovoid, 13–20 cm (5–8 in) long and 7–12 cm (2.6–4.8 in) in diameter, weighing approximately 800 g (1.8 lb). The skin is dull green to green-yellow when ripe with a spiny texture from the pointed, flexible, 5–12 mm (0.2–0.5 in) long tips of individual flowers. The scanty pulp is yellow-whitish when ripe with a sweet aroma and taste. The fruit is not as solid or dense as breadfruit because the individual flowers forming the fruit are fused together only at their bases.

Seeds

This species is grown for its seeds, and there is much variation in seed number, size, and nutritional composition. The fruit contains numerous seeds, from 12 to as many as 150, each weighing an average of 7–10 g (0.25–0.36 oz), comprising 30–50% or more of the total fruit weight. The seeds are rounded or flattened by compression and about 2.5 cm (1 in) long. They have a thin, light-brown outer seed coat that is patterned with darker veins. In contrast, the seeds of breadfruit and dugdug usually have a dark-brown, shiny seed coat. The seeds have little to no endosperm, no period of dormancy, germinate immediately, and are unable to withstand desiccation. Typically spread by flying foxes and arboreal mammals. Seeds are harvested from soft, ripe fruits.

Rooting habit

The roots are spreading and grow on or slightly below the surface. Extensive buttresses develop when mature.

How to distinguish from similar species/ look-a-likes

Breadnut can be readily distinguished from its close relative, breadfruit (*A. altilis*), by its very spiny fruits with little pulp and numerous large, light-brown seeds. Dugdug (*A. mariannensis*) has small, dark-green, cylindrical or kidney-shaped fruits with dark yellow flesh, dark brown seeds, and small, entire to shallowly 1–3-lobed leaves.

Top: Variation in seeded and seedless varieties of breadfruit (*A. altilis*) and seeds of breadnut (upper right corner). Bottom: Breadnut fruits are readily identified by their spiny skin. PHOTOS: D. RAGONE

GENETICS

Variability of species

Breadnut is genetically variable, diploid, and produces abundant fertile pollen. Most of the trees in cultivation throughout the tropics originated from a few early introductions, and little work has been done to evaluate and select superior seedlings.

Known varieties

There are no varieties of breadnut.

ASSOCIATED PLANT SPECIES

General flora of native habitat

Breadnut is an important component of the vegetation associated with lowland mixed alluvial forests of New Guinea (Papua New Guinea and Irian Jaya) below 1000 m (3300 ft) elevation. This tall forest (canopy of 30 m (100 ft) or greater) is floristically and structurally very rich. The forest is rather open and the upper story is characterized by *Pometia pinnata*, *Ficus* spp., *Alstonia scholaris*, and *Terminalia* spp. Typical lower-story trees are *Garcinia*, *Diospyros, Myrstica, Maniltoa*, and *Microcos*. Palm species, such as rattans and *Licuala* spp., gingers, and members of the Marantaceae family abound in the understory and shrub layer. Drainage affects forest height and composition. In regularly inundated areas, *Planchonia papuana, Bischofia javanica*, *Terminalia complanata*, *Cananga odorata*, *Teysmanniodendron bogoriense*, *Intsia bijuga*, *Nauclea coadunata, Alstonia scholaris, Vitex cofassus*, and *Anthocephalus chinensis* are locally abundant in the riverside forest, and the shrub and herb layer are typically sparse. The wild breadnut tree is one of the first trees to appear on the tops of frequently flooded, low levee banks. In areas where the banks are higher and less frequently flooded, it is joined by *Octomeles sumatrana*, and a young forest dominated by one or both species develops. *Ficus, Dendrocnide, Nauclea, Kleinhovia hospita,* and *Terminalia* eventually invade the young forest. On the inner curves of larger river banks of oxbows, sinuous low ridges separated by swampy swales are built up. Trees of *Timonius* spp., *Althoffia* spp., *Artocarpus camansi,* and *Octomeles sumatrana* form narrow, even-aged, and increasingly higher stands on successively older ridges. During the clearing of the lowland forest for plantations and tree gardens, wild breadnut trees and other species such as *Canarium indicum, Terminalia kaernbackhii, Dracontomelon puberulum, Pangium edule, Gnetum gnemon, Areca betel,* and *Ceiba bombax* are left standing or planted.

Associated introduced species in Pacific islands

Breadnut is a modern introduction in only a few Pacific islands, where it is usually grown as a backyard tree around homes. It is associated with banana (*Musa* spp.), coconut (*Cocos nucifera*), Indian mulberry (*Morinda citrifolia*, noni), sugarcane, ornamental plants, and other common homegarden species.

ENVIRONMENTAL PREFERENCES AND TOLERANCES

Climate

Breadnut, like breadfruit, has a wide range of adaptability to ecological conditions. It requires a tropical climate and will not grow where the temperatures go below 5°C (41°F). It grows best in equatorial lowlands below 600–650 m (1970–2130 ft) but is found at elevations up to 1550 m (4950 ft). The latitudinal limits are approximately 17° N and S; maritime climates extend that range to the Tropics of Cancer and Capricorn. It should do well wherever breadfruit is grown.

Elevation range

0–1550 m (0–4950 ft)

Mean annual rainfall

1300–3800 mm (50–150 in)

Rainfall pattern

Prefers climates with summer rains.

Dry season duration (consecutive months with <40 mm [1.6 in] rainfall)

0–3 months

Mean annual temperature

15–40°C (50–104°F), does best at 21–32°C (70–90°F)

Mean maximum temperature of hottest month

32–38°C (90–100°F)

Mean minimum temperature of coldest month

16–18°C (61–64°F)

Minimum temperature tolerated

5–10°C (41–50°F)

Soils

Deep, fertile, well drained soils are preferred.

Soil texture

The tree prefers light, well drained soils (sands, sandy loams, loams, and sandy clay loams).

Soil drainage

It requires freely draining soils.

Soil acidity

Neutral to alkaline soils (pH 6.1–7.4+)

Tolerances

Drought

Can withstand drought for a few months but will prematurely drop fruits.

Full sun

Does best in full sun.

Shade
Seedlings do best in 20–50% shade but prefer full sun conditions once established.

Frost
It is damaged by frost, which causes it to lose all fruits and leaves, and branch dieback will occur.

Waterlogging
It can tolerate waterlogged soils and periodic flooding for brief periods, and is the first species to colonize riverbanks in its native habitat.

Wind
It can withstand strong winds and will resprout after sustaining wind damage.

Abilities
It produces new shoots and branches after wind damage.

GROWTH AND DEVELOPMENT

Growth rate
This species is fast growing in favorable conditions, growing 0.5–1.5 m (1.5–5 ft) in height per year for the first 10–12 years. The canopy diameter keeps pace at approximately one-half the height of the tree. Branches are widely spaced. Small branches often die back at the tip after fruiting, but new shoots and branches continue to develop throughout the life of the tree.

Flowering and fruiting
Fruiting season is October to May, with some fruits available into July in Hawai'i. It begins in April or May in the Philippines. Trees begin producing at 8–10 years of age.

Yields
Mature breadnut trees in the Philippines have been reported to produce 600–800 fruits per season. The average number of seeds per fruit is variable, ranging from 32 to 94 per fruit, each seed weighing an average of 7.7–10 g (0.25–0.33 oz). Based on 100 trees/ha (40 trees/ac) producing 200 fruits per tree, an average yield of 11 mt/ha (4.9 t/ac) of fresh seeds has been estimated.

Reaction to competition
As evidenced by its widespread distribution in the native lowland forest, this species is able to withstand competition from other forest trees.

PROPAGATION
Breadnut is easily propagated by seeds. The trees do not produce root shoots and cannot be grown from root cuttings as can breadfruit. It has been successfully grafted in the Philippines using inarching (where one branch is grafted to another plant without first separating it from its parent) and budding. Seeds are typically gathered from soft, ripe fruits.

Propagation by seeds
Seeds quickly germinate and will often sprout inside the fallen fruits. Collect seeds from soft, ripe fruits and wash to remove all pulp. Select firm, shiny, uniform seeds that do not yield to the touch when squeezed. Discard any sprouted or aborted seeds. The latter are typically misshapen, flat, and contain little or no endosperm. Surface-clean in a 2% bleach solution for 5–10 minutes or treat with a fungicide according to the manufacturer's recommendation. Plant immediately, as seeds are recalcitrant and cannot be dried or chilled. Germination rates are high, close to 100%.

Place seeds in seedling flats in a loose, well drained medium. Plant at a depth twice the width of the seed. Keep moist, but not wet. Seeds germinate within 10–14 days. Transplant into 1–2 gallon (4–8 liter) pots once the true leaves have hardened. If adding fertilizer (such as balanced 8-8-8 slow-release), use only sparingly, less than half the manufacturer's recommendations. Keep plants in partial shade and weed-free. Seedlings grow quickly, reaching 1 m (3.3 ft) in approximately 6 months and are ready to plant into the field in less than a year.

Establishment in the Nursery
Young plants prefer partial shade. If they are to be planted in full sun, gradually move them to full-sun conditions in the nursery for 1–2 months to harden them to the site conditions. Young plants should never be allowed to dry out or be exposed to strong wind.

Outplanting
Outplant when the plants have reached the desired size of about 1.25 m (4 ft) tall and 2 cm (0.8 in) in diameter. Because of their large surface area, it is best to reduce the size of the leaves to reduce transpiration. Carefully remove 1/2 to 2/3 of the lower leaves by trimming the blade and leaving only a small section attached to the petiole. Do not remove or damage the growing point of the plant where new leaves develop. Protect from wind and excessive heat during transport. Dig a hole the same depth as the container and twice as wide. Add a small amount of slow-release fertilizer, such as 8-8-8, to the bottom of the hole and cover with soil. To prevent injury to the brittle root system,

Breadnut seeds readily germinate and should be gathered from soft, ripe fruits before they fall to the ground. PHOTO: D. RAGONE

carefully cut off the container rather than pulling the plant out. Place the tree in the hole, add soil no higher than the level of the plant in the pot, topdress with compost, and water well.

The young plants prefer partial shade. It is best to plant at the onset of the rainy season, but if the weather is dry, irrigate for the first 1–3 months of establishment. Once established, breadnut trees can withstand a dry season of 3–4 months, although they prefer moist conditions. Mulching young plants is beneficial by helping keep the soil moist and adding a steady supply of nutrients. It also helps control weeds around the root system. Use of herbicide to control weeds around the base of the tree can damage the tree if it comes in contact with the surface roots or young trunk. Young trees need to be protected trees from cattle, goats, horses, and pigs, which will eat the bark and tender shoots. Close to 100% success rate can be expected if the above precautions are taken.

DISADVANTAGES

Potential for invasiveness

This species has little potential for invasiveness because the large, fleshy seeds quickly lose viability and are not readily spread except by flying foxes.

Susceptibility to pests/pathogens

It has few serious diseases or pests and is relatively trouble-free, with disease and pest problems localized. Breadnut does not appear to be as susceptible as breadfruit to fruit rots caused by *Phytophthora*, *Colletotrichum* (anthracnose), and *Rhizopus*.

Host to crop pests/pathogens

Fruit flies are attracted to ripe fruits on the trees and ground and infest many fruit and vegetable crops.

Other disadvantages or design considerations

The spreading surface roots can interfere with other plants and are easily hit by mowers or other equipment.

AGROFORESTRY/ENVIRONMENTAL PRACTICES

Mulch/organic matter

The large leaves of this evergreen species provide abundant mulch for the tree and other plants growing beneath the canopy.

Soil stabilization

Breadnut naturally occurs on frequently flooded river banks.

Crop shade/overstory

Can be interplanted with a wide range of crops and plants, such as yam, banana, medicinal plants, aroids, ginger, Indian mulberry, small fruit trees, and field and vegetable crops such as corn, beans, peanut, tomato, and eggplant.

Homegardens

Breadnut is ideal for homegardens, producing nutritious, high-protein seeds and providing beneficial shade.

Animal fodder

All parts—flesh, peel, core, and seeds—of both mature and ripe fruits are edible and are fed to pigs and other livestock.

Native animal/bird food

Breadnut is an important food source for flying foxes and arboreal mammals in its native range.

Host plant trellising

Could be used as a trellis tree for yam (*Dioscorea* species).

Bee forage

Honeybees visit male inflorescences and collect pollen and also collect latex that oozes from the fruit surface.

USES AND PRODUCTS

Staple food

The nutritious fruits are usually consumed when immature, thinly sliced and boiled as a vegetable in soups or stews.

Nut/seed

Breadnut is primarily grown for its nutritious seeds; it is a good source of protein and low in fat compared to nuts such as almond, brazil nut, and macadamia nut. The fat extracted from the seed is a light yellow, viscous liquid at room temperature with a characteristic odor similar to that of peanuts. It has a chemical number and physical properties similar to those of olive oil. Its seeds are a good source of minerals and contain more niacin than most other nuts. In 100 g edible portion, four amino acids, methionine (3.2 g), leucine (2.6 g), isoleucine (2.4 g), and serine (2.1 g) comprised 50% of 14 amino acids analyzed.

Seeds comprise 30–50 percent or more of the weight of breadnut fruit. PHOTO: J. WISEMAN

Nutritional composition of breadnut seeds per 100 grams edible portion (dry weight basis)

Water (%)	56.0–66.2
Protein (g)	13.3–19.9
Carbohydrate (g)	76.2
Fat (g)	6.2–29.0
Calcium (mg)	66–70
Potassium (mg)	380–1620
Phosphorus (mg)	320–360
Iron (mg)	8.7
Magnesium (mg)	10.0
Niacin (mg)	8.3
Sodium (mg)	1.6

From Ragone (2003) based on McIntoch & Manchew (1993), Negron de Bravo et al. (1983), and Quijano & Arango (1981).

Medicinal

No specific medicinal uses are reported, but the breadnut tree probably has medicinal properties similar to breadfruit.

Timber

The wood is lightweight, flexible, and easy to work.

Fuelwood

The wood is fast burning, but generally only older, less productive trees are used for fuel.

Craft wood/tools

The wood is easy to work and carve into statues, bowls, fishing floats, and other objects.

Toxin/insecticide/fish poison

Dried male flowers can be burned to repel mosquitoes and other flying insects.

Other uses

The breadnut tree is not as extensively used as breadfruit, but its timber, latex, and inner bark can be utilized in the same fashion.

COMMERCIAL PRODUCTS

Breadnut is a natural component of the forests of New Guinea and is an important part of the subsistence economy in lowland areas. The seeds are a valued food and are widely collected. Gathered seeds are sold in village markets, providing an important source of income for women in some areas. In the Caribbean and parts of Central and South America, the seeds are locally consumed and available in markets and restaurants. Since breadnut seeds are so similar in taste and texture to chestnuts, they could have commercial possibilities roasted, canned in brine, or processed into nut butter or nut paste, flour, or oil.

INTERPLANTING/FARM APPLICATIONS

Breadnut trees provide shade, mulch, and a beneficial microclimate. It is generally planted as part of a homegarden or mixed agroforestry system with a wide array of useful plants. Widely spaced trees in an orchard can be interplanted with small fruit trees such as citrus and a leguminous cover crop. Short-term fruit crops such as pineapple, banana, and papaya, or field and vegetable crops including taro, tomato, and eggplant can also be grown between breadfruit trees. A leguminous cover crop should replace these intercrops when they begin to interfere with orchard operations. Interplanting systems include:

Example system 1

In the Philippines the center of the square formed by four breadnut trees is planted with small fruit trees such as guayabano or soursop (*Annona muricata*), citrus, chico or sapodilla (*Manilkara zapota*), and atis or sugar apple (*Annona squamosa*).

Example system 2

Gnetum gnemon is grown for its edible leaf in *Artocarpus camansi* and *Pandanus* orchards in the Jimi Valley, Papua New Guinea.

PUBLIC ASSISTANCE AND AGROFORESTRY EXTENSION

Extension offices for agroforestry and forestry in the Pacific: http://www.traditionaltree.org/extension.html

GERMPLASM RESOURCES

A germplasm collection at the National Tropical Botanical Garden in Hawai'i has 24 accessions of *A. camansi* from Papua New Guinea, Indonesia, Hawai'i, Pohnpei, Palau, and Tahiti.

INTERNET

The Breadfruit Institute: <http://www.breadfruit.org>.

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Species Profiles for Pacific Island Agroforestry (www.traditionaltree.org)

Artocarpus camansi (breadnut)

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Acknowledgments: The author and publisher thank Roberto Coronel, Dale Evans, and Art Whistler for their input. A photo contribution by Jim Wiseman is greatly appreciated.

Recommended citation: Ragone, D. 2006. *Artocarpus camansi* (breadnut), ver. 2.1. In: Elevitch, C.R. (ed.). Species Profiles for Pacific Island Agroforestry. Permanent Agriculture Resources (PAR), Hōlualoa, Hawai'i. <http://www.traditionaltree.org>.

Sponsors: Publication was made possible by generous support of the United States Department of Agriculture Western Region Sustainable Agriculture Research and Education (USDA-WSARE) Program; SPC/GTZ Pacific-German Regional Forestry Project; USDA Natural Resources Conservation Service (USDA NRCS); State of Hawai'i Department of Land & Natural Resources Division of Forestry & Wildlife; and the USDA Forest Service Forest Lands Enhancement Program. This material is based upon work supported by the Cooperative State Research, Education, and Extension Service, U.S. Department of Agriculture, and Agricultural Experiment Station, Utah State University, under Cooperative Agreement 2002-47001-01327.

Series editor: Craig R. Elevitch

Publisher: Permanent Agriculture Resources (PAR), PO Box 428, Hōlualoa, Hawai'i 96725, USA; Tel: 808-324-4427; Fax: 808-324-4129; E-mail: par@agroforestry.net; Web: <http://www.agroforestry.net>. This institution is an equal opportunity provider.

Species Profiles for Pacific Island Agroforestry
www.traditionaltree.org

April 2006
ver. 1.1

Artocarpus heterophyllus (jackfruit)

Moraceae (mulberry family)

jack, jack tree, jackfruit, jak, jakfruit (English)*; jacquier* (French)*; kapiak* (Papua New Guinea)*; uto ni India* (Fiji)*; 'ulu initia* (Samoa)

Craig R. Elevitch and Harley I. Manner

IN BRIEF

Distribution Common in southeast Asia and found occasionally in Pacific island homegardens.

Size Trees typically reach a height of 8–25 m (26–82 ft) and a canopy diameter of 3.5–6.7 m (11–22 ft) at 5 years of age.

Habitat The tree grows well in equatorial to subtropical maritime climates at elevations of 1–1600 m (3.3–5250 ft) and average rainfall of 1000–2400 mm (40–95 in).

Vegetation A common component in polycultures together with numerous other cultivated species.

Soils Grows in freely draining, acid to neutral soils (pH 5.0–7.5).

Growth rate Grows moderately rapidly in early years, up to 1.5 m/yr (5 ft/yr) in height, slowing to about 0.5 m/yr (20 in/yr) as trees reach maturity.

Main agroforestry uses Shade, windbreak, homegarden.

Main products Fruit, timber, fodder, latex.

Yields 70–100 kg/tree/yr (150–220 lb/tree/yr) is typical, although much larger yields have been reported.

Intercropping It is interplanted with many other tree crops.

Invasive potential Not considered invasive; naturalization in new environments is unusual.

Row of trees with fruit.

INTRODUCTION

Jackfruit (*Artocarpus heterophyllus*) is one of the most significant trees in tropical homegardens and perhaps the most widespread and useful tree in the important genus *Artocarpus*. It is a medium-size evergreen tree typically reaching 8–25 m (26–82 ft) in height that is easily recognized by its fruit, the largest among cultivated plants. The succulent, aromatic, and flavorful fruit is eaten fresh or preserved in myriad ways. The nutritious seeds are boiled or roasted and eaten like chestnuts, added to flour for baking, or cooked in dishes. It is also known for its remarkable, durable timber, which ages to an orange or red-brown color. The leaves and fruit waste provide valuable fodder for cattle, pigs, and goats. Many parts of the plant including the bark, roots, leaves, and fruit are attributed with medicinal properties. Wood chips yield a dye used to give the famous orange-red color to the robes of Buddhist priests.

The tree can provide many environmental services. It is highly wind tolerant and therefore makes a good component in a windbreak or border planting. Growing in pastures, it can provide fallen fruit for livestock, shade, and long-term timber. In homegardens, the dense jackfruit canopy can provide a visual screen and is very ornamental.

Introduced to most Pacific islands after European contact, the tree can be found throughout the Pacific, mainly in homegardens, where it finds a place among other favorite multipurpose plants. It is easy to grow and more adaptable than some of the other common *Artocarpus* species such as breadfruit (*A. altilis*). It is not considered to be an invasive species.

DISTRIBUTION

Native range

The tree is reportedly native to the rainforests of Malaysia and the Western Ghats of India.

Current distribution

Jackfruit has been cultivated since prehistoric times and has naturalized in many parts of the tropics, particularly in Southeast Asia, where it is today an important crop of India, Burma, China, Sri Lanka, Malaysia, Indonesia, Thailand, and the Philippines. It is also grown in parts of Africa, Brazil, Suriname, the Caribbean, Florida, and Australia. It has been introduced to many Pacific islands since post-European contact and is of particular importance in Fiji, where there is a large population of Indian descent. In a 1985 survey, jackfruit was present on 10–24% of Indo-Fijian sugarcane farms in western Viti Levu, Fiji (Thaman and Ali 1993). In comparison, mango (*Mangifera indica*), papaya (*Carica papaya*), drumstick tree (*Moringa oleifera*), *Murraya koenigii*, and tamarind (*Tamarindus indica*) were found on 75–100% of the farms. In Hawai'i, it is occasionally found in homegardens, and it is sold in farmer's markets, although commercial production is minor. Jackfruit is occasionally planted in backyard gardens in Guam. The species is also reported to have been introduced to Palau, Yap, Pohnpei, Nauru, Tabiteuea in Kiribati, Samoa, and other islands (Fosberg et al. 1979).

BOTANICAL DESCRIPTION

Preferred scientific name

Artocarpus heterophyllus Lam.

Family

Moraceae (mulberry family)

Non-preferred scientific names

Artocarpus brasiliensis Gomez
Artocarpus heterophylla Lam.
Artocarpus maxima Blanco
Artocarpus philippinensis Lam.
Polyphema jaca Lour.
Soccus arboreus major Rumph.

Artocarpus integer (Thunb.) Merr and its synonym *A. integrifolia* L. f. are a different species (champedak), and these names have often mistakenly been used as synonyms for *A. heterophyllus*.

Common names

Pacific islands

dapanapan(?) (Yap)
jack, jack tree, jackfruit, jak, jakfruit (English)
jacquier (French)
kapiak (Papua New Guinea)
uto ni India (Fiji)
'ulu initia (Samoa)

Other regions

banun, *khanun*, *makmi* (Thai)
buen pan, *jaca*, *pan de fruta*, *rima* (Spanish)
chakki, *kanthal*, *kathal*, *kathar*, *panos* (Hindi)
Jackfrutchbaum (German)
langka, *nancas* (Filipino)
nangka, *nongko* (Javanese)

Size and form

Jackfruit is a medium-size, evergreen tree that typically attains a height of 8–25 m (26–82 ft) and a stem diameter of 30–80 cm (12–32 in). The canopy shape is usually conical or pyramidal in young trees and becomes spreading and domed in older trees. The canopy diameter at 5 years old ranges from 3.5–6.7 m (11–22 ft) and can reach 10 m or more in older trees. The tree casts a very dense shade. Heavy side branching usually begins near the ground. All parts of the tree exude a sticky white latex when injured.

Flowers

This species is monoecious, having male and female inflorescences (or "spikes") on the same tree. Male and female spikes are borne separately on short, stout stems that sprout from older branches and the trunk. Male spikes are found on younger branches above female spikes. Male spikes are dense, fleshy, cylindrical to club-shaped, and up to 10 cm (4 in) in length. Flowers are tiny, pale green when young, turning darker with age. Female flowers are larger, elliptic or rounded, with a tubular calyx. The flowers are reportedly pollinated by insects and wind, with a high percentage of cross-pollination.

Leaves

Leaves are dark green, alternate, entire, simple, glossy, leathery, stiff, large (up to 16 cm [6 in] in length), and elliptic to oval in form. Leaves are often deeply lobed when juvenile and on young shoots.

Fruit

Jackfruit has a compound or multiple fruit (syncarp) with a green to yellow-brown exterior rind that is composed of hexagonal, bluntly conical carpel apices that cover a thick, rubbery, whitish to yellowish wall. The acid to sweetish (when ripe) banana-flavored flesh (aril) surrounds each seed. The heavy fruit is held together by a central fibrous core. Fruits are oblong-cylindric in shape, typically 30–40

Left: Female (top) and male (bottom) flower spikes. Right: Seedlings have lobed leaves compared to the entire leaves on mature trees. PHOTOS: C. ELEVITCH cm (12–16 in) in length but sometimes up to 90 cm (35 in). They usually weigh 4.5–30 kg (10–66 lb), although a weight of 50 kg (110 lb) has been reported (Morton 1987). The heavy fruit is borne primarily on the trunk and interior part of main branches.

Fruits take 90–180 days to reach maturity. In the Northern Hemisphere, the main bearing season is late spring to early fall (between March and September). A few fruits mature in winter or early spring.

Seeds

Seeds are light brown to brown, rounded, 2–3 cm (0.8–1.2 in) in length by 1–1.5 cm (0.4–0.6 in) in diameter, and enclosed in a thin, whitish membrane. Up to 500 seeds can be found in each fruit. Seeds are recalcitrant and can be stored up to a month in cool, humid conditions.

Rooting habit

Jackfruit has a strong taproot.

Similar species

Champedak (*Artocarpus integer* [Thunb.] Merr.) is easily mistaken for jackfruit. There are several indicators differentiating the two species; perhaps the easiest to see is that champedak has smaller, rounder fruits, with less latex and thicker rind. However, champedak is rarely found in the Pacific.

GENETICS

Variability of species

Because the flowers are open-pollinated, there is usually great variation in seedlings. Variation is exhibited in a wide range of characteristics such as tree size and structure, leaf and fruit form, age to bearing, and fruit quality. Fruit size, shape, and color of the fruit and texture, odor, and taste of the edible pulp vary tremendously. An exception is the 'Singapore' (or 'Ceylon') cultivar, which bears comparatively quickly from seed—usually in 18–30 months—and

Fruit on 7-year-old tree. PHOTOS: C. ELEVITCH is relatively true to type. It has medium-size fruits (6–12 kg [13–26 lb]) with soft, fibrous, and very sweet flesh.

Known varieties

Commercially, grafted cultivars are normally planted. The fruit of most cultivars weighs 10–30 kg (22–66 lb), although the full range of known cultivars is 2–36 kg (4.4–79 lb) and even heavier. The fruit is generally grouped into two major types by fruit quality: 1) thin, fibrous, and mushy edible pulp, usually very sweet and emitting a strong odor, and 2) thick, firm, often crisp, less fragrant pulp. There are numerous cultivars of each type in regions where jackfruit is a significant food crop, including South India, Thailand, Malaysia, the Philippines, and Ceylon. In Hawai'i, grafted cultivars include 'Black Gold', 'Dang Rasimi', 'Golden Nugget', 'Honey Gold', and 'NS1'. Jackfruit usually has two main seasons; in Hawai'i it bears in May–August and November–January. Details on these and other cultivars are available from several excellent references (e.g., Crane et al. 2002, Campbell and Lesdesma 2003, and Morton 1987) and in Tables 1 and 2 below.

Culturally important related species in the genus

Jackfruit belongs to the genus *Artocarpus*, a genus rich in culturally important species including breadfruit (*A. altilis*), dugdug (*A. mariannensis*), and breadnut (*A. camansi*). These three species represent some of the most important traditional subsistence trees of Pacific islands. Elsewhere in Southeast Asia and India, champedak (*A. integer*), lakoocha (*A. lakoocha*), marang (*A. odoratissima*), kwai muk (*A. lingnanensis*), and others are important fruit trees, all with culturally important uses, and many with other valuable products, such as timber.

ASSOCIATED PLANT SPECIES

Associated native species commonly found

Jackfruit is reported as a locally common endemic tree species of the evergreen and semi-evergreen forests of the Western Ghats of India. These mountains are a center of biodiversity where more than 800 species of trees have been recorded. Ramesh (no date) classifies the vegetation of the Western Ghats into the following: Wet evergreen forests (with three subtypes based on elevation, with the highest located above 1400 m [4600 ft]); dry evergreen forests; moist deciduous forests; dry deciduous forests; and grasslands. In these forests, jackfruit is one of 352 endemic tree species.

There is great variation in fruit size, shape, color, etc., as shown here at a jackfruit competition in Rayong, Thailand. PHOTO: C. ELEVITCH

Species commonly associated as aboriginal introductions in Pacific islands

Jackfruit is a post-European-contact introduction to Pacific islands. The tree is commonly planted in smallholder cane farms in Fiji held by farmers of Indian ancestry. It is occasionally found in small farms and homegardens throughout the Pacific. Associated tree species include breadfruit (*Artocarpus altilis*), dugdug (*A. mariannensis*), betel nut palm (*Areca catechu*), coconut (*Cocos nucifera*), *Musa textilis*, *M. paradisiaca*, *M. sapendium*, mango (*Mangifera indica*), *Annona* spp., *Pangium edule*, cocoa (*Theobroma cacao*), *Eugenia* spp., and guava (*Psidium guajava*). Jackfruit is found growing together with more than 50 tree species in Yapese homegardens (Falanruw 1990). It is found occasionally on farms and in homegardens throughout Hawai'i.

Species commonly associated in modern times or as recent Pacific island introduction

The tree is often found as a component of homegardens in many tropical regions, albeit few in number at each site. One example from Java shows but one jackfruit tree among a listing of 39 homegarden plants (Abdoellah 1990). The species is also a common associate of village tree gardens. Other tree species include durian (*Durio zibethinus*), *Gnetum gnemon*, *Eugenia polycephala*, *Mangifera caesia*, coffee (*Coffea robusta*), *Pangium edule*, and bilimbi (*Averrhoa bilimbi*), to name a few (Michon and Mary 1990).

ENVIRONMENTAL PREFERENCES AND TOLERANCES

Jackfruit grows in a wide range of tropical to subtropical environments. It is most common in lowland forests up to 250 m (820 ft), decreasing in abundance up to 1000 m above sea level; it thrives best in moist tropical environments below 1000 m (3300 ft). Although tolerant of cooler environments up to 1600 m (5250 ft), jackfruit may suffer dieback in light frosts and does not tolerate freezing temperatures. It bears fruit at latitudes of up to 30° from the equator, with good crops at latitudes within ±24°.

Climate

The tree grows well in the equatorial to subtropical maritime climates of the Indian and Pacific oceans. It is a component of the tropical moist (rainforest) to semi-dry forest.

Elevation range

1–1600 m (3.3–5250 ft)

Mean annual rainfall

1000–2400 mm (40–94 in)

Rainfall pattern

It favors environments with a uniform rainfall pattern, although it will grow in seasonally dry climates.

Dry season duration (consecutive months with <40 mm [1.6 in] rainfall)

2–4 months

Mean annual temperature

24–28°C (75–82°F)

Mean maximum temperature of hottest month

32–35°C (90–95°F)

Mean minimum temperature of coldest month

16–20°C (61–68°F)

Minimum temperature tolerated

-3–0°C (27–32°F)

Soils

Jackfruit grows best in well drained, deep soils of moderate fertility but tolerates a wide range of soils including shallow limestone, sand, and rocky substrates. The tree does not tolerate water stagnation or poor drainage. If the roots touch stagnant water, the tree fails to bear fruit, or it may die.

Soil texture

The tree can grow in light- and medium-texture soils (sands, sandy loams, loams, and sandy clay loams).

Soil drainage

It requires free drainage.

Soil acidity

The tree tolerates moderately acid to neutral soils (pH 5.0–7.5).

Special soil tolerances

Jackfruit tolerates shallow, slightly saline, and infertile soils. It also tolerates high pH limestone soils, rocky, and laterite soils.

Tolerances

Drought

Jackfruit tolerates 3–4 months of drought. However, it does best with even and continuous soil moisture.

Full sun

The tree prefers full sun at maturity.

Shade

Seedlings are best grown in 30–50% sunlight, with sun exposure increasing to 100% as the tree matures.

Frost

Jackfruit is more cold-tolerant than other species in the genus and can even tolerate light frost. At 0°C (32°F) the leaves may be damaged, and at −2°C (28°F), branches or the whole tree may die.

Waterlogging

The tree does not tolerate waterlogging or poor drainage and will decline and die if roots become waterlogged for more than a day or two.

Salt spray

Jackfruit has moderate tolerance for salt spray.

Wind

The tree tolerates moderate wind quite well and has been known to survive hurricane-force winds, recovering from loss of leaves and small limbs.

Abilities

Self-prune

Jackfruit tends not to self-prune, instead retaining side branches along the main trunk. Even when side branches are pruned off, fruiting branchlets continue to sprout on the lower trunk.

Coppice

The tree regrows well even after heavy pruning.

GROWTH AND DEVELOPMENT

Jackfruit is a rapid grower, reaching a height of 3 m (10 ft) and canopy diameter of 2 m (6.6 ft) in 2 years. Height growth for the first few years is about 1.5 m/yr (5 ft/yr), slowing to 36–60 cm/yr (14–18 in/yr) (Acedo 1992). A 20-year-old tree can reach 17.5 m (57 ft) in height and 20 cm (8 in) in trunk diameter (Morton 1987). While trees can live to 100 years of age, their removal and replacement in Thailand plantations after 20 years of growth suggests a significant decrease in productivity with age.

Flowering and fruiting

Seedlings usually take 4–14 years before bearing fruit, although the 'Singapore' (or 'Ceylon') cultivar begins bearing fruit 18–30 months after transplanting (Morton 1987). Fruits of most cultivars reach maturity in middle to late summer. Morton (1987) reports that in Asia, depending on the climatic region, fruits ripen mainly from March to June, April to September, or June to August, with some off-season crops from September to December.

Reaction to competition

Jackfruit seedlings grow slowly in heavy shade. Weeding is recommended to lessen competition for light, water, and nutrients.

PROPAGATION

(after Wilkinson and Elevitch 2003)

Jackfruit seedlings are very easy to grow. Seedlings develop very quickly, reaching 25 cm (10 in) in height within 3–4 months. Seeds are cross-pollinated and therefore not true-to-type, so grafting known varieties onto rootstocks is often done, especially for commercial production where a uniform product with the best market qualities is important. Because the seeds are large and grow quickly and their root systems are sensitive to damage during transplanting, direct-seeding in the field can give the best results. Field-sown seedlings can be top-worked (grafted) with select varieties once they are established. Propagation by vegetative means such as cuttings and air-layering is also possible, although uncommon.

Seedlings

Seed collection

Trees usually bear fruit in two main seasons, although off-season fruiting is common. Collect seeds from fruits of trees with outstanding growth and fruit qualities.

Seed processing

After opening the fruit with a large knife, seeds are separated from the fleshy sheaths that enclose the seeds. Each fruit contains 100–500 seeds; there is no correlation between fruit size and the number of seeds it contains. There are about 50–90 seeds/kg (23–41 seeds/lb). The thin, slimy coating around the seed (perianth lobe) should be removed and the seeds thoroughly rinsed in water to remove any remaining pulp juice or sugary residue. Only the largest seeds should be used, as these will give the earliest and highest germination and produce the strongest seedlings. Seeds may be air-dried in the shade for about an hour for ease of handling, but they should not be allowed to dry out, as this will kill them. Germination for seed sown within a few days of harvesting is usually high, around 90%.

Seed storage

Seeds are recalcitrant, i.e., they do not retain viability when dried or stored for extended periods. They should be planted immediately for best germination and seedling vigor. Seeds can be stored moist in a plastic container in the refrigerator for up to a few weeks. Stored seeds germinate more slowly than fresh seeds.

Seed pretreatment

No pretreatment is required. However, soaking in water or a dilute gibberellic acid solution for 24 hours prior to sowing hastens germination and is recommended. Hot water treatment has been used successfully to stimulate germination (Oyen and Dung 1999).

Growing area

Seeds are sown at a depth of 2 cm (0.8 in), and can be laid flat or planted with the hilum pointing down.

Germination

Germination begins in 1–3 weeks, or longer (up to 6 weeks) if seeds were stored more that a few days after collection. Daily watering is often necessary once seeds germinate.

Media

A well drained medium is recommended, such as 50% peat moss, 25% perlite, 25% vermiculite amended with a little compost, dolomite lime, gypsum, and a 14-14-14 slow-release or an organic fertilizer. In the nursery, 2–4 l (2–4 qt) root-training containers work well. The seedlings should not be allowed to root through the container into the underlying substrate, as the roots would have to be cut or broken for transplanting.

Approximate size at outplanting

Seedlings have reached target size when approximately 20 cm in height and have a stem diameter of 9 mm (0.35 in). This takes about 3–4 months in good growing conditions.

Guidelines for outplanting

If seedlings are grown in the nursery, it is crucial to outplant them before they become root-bound. Transplanting seedlings when they have just filled out their growing container will ensure minimal trauma to the root system. In ideal conditions, field survival of about 90% can be expected.

Direct-seeding

Direct-seeding in the field is the best propagation method if the planting locations are well prepared, weed free, and frequently tended for the first 6–12 months of growth. It eliminates any transplant trauma. In direct-seeding, an area is prepared for each planting spot, cleared of weeds, and cultivated to a depth of 50 cm (20 in) if the soil is compacted. Seeds are planted at a depth of 2–3 cm (0.8–1.2 in). Sowing several seeds at each site allows for selecting the most vigorous seedling and can prevent the necessity of reseeding. The drawbacks of direct-seeding include risk of predator damage (e.g., rats, pigs, cattle, etc.), lack of rains to sustain the newly germinated seeds, and the mandatory frequent maintenance that must be done to ensure weeds do not overcome the seedlings.

DISADVANTAGES

Jackfruit is susceptible to damage by a wide number of boring insects and plant diseases. Although the tree is long-lived, the recommended practice in some regions is to remove 20-year-old trees because of declining productivity. Some people find the aroma of the fruit to be objectionable, particularly in confined spaces.

Potential for invasiveness

Jackfruit does not spread readily and is not considered invasive. In most areas of the world where jackfruit is grown, its presence is indicative of human cultivation.

Pests and diseases

In southwestern and southern Asia, boring insects seem to be the major pests of jackfruit. These include *Indarbela tetraonis, Batocera rufomaculata*, *Margaronia caecalis,* and *Ochyromera artocarpio* (Morton 1987). In India the main insect pests are the shoot-boring caterpillar (*Diaphania caesalis*), mealybugs (*Nipaecoccus viridis*, *Pseudococcus corymbatus*, and *Ferrisia virgata*), spittle bug (*Cosmoscarta relata*), and jack scale (*Ceroplastes rubina*).

In southern China, the fruit stem is susceptible to damage from the larvae of the longicorn beetles *Aprona germarri*, *Pterolophia discalis*, *Xenolea tomenlosa asiatica*, and *Olenecamptus bilobus*. The caterpillars of leaf webbers (*Perina nuda* and *Diaphania bivitralis*), aphids (*Greenidea artocarpi* and *Toxoptera aurantii*), and thrips (*Pseudodendrothrips dwivarna*) are minor problems (Morton 1987).

Important diseases of jackfruit are pink disease (*Pelliculana* [syn. *Corticum*] *salmonicolor*); stem, fruit, and male inflorescence rot caused *by Rhizopus artocarpi*; and leafspot due to *Phomopsis artocarpina*, *Colletrotrichum lagenarium*, *Septoria artocarpi*, and other fungi. Gray blight (*Pestalotia elasticola*), charcoal rot (*Ustilana zonata*), collar rot (*Rosellinia arcuata*), and rust (*Uredo artocarpi*) occur on jackfruit in some regions (Morton 1987).

According to Crane et al. (2002), wood boring insects in Florida include *Elaphidion mucronatum*, *Nyssodrysina haldemani*, and *Leptostylopsis terraecolor*. Various scales and mealybugs may attack stems and fruit.

Diseases include *Rhizopus* fruit rot (*Rhizopus artocarpi*), gray mold (*Botrytis cinerea*), root rot (*Pythium splendens*, *Phytophthora* spp., *Fusarium* spp., and *Rhizoctonia* spp.), and leaf spotting by fungi (*Gloeosproium* sp. and *Phyllosticta artocarpi*).

Other disadvantages

The fruit is relatively uncommon in many parts of the Pacific including Hawai‘i, and the large size and characteristic odor can be deterrents in the marketplace. Young plants require protection from grazing animals and sun scald. In plantations, fairly wide spacing between trees is required in order to reduce competition for light, water, and nutrients.

AGROFORESTRY/ENVIRONMENTAL PRACTICES

Soil stabilization

The tree can be planted on farms to control soil erosion.

Crop shade/overstory

Jackfruit is used as a shade tree for coffee, pepper, betel nut, and cardamom. Because the tree casts a deep shade, wide spacing such as 15 x 15 m (50 x 50 ft) is recommended unless the intercrop is considered short-term.

Intercropping

In the Philippines, jackfruit has been used as an intercrop with coconuts. Other intercrops include durian, mango, and citrus. At an early age, short-term crops such as banana, sweet corn, and groundnut have been grown.

Homegardens

Jackfruit makes an excellent tree for a homegarden for its beautiful foliage, many products, and bountiful production. One large tree in its prime can supply fruit for several families.

Windbreaks

Jackfruit makes a very good component in a multi-species windbreak and has been known to withstand hurricane-force winds. Because the fruit is borne on the main trunk and interior of larger branches, fruit damage due to

Left: A heavily bearing mature jackfruit growing among other fruit trees including banana. Right: Trees grown for timber with side branches pruned and fruiting branchlets regularly removed from the lower trunk. PHOTOS: C. ELEVITCH moderate wind is minimal.

Silvopasture

Livestock readily eat jackfruit foliage, so young trees would not survive exposure to grazing animals. However, livestock can be pastured among mature trees. Fallen fruit are readily eaten by livestock and make an excellent contribution to their diet.

Host plant trellising

Jackfruit has been used a support for pepper vine and yam (*Dioscorea* spp.).

Ornamental

Jackfruit has glossy, medium to deep green foliage and makes a wonderful ornamental. The highly fragrant fruit may be offensive to neighbors, which can be a drawback to growing jackfruit near houses, especially in urban areas.

USES AND PRODUCTS

Staple food

The pulp of the young fruit is cooked as a starchy food and has a consistency resembling meat. The young fruit is also pickled or canned in brine or curry.

Fruit

The ripe fruit is eaten fresh or is processed into numerous delicacies including jam, jelly, and chutney. It also makes an excellent dried fruit or preserved candy when combined with sugar or honey. The pulp is also used as a flavoring in ice cream and drinks. Canned fruit is available in ethnic markets (e.g., Hawai'i).

Nut/seed

The seeds must be cooked by boiling or roasting prior to eating. They are an excellent addition to curries, or can be eaten freshly cooked or dried with salt as a snack. The cooked and dried seeds are milled to a flour-like consistency and added to bread dough.

Leaf vegetable

The tender young leaves are cooked and eaten as a vegetable.

Other vegetable

Young male flower spikes can be grated or smashed and eaten with salt and vinegar as a vegetable, or pickled. They are also cooked and served as a vegetable.

Beverage/drink/tea

Aside from flavoring for beverages, the fruit can be fermented and distilled to produce an alcoholic liquor.

Medicinal

All parts of the tree are said to have medicinal properties. Morton (1987) reports, "The Chinese consider jackfruit

TIPS

How to tell if a fruit is mature

In order to achieve best fruit quality, the fruit must be allowed to develop to full maturity on the tree, then ripen after harvest. Harvested even a few days too early, the fruit will not ripen to its best quality. Fruits take 3–8 months from flower to mature fruit, depending on the individual tree, growing conditions, and weather; therefore, time from flowering alone is not a good indicator of maturity. It takes some experience to gauge maturity. There are four primary indicators. 1) The skin turns from light green to yellowish or brownish green; 2) the points of the spines grow further apart and flatten slightly, and the skin yields slightly to pressure; 3) The last leaf on the stalk turns yellow; 4) the fruit produces a dull, hollow sound when tapped. Usually two or more of these indicators are used to evaluate the maturity of fruit. After harvesting a mature fruit, it ripens in 3–7 days and begins to emit its strong, characteristic fragrance. For most people, the fragrance is too strong to bear indoors, and the fruit is kept outside or in an open shed until eaten.

Harvesting fruit

Fruits are collected using an orchard ladder or by climbing the trees, cutting the stem of the fruit, and carefully lowering the fruit to the ground with a rope if necessary.

Reducing latex

Harvesting ripe fruits between mid-morning and late afternoon can reduce latex flow (Acedo 1992).

How to avoid a sticky mess

When cutting into a jackfruit, a very sticky latex is exuded from the rind and fibrous parts of the fruit. Coating the knife and hands with edible oil (such as coconut oil) will prevent the latex from sticking. If some latex becomes inadvertently stuck to the skin or hair, it can be removed by rubbing with edible oil.

George and Margaret Schattauer show a 'Black Gold' fruit from their orchard weighing 34.7 kg (76.4 lb). Kealakekua, Hawai'i. PHOTO: K. LOVE

pulp and seeds tonic, cooling and nutritious, and to be 'useful in overcoming the influence of alcohol on the system'. The seed starch is given to relieve biliousness and the roasted seeds are regarded as aphrodisiac. The ash of jackfruit leaves, burned with corn and coconut shells, is used alone or mixed with coconut oil to heal ulcers. The dried latex yields artostenone, convertible to artosterone, a compound with marked androgenic action (having male hormone activity). Mixed with vinegar, the latex promotes healing of abscesses, snakebite and glandular swellings. The root is a remedy for skin diseases and asthma. An extract of the root is taken in cases of fever and diarrhea. The bark is made into poultices. Heated leaves are placed on wounds. The wood has a sedative property; its pith is said to produce abortion."

Animal fodder

Cattle, goats, and other small ruminants relish the leaves. Cattle and pigs also readily eat fallen fruit. The waste after removing the pulp from fruits ("rags") is considered good fodder for cattle and pigs.

Flavoring/spice

The ripe pulp, fresh, concentrated, or powdered, is made into flavoring for ice cream and beverages.

Masticant/stimulant

The latex can be used as chewing gum.

Timber

The wood is classified as a medium hardwood (specific gravity 0.6–0.7) and is highly valued for building material, furniture and cabinet making, and even for musical instruments. It is highly durable, resisting termites and decay, seasons easily, resembles mahogany in appearance, and takes a beautiful polish. As the wood ages, it turns from yellow or orange to red or brown. Although not as strong as teak (*Tectona grandis*), jackfruit wood is considered superior for many purposes including furniture, construction, turnery, masts, oars, implements, and musical instruments. The excavated roots of old trees are highly prized for carving and picture frames.

Fuelwood

Branches and trunk are burned for fuelwood.

Craft wood/tools

In the province of Cebu, Philippines, the wood is highly prized for making guitars, ukuleles, and other musical instruments.

Rope/cordage/string

The inner bark can be made into cordage or cloth.

Wrapping/parcelization

In India, leaves are used to wrap food for cooking and are woven together for plates.

Resin/gum/glue/latex

The heated latex can be used as a glue for mending chinaware and pottery and as caulking for boats and buckets. The latex contains resins that may have use in varnishes. The latex also has bacteriolytic value comparable to that of papaya latex. Additionally, the sticky latex is used for trapping birds (birdlime) and for insect traps.

Tannin/dye

There is 3.3% tannin in the bark. When boiled with alum, wood chips, or sawdust, it yields a dye that is commonly used to give the characteristic color to the robes of Buddhist priests and in dying silk.

Cutting a large fruit, Rayong, Thailand. PHOTO: C. ELEVITCH

Ceremonial/religious importance

In India and Nepal, flowers and fruit are offered to Lord Vishnu on the eleventh day of Shravan. According to Morton (1987), dried branches are used to produce fire by friction in religious ceremonies in Malabar.

COMMERCIAL CULTIVATION

The primary commercial products of jackfruit are fruit, timber, and to a lesser extent, fodder. In the Pacific the tree is most commonly grown in homegardens rather than for commercial purposes. Jackfruit is a popular tree for homegardens in India, the Philippines, Thailand, Sri Lanka, and other regions where jackfruit is grown commercially.

Spacing

For fruit production, trees are planted 7.5–12 m (25–40 ft) apart. Closer in-row spacing can be used for slower growing or more compact clonally reproduced cultivars (usually grafted clones) with in-row spacing of 4.6–7.6 m (15–25 ft) and between-row spacing of 6.1–7.6 m (20–25 ft) (Crane et al. 2002). For timber production, closer spacing should be used to inhibit side branching by shading and promote long, straight trunks. Spacing for timber of 2 x 3 m or 3 x 3 m (6.6 x 10 or 10 x 10 ft) is suitable.

Management objectives and design considerations

During early establishment it is essential to control weeds, maintain soil moisture, and protect the area from all grazing animals. Weed-seed-free mulch such as leaves, chipped tree branches, or hay works very well to help suppress weeds and reduce soil evaporation. An alley cropping system to produce mulch for a jackfruit orchard gave promising results (Elevitch and Wilkinson 1999). At an age of 2–3 years, the trees can be topped at 3–5 m (10–16 ft) height to encourage lateral growth for fruit production at an accessible height. Once a tree is topped, however, new branches will not be as strong as the original frame of the tree, and top pruning will have to be done throughout the life of the tree to avoid branches breaking off due to wind or the weight of the fruit.

Pruning damaged branches, especially on the lower interior of the tree, is advised. Fertilizer needs are not well studied for jackfruit. The tree seems to perform well even on moderately fertile soils. A recommended commercial fertilizer regime is 100–150 g (3.5–5 oz) ammonium sulfate (20-0-0) per tree in the first year, increasing in pre-bearing years; then 0.5–1.0 kg (1.1–2.2 lb) of 14-14-14 fertilizer per tree increasing with age and size, with a full-grown tree 15–20 years old receiving 2–3 kg (4.4–6.6 lb) complete fertilizer (Coronel 1983). The use of nutrient-rich organic mulches such as prunings from fast-growing nitrogen-fixing trees can reduce or eliminate the use of industrial fertilizer.

For timber production, it is important to keep the lower portion of the trunk clear of branches and fruit-bearing lateral spikes in order to produce clear, knot-free wood. Because jackfruit has a tendency to produce fruit-bearing spikes low on the trunk, annual pruning of these spikes is often necessary.

Advantages of polycultures

During the early years, jackfruit can be successfully intercropped with a number of short-term crops such as legumes, vegetables, and banana. The intercrop makes use of the unproductive space available in the early years and gives an income before the jackfruit trees come into production. As the trees grow closer, the crops grown among the trees can be replaced by a permanent ground cover.

Table 1. Tree characteristics of cultivars found in Hawai‘i (after Crane et al. 2002).

Cultivar and origin	Growth habit and rate	Fruit weight	Fruit shape	Yield per tree	Season and months	Comments
‘Black Gold’ Australia	Open, spreading, fast	10 kg (22 lb)	Long, tapered	55–90 kg (120–200 lb)	Late, Sept.–Oct.	Tree easily pruned to maintain small tree (~2.5 m [8 ft])
‘Dang Rasimi’ Thailand	Open, spreading, fast	8–9 kg (18–20 lb)	Uniform oblong	(75–125 kg (165–275 lb)	Mid, July–Aug.	Vigorous tree; annual pruning needed to maintain moderate size (~3.3 m [11 ft])
‘Gold Nugget’ Australia	Dense, spreading, fast	3–5.5 kg (7–12 lb)	Round	60–80 kg (132–176 lb)	Early, May–June	Thinning number of fruit recommended; tree easily pruned to maintain small tree (~2.5 m [8 ft])
‘Honey Gold’ Australia	Sparse, spreading, slow-moderate	4.5–5.5 kg (10–12 lb)	Blocky	35–50 kg (77–110 lb)	Mid, July–Aug.	Thinning number of fruit recommended; tree easily pruned to maintain small tree (~2.5 m [8 ft])
‘Lemon Gold’ Australia	Moderately dense, spreading, moderate	6 kg (13 lb)	Blocky	30–45 kg (66–100 lb)	Mid, July–Aug.	Vigorous tree; annual pruning needed to maintain moderate size (~3.5 m [12 ft])
‘NS1’ Malaysia	Dense, upright, moderate	4–5.5 kg (9–12 lb)	Blocky	90 kg (200 lb)	Early, May–June	Thinning number of fruit recommended for young trees; moderately vigorous tree; annual pruning to maintain moderate size (~3 m [10 ft])

Table 2. Characteristics of edible portion, cultivars found in Hawai‘i (after Crane et al. 2002).

Cultivar	Color	Texture	Flat spines at ripening	% edible flesh	# seeds per fruit; seed %	Flavor	Comments
‘Black Gold’	Deep orange	Medium-firm to melting, soft	No	35%	192; 17%	Good, sweet, aromatic	Flesh easily removed
‘Dang Rasimi’	Deep orange	Firm to soft	No	32%	187; 12%	Mild, sweet flavor, pleasant aroma	Flesh thin walled
‘Golden Nugget’	Deep orange	Soft to medium firm	Yes	41%	79; 13%	Very pleasant flavor	Fruit may split after heavy rains
‘Honey Gold’	Dark yellow to orange	Firm	Yes	36%	42; 5%	Sweet, rich flavor and aroma	Flesh thick walled, excellent texture
‘Lemon Gold’	Lemon yellow	Firm	Yes	37%	104; 14%	Sweet and aromatic flavor	Flesh thick walled
‘NS1’	Dark orange	Firm	Yes	34%	63; 5%	Sweet rich flavor	Excellent texture

Once topped, trees require continual pruning or the new growth of stems often breaks under the weight of the fruit. PHOTO: C. ELEVITCH

Perennial crops such as durian, coffee, and citrus can be grown together with jackfruit, given wider spacing between jackfruit trees to allow sufficient space for the other crop trees.

Yields

Potential yields of 100–200 fruits per tree per year have been estimated. For example, in India a good annual yield is considered to be 150 large fruits per tree (Morton 1987). Actual yields of mature trees are 70–100 kg (150–220 lb) of fruit/tree/yr depending on variety, cultural practice, and environmental factors (Soepadmo 1992).

On-farm processing methods

The fruit can be processed in several ways such as drying, candying, and pickling. These are relatively simple methods to preserve the fruit that can be done on-farm.

Markets

Jackfruit is heavy and cumbersome to transport and should be harvested when mature only 3–5 days from ripening, so it is best to have a market close by if selling fresh fruit. For more remote areas, where the local market is small, processing the fruit into a more stable product such as dried or processed fruit may be necessary.

INTERPLANTING/FARM APPLICATIONS

Jackfruit has been planted as an intercrop in coconut groves, in durian, mango, and citrus orchards, and for dispersed shade in coffee plantations. In young jackfruit orchards, where there is ample space between trees, annual crops can be grown. One or two trees growing in mixed homegardens together with numerous other tree crops is also very common.

Example system

(after Elevitch and Wilkinson 1999a)

Location

Holualoa, Hawai'i.

Description

This project studied alley cropping for mulch production in a jackfruit orchard. In alley cropping, fast growing nitrogen-fixing trees (NFTs) are grown in contour hedgerows alternated with crops to provide an abundant source of nutrient-rich organic matter that is applied to the soil as mulch. By cycling nutrients in the agricultural system, alley cropping in an orchard setting holds promise for greatly reducing, and possibly eliminating, the need for manufactured or imported fertilizer inputs, replacing them with an on-site organic source of fertility. Research focused primarily on the ability of the alley cropping technique to provide sufficient nutrients to tree crops, as well as the economic feasibility of the practice for orchards. The two NFT species were *Acacia angustissima* and *Calliandra calothyrsus*.

Crop/tree interactions

The hedgerows were pruned for mulch four times during the project. Hedgerow prunings fresh weight and nutrient concentrations for the two NFT species were measured at each cutting to ascertain fertilizer replacement values. Data show that the hedgerows produced about 136 kg (300 lb) of mulch per fruit tree per year. Nutrients from this mulch source provided the nutrient equivalent of over 561 kg chemical fertilizer per hectare per year (500 lb/ac/yr), potentially replacing 180 kg (400 lb) urea, 11 kg (25 lb) treble

Hedgerows of fast-growing nitrogen-fixing trees grown between rows of jackfruit. PHOTO: C. ELEVITCH

superphosphate, and 55 kg (120 lb) muriate of potash. Soil analysis showed significant increases in total nitrogen and potassium as a result of the practice. Soil pH also improved, becoming less acidic. The mulch also reduced the need for weed control around the crop trees and conserved soil moisture. The health and vigor of the mulched crop trees visibly surpassed that of the control trees without mulch, and analysis of the data shows a trend of faster growth and larger stem diameter in the mulched trees over unmulched. The costs of this practice are roughly equivalent to using purchased mulch materials. This practice may be particularly of benefit to cash-poor Pacific island farmers, who have better access to labor than cash.

Spacing/density of species

The jackfruit trees were planted in contour rows 8–12 apart with 4 m (13 ft) spacing between trees in-row. The contour hedgerows were planted midway between jackfruit rows.

PUBLIC ASSISTANCE AND AGROFORESTRY EXTENSION

Extension offices for agroforestry and forestry in the Pacific: http://www.traditionaltree.org/extension.html

GENETIC RESOURCES

Germplasm collections are located in the United States (U.S. Department of Agriculture, Subtropical Horticultural Research Unit, Miami, Florida), Indonesia (Centre for Research & Development in Biology, Bogor), the Philippines (Institute of Plant Breeding, Los Baños), and Thailand (Plew Horticultural Research Centre).

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Traditional Tree Initiative—Species Profiles for Pacific Island Agroforestry (www.traditionaltree.org)

Artocarpus heterophyllus (jackfruit)

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Acknowledgments: The authors and publisher thank Dale Evans, David Frenz, Ken Love, and Diane Ragone for their input. Photos contributed by Ken Love are greatly appreciated.

Recommended citation: Elevitch, C.R., and H.I. Manner. 2006. *Artocarpus heterophyllus* (jackfruit), ver. 1.1v. In: Elevitch, C.R. (ed.). Species Profiles for Pacific Island Agroforestry. Permanent Agriculture Resources (PAR), Hōlualoa, Hawai'i. <http://www.traditionaltree.org>.

Sponsors: Publication was made possible by generous support of the United States Department of Agriculture Western Region Sustainable Agriculture Research and Education (USDA-WSARE) Program; SPC/GTZ Pacific-German Regional Forestry Project; USDA Natural Resources Conservation Service (USDA NRCS); State of Hawai'i Department of Land & Natural Resources Division of Forestry & Wildlife; and the USDA Forest Service Forest Lands Enhancement Program. This material is based upon work supported by the Cooperative State Research, Education, and Extension Service, U.S. Department of Agriculture, and Agricultural Experiment Station, Utah State University, under Cooperative Agreement 2002-47001-01327.

Series editor: Craig R. Elevitch

Publisher: Permanent Agriculture Resources (PAR), P.O. Box 428, Hōlualoa, Hawai'i 96725, USA; Tel: 808-324-4427; Fax: 808-324-4129; E-mail: par@agroforestry.net; Web: http://www.agroforestry.net. This institution is an equal opportunity provider.

April 2006
ver. 2.1

Artocarpus mariannensis (dugdug)

Moraceae (mulberry family)

***chebiei, ebiei meduuliou, mai* (Palau); *dugdug, dokdok* (Guam: Chamorro); *maiyah* (Puluwat, Yap); Marianas breadfruit, seeded breadfruit (English); *mei chocho* (Chuuk); *mei kole* (Pohnpei); *mej-waan* (Marshall Islands); *mos en kosrae* (Kosrae); *te mai* (Kiribati); *ulu elihe, ulu elise* (Tokelau)**

Diane Ragone and Harley I. Manner

IN BRIEF

Distribution Palau, Mariana Islands, FS Micronesia, Kiribati, Marshall Islands, Tokelau, Tuvalu, Nauru, Banaba, and Rabi Island, Fiji.

Size Large tree 20 m (66 ft) or more at maturity.

Habitat Tropical regions, usually found sea level to 150 m (490 ft) with rainfall of 1300–3800 mm (50–150 in).

Vegetation Associated with remnants of tall native-canopy forest and secondary forest.

Soils Associated with raised coral or elevated limestone.

Growth rate Moderately fast growing in favorable conditions, growing 0.5–1.5 m (1.5–5 ft) per year.

Main agroforestry uses Soil stabilization, overstory, homegardens.

Main products Staple food, medicinal, wood for crafts and timber.

Yields 50 kg (110 lb) or more fruit per tree per year.

Intercropping Interplanted with small fruit trees or short-term fruit and vegetable crops.

Invasive potential It has little potential to become invasive.

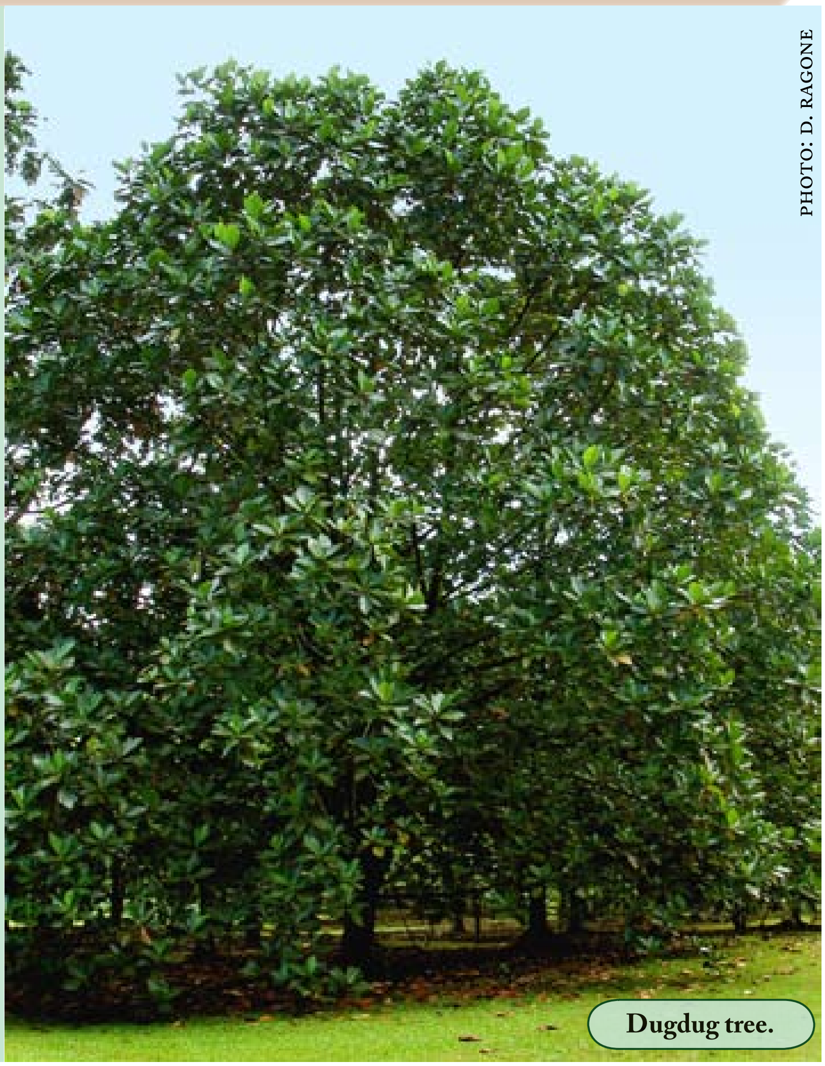


PHOTO: D. RAGONE

Dugdug tree.

INTRODUCTION

Artocarpus mariannensis (dugdug) is native to the Mariana Islands and Palau and is closely related to breadfruit (*A. altilis*), with which it has naturally hybridized. It is recognized on those islands as being distinct from breadfruit. However, this species and the numerous interspecific hybrids in Micronesia are considered to be "breadfruit," whether they are seeded or seedless. Micronesian navigators spread it throughout the region and it is now widely cultivated, mostly in coastal areas and on atolls. In Kosrae it is believed to generally occur in the long-abandoned interior of the island, although some trees are found in lowland areas. It has been distributed as far south as Tuvalu, Tokelau, and Rabi Island, Fiji, and a few trees have been introduced to Hawai'i. It is not grown elsewhere in the Pacific or in other tropical regions. This species, its close relative, *Artocarpus altilis*, and the many hybrid varieties are a major staple food tree in the Micronesian region. It tolerates salinity better than seedless breadfruit, but is usually cultivated in the interior of the atolls' islets (motus) in close proximity to the taro swamps, where damage from salinity is less. The fruit is high in carbohydrates and is a good source of minerals and vitamins, especially vitamin A. The high-protein, relatively low-fat seeds are roasted and eaten. The large evergreen trees can reach heights of 20 m (66 ft) or more with buttressed trunks more than 2 m (6.6 ft) in diameter at the base. Trees of dugdug and hybrid varieties tend to be more massive than *A. altilis*, often not branching below 5 m (16 ft) from the ground. The straight trunks are very desirable for canoes, although the wood needs to be protected from direct sunlight. The sticky white latex is used as caulking and glue. Wild populations in Guam and the Northern Marianas are seriously declining due to typhoon damage and the disappearance of its important natural disperser, flying foxes.

DISTRIBUTION

Native range

This wild seeded relative of breadfruit (*Artocarpus altilis*) is native to the Mariana Islands, in limestone and ravine forests from coastal to lower mountain slopes. In Palau, it is common in the Rock Islands, in Peleliu, Angaur, and Kayangel, and in the Southwest Islands of Sonsorol, Fana, Pulo, Ana, Merir, and Tobi. It also found in calcareous soils along the northeast coast and on the volcanic island of Babeldaob. It is distributed through its natural range by flying foxes (fruit bats).

Current distribution

Dugdug and hybrid varieties (*A. mariannensis* × *A. altilis*) are cultivated throughout the Republic of Palau, Federated States of Micronesia, Kiribati, Republic of the Marshall Islands, Tokelau, Tuvalu, Nauru, Banaba, and Rabi Island, Fiji. A few dugdug trees can be found in Hawai'i. It has not been distributed elsewhere in the Pacific or to other tropical regions.

BOTANICAL DESCRIPTION

Preferred scientific name

Artocarpus mariannensis Trécul

Family

Moraceae

Non-preferred scientific names

Artocarpus altilis
A. camansi
A. communis
A. incisa

Common names

chebiei, ebiei, meduuliou, mai (Palau)
dugdug, dokdok (Guam: Chamorro)
maiyah (Puluwat, Yap)
Marianas breadfruit, seeded breadfruit (English)
mei chocho (Chuuk)
mei kole (Pohnpei)
mejwaan (Marshall Islands)
mos en kosrae (Kosrae)
te mai (Kiribati)
ulu elihe, ulu elise (Tokelau)

Size

It can reach heights of 20 m (66 ft) or more at maturity. The trunk may be 2 m (6.6 ft) or larger in diameter, often growing to a height of 5 m (16 ft) or more before branching. A sticky white latex is present in all parts of the tree. The bark is smooth, brownish-gray, with new shoots purplish-green.

Form

Single-trunked tree with rounded, spreading evergreen canopy and typically forms buttresses at the base of the trunk.

Flowering

Monoecious with male and female flowers on the same tree at ends of branches, with the male inflorescence appearing first. Male flowers are club-shaped, up to 3 cm (1.2

in) in diameter and 8–12 cm (3.1–4.7 in) long. Thousands of tiny flowers with two anthers each are attached to a central spongy core. Female inflorescences consist of 1500–2000 reduced flowers attached to a spongy core. The flowers fuse together and develop into the fleshy, edible portion of the fruit. Cross pollinated but pollination is not required for a fruit to form.

Leaves

Leaves are alternate, 15–30 cm (5.9–11.8 in) long, broadly obovate to broadly elliptic, typically entire or shallowly 1–3-lobed on the upper third of leaf. Blade is smooth, glossy, flexible, dark green with greenish-yellow veins and few hairs on upper veins. Few to many appressed reddish hairs are found on veins on the leaf underside. Two large green stipules enclose the bud and turn yellow before dehiscing.

Fruit

The fruit is a small fleshy syncarp, cylindrical, kidney-shaped or asymmetrical, about 15 cm (5.9 in) long, weighing approximately 500 g (1.1 lb). Its skin is dark green, even when mature, with a pebbly texture from the raised, flattened, hexagonal disks of individual flowers. The pulp is whitish-yellow when immature and deep yellow when ripe, with a sweet aroma and taste. The fruit is not as solid or dense as breadfruit because the individual flowers forming the fruit are fused together only at their bases. Fruit is produced mainly in summer.

Variable leaf form of dugdug. PHOTO: J. WISEMAN

Seeds

The fruit contains up to 15 large, dark brown, shiny edible seeds 1.5 cm (0.6 in) long, with little to no endosperm and no period of dormancy. They germinate immediately and are unable to withstand desiccation. They are typically spread by flying foxes.

How to distinguish from similar species/look-a-likes

This species can be readily distinguished from breadfruit (*A. altilis*) by the small, typically entire leaves. The dark green, lumpy fruit is smaller and more asymmetrical than breadfruit, with a dark yellow pulp. *Artocarpus camansi* (breadnut,

Left: Immature fruit and leaves. Right: Dugdug fruits are asymmetrical or kidney shaped with up to 15 large seeds. PHOTOS: D. RAGONE kamansi) has oblong, very spiny fruits with little pulp and numerous large, light brown seeds, and large, shallowly dissected leaves with 4–6 pairs of lobes.

GENETICS

Variability of species

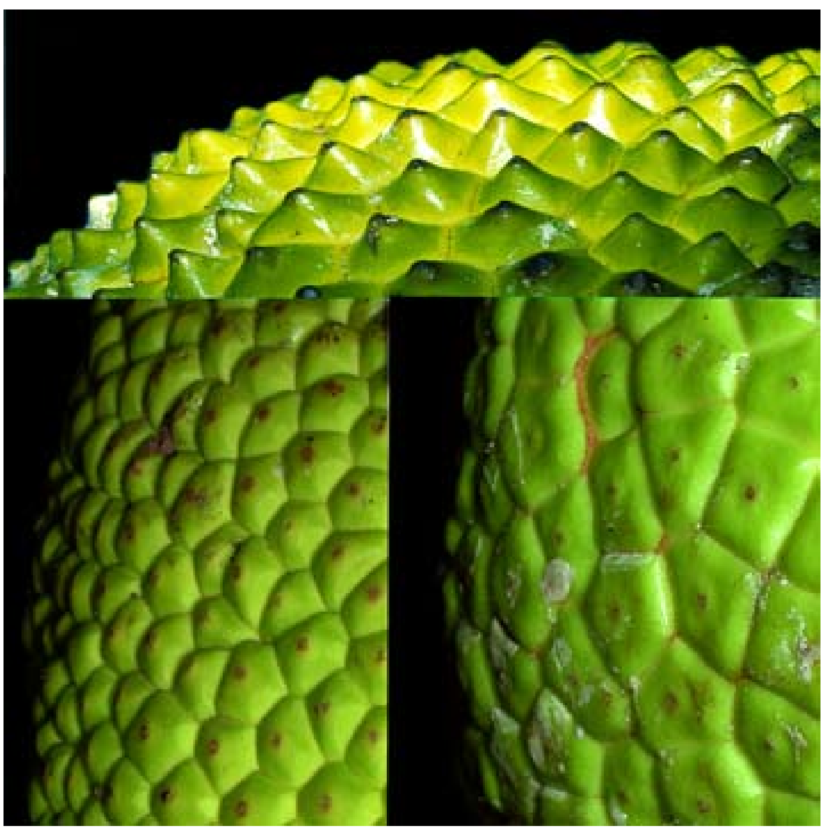
Dugdug is a genetically variable diploid species, produces abundant fertile pollen, and has naturally hybridized with *A. altilis* in Micronesia. Seeded hybrids and dugdug will readily cross with seeded forms of *A. altilis* when grown together, and there is much variation in the resulting seedlings.

Known varieties

There are no varieties of dugdug, but there are numerous varieties that are hybrids of *A. mariannensis* and *A. altilis*. These hybrid varieties exhibit great variability in leaf and fruit form and can be seeded or seedless. The fruits typically are rough-skinned or pebbly, light to dark green in color, with flesh intermediate in fusion between dugdug and the dense, solid fruits typical of seedless Polynesian breadfruits. Seeded types typically have lumpy, asymmetrical fruits 12–30 cm (3.7–11.8 in) long; some unusual forms have narrow, elongated fruits up to 45 cm long. Most seeded types are unique to a particular area, because they are local seedling selections. Some seedless hybrid cultivars such as 'Mein padahk' are widely distributed and grow on both high islands and coral atolls.

'Mein padahk' ('Butatak', 'Betaaktak') is important throughout the FSM and the Marshall Islands and is well adapted to atoll conditions. It is tall, reaching heights of 12–15 m (39–49 ft), with a dense, spreading canopy. The small, shiny, moderately dissected leaves have three to five pairs of lobes (some have only one or two pairs). The oval to asymmetrical, light yellow-green, seedless fruits are 12–24 cm (4.8–9.6 in) long and 11–16 cm (4.4–6.4 in) wide and weigh 0.7–3.1 kg (1.5–6.8 lb), averaging 1.8 kg (3.9 lb).

'Te mai keang' is found in Kiribati, the outer islands of Chuuk and Yap, Banaba, other Micronesian atolls, and Rabi island, Fiji. This seeded hybrid cultivar has pebbly-textured fruits typical of dugdug and deeply dissected leaves with 4–6 pairs of widely spaced, narrow lobes typical of *A. altilis*.



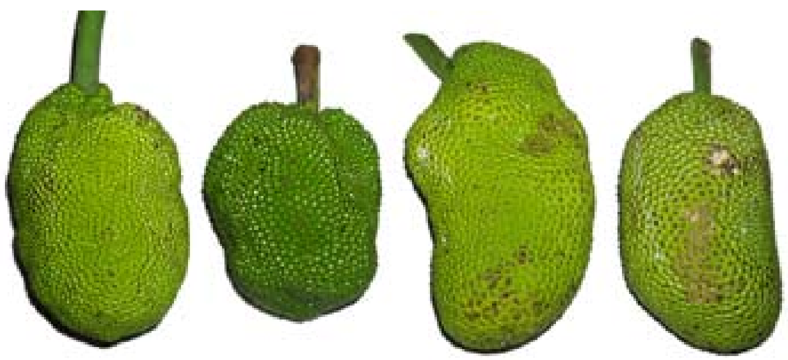
Hybrids are easily recognized by their shiny, bumpy or pebbly skin. PHOTOS: D. RAGONE

Genetic resources where collections exist

A breadfruit germplasm collection at the National Tropical Botanical Garden in Hawai'i has eight accessions of dugdug from the Northern Mariana Islands, Chuuk, and Pohnpei and more than 30 accessions of *A. altilis* × *A. mariannensis* hybrids from Chuuk, Pohnpei, Palau, Guam, and Tokelau.

ASSOCIATED PLANT SPECIES

Dugdug is an important component of the vegetation associated with raised coral or elevated limestone. In the southern Marianas what remains of the once-extensive, tall, closed-canopy forest is dominated by enormous wild dugdug trees and banyan (*Ficus* spp.). The most common trees in inland areas of elevated limestone belong to the genera *Ficus, Pandanus, Intsia, Elaeocarpus, Aglaia, Fagraea, Pipturus, Cycas, Claoxylon, Osmoxylon, Syzygium* (*Eugenia*), *Premna, Guamia, Hernandia, Pouteria, Erythrina, Aidia, Melanolepis, Cynometra, Semecarpus, Meryta, Milletia,* and *Dracaena*. Depending on the area, the undergrowth includes *Psychotria, Clerodendrum, Morinda, Tarenna, Phyllanthus, Polyscias, Maesa, Ficus, Maytenus,* and *Syzygium* and tangled vines of *Canavalia, Mucuna, Operculina, Alyxia, Caesalpinia, Connarus,* and *Freycinetia.*



Clockwise from top left: Long hybrid; hybrid variety 'Te mai keang;' hybrid variety 'Mein padahk;' variation in fruits from different dugdug trees. PHOTOS: D. RAGONE

In the Marianas this forest occurs largely on flat terraces and cliffs.

In Palau dugdug occurs on elevated limestone islands with steep slopes and ridges as well as on coral platform islands and an atoll. The sharply eroded limestone karst is densely wooded with a closed and diverse broadleaf evergreen forest composed of *Eugenia reinwardtiana, Morinda latibracteata, Garcinia matudai, G. rumiyo* var. *calcicola, Intsia bijuga, Rinorea* sp., *Cycas circinalis, Flacourtia rukam, Aidia cochinchinensis, Mertya sensfftiana, Polyscias grandifolia, Geniostoma sessile, Premna serratifolia, Cyrtandra todaiensis, Guettarda speciosa, Badusa palauensis, Psychotria hombroniana, Ixora casei,* and *Tarenna sambucina*, with such lianas as *Alyxia palauensis, Cayratia trifolia, Trichosanthes hosokawae, Derris trifoliate, Canavalia cathartica, Caesalpinia crista*, and others. The endemic palm *Gulubia palauensis* was once a conspicuous component of this forest. Epiphtyes, especially ferns, are found in the Marianas and Palau, with *Asplenium nidus, Phymatosorus* spp., *Davallia solida*, and *Nephrolepis acutifolia* common.

Dugdug is usually not found on bluffs and seaward slopes. Much of the primary forest of the Marianas was cleared for agriculture, disturbed by war activities in the 1940s, or damaged by typhoons, and it has been replaced by secondary scrub vegetation or forest. Scrub vegetation includes *Leucaena leucocephala, Morinda citrifolia, Carica papaya, Triphasia trifolia*, and *Casuarina equisetifolia.* Trees of *Macaranga* spp., *Pipturus argenteus, Hibiscus tiliaceus,* *Commersonia bartramia, Casuarina equisetifolia, Ambroma augusta, Pithecellobium dulce,* and *Pandanus* spp. form dense thickets with understory shrubs such as *Triphasia, Morinda,* and *Melochia*.

Species commonly associated as aboriginal introductions

Dugdug is an aboriginal introduction in Micronesia and is cultivated around homes and in villages, especially on the coral atolls. On the atolls it is associated with coconut, taro (*Cyrtosperma chamissonis* and *Colocasia esculenta),* banana (*Musa* spp.), edible pandanus (*Pandanus tectorius*, screwpine), sugarcane, arrowroot (*Tacca leontopetaloides), Guettarda speciosa*, beach hibiscus (*Hibiscus tiliaceus*), *Cordia subcordata*, and Indian mulberry (*Morinda citrifolia*, noni). It is often grown with papaya (*Carica papaya*), citrus, and soursop (*Annona muricata*), all of which are modern introductions.

Breadfruit canopy and vegetation zonation on Alei Islet, Puluwat Atoll, Chuuk, FSM. Photo taken from the lighthouse shows the 10 m (33 ft) high canopy of dugdug. Coconuts and more salt-resistant vegetation are found toward the coast. PHOTO: H. MANNER

ENVIRONMENTAL PREFERENCES AND TOLERANCES

Climate

Dugdug requires a tropical climate and will not grow where the temperature goes below 5°C (41°F). Its latitudinal limits are approximately 10° S and 20° N in the Pacific, but this is due to its distribution by islanders, not by environmental factors. It should do well wherever breadfruit (*A. altilis*) is grown.

Elevation range

0–150 m (0–490 ft)

Mean annual rainfall

1300–3800 mm (50–150 in), but it can yield regularly on atolls that receive 1000 mm (40 in)

Rainfall pattern

Prefers climates with summer rains

Dry season duration (consecutive months with <40 mm [1.6 in] rainfall)

Two months, based on mean rainfall from Eniwetok: 23–27 mm (0.9–1.1 in)

Mean annual temperature

26–28°C (79–82°F)

Mean maximum temperature of hottest month

29–31°C (84–88°F)

Mean minimum temperature of coldest month

16–18°C (61–64°F)

Minimum temperature tolerated

5–10°C (41–50°F)

Soils

This species is adapted to limestone ridges and outcrops and shallow calcareous soils. It thrives in volcanic soil but good drainage is essential. Hybrid varieties are well adapted to shallow sandy soils of coral atolls and should do well in coastal areas throughout the tropics.

Soil texture

It prefers light, well drained soils (sands, sandy loams, loams)

Soil drainage

It requires freely draining soils.

Soil acidity

Alkaline to neutral soils (pH >6.1–7.4)

Special soil tolerances

It tolerates saline soils as well as coralline soils and atolls (e.g., Histic Anthropics, Inceptisols, Psamments).

Tolerances

Drought

The tree can withstand drought for a few months but will prematurely drop fruits.

Full sun

It does best in full sun.

Shade

Seedlings prefer 20–50% shade.

Fire

Dugdug can sprout back from the roots after a small fire, but the trunk and branches are not fire tolerant.

Frost

It is damaged by frost, which causes it to lose all fruits and leaves, and some branch dieback will occur.

Waterlogging

It cannot tolerate waterlogged soils.

Salt spray

It can tolerate salt spray for brief periods.

Wind

Trees are shallow-rooted and may topple during typhoon-intensity winds but will produce new shoots and branches after sustaining wind damage.

Dugdug tree at Pagat, Guam in April 2003 regenerating from typhoon damage that took place in December 2002. PHOTO: H. MANNER

GROWTH AND DEVELOPMENT

Growth rate

This species is fast growing in favorable conditions, growing 0.5–1.5 m (1.5–5 ft) per year and to a diameter of up to 1 m (3.3 ft) for the first 10–12 years. Small branches often die back at the tip after fruiting, but new shoots and branches continue to develop throughout the life of the tree.

Flowering and fruiting

Bearing is seasonal, with a peak during July through September throughout its range. Trees begin producing in approximately 5 years.

Yields

Little information is available for yields. An estimated 100 or more fruits per year are produced with an average weight of 500 g (1.1 lb).

Rooting habit

The roots spread and grow on or slightly below the surface.

The tree develops extensive buttresses when mature.

Reaction to competition

As evidenced by its widespread distribution in the limestone forest, this species is able to withstand competition from other forest trees.

Diseases and pests

It has few serious diseases or pests other than some damage by termites. Tree decline and dieback has been a problem throughout the atolls. No pathological cause has been identified. It is considered to be the result of storm damage, drought, aging of the trees, and salinity. Proper husbandry, such as removing dead and dying branches and mulching, are essential to maintaining its health and vigor.

PROPAGATION

Dugdug is easily propagated by seed. The trees do not produce root shoots and cannot be grown from root cuttings. Seeds are collected and grown, and occasionally seedlings will be gathered from beneath fruiting trees and transplanted to the desired location. Varieties that are seedless hybrids with *A. altilis* are vegetatively propagated by root shoots, root cuttings, or air-layering (see propagation methods for breadfruit). Seeded hybrids are typically grown from seed, although few-seeded forms occasionally produce root shoots and can also be air-layered.

Propagation by seeds

The seeds germinate quickly and will often sprout inside fallen fruits. Collect seeds from soft, ripe fruits and wash to remove all pulp. Select firm, shiny, uniform seeds that do not yield to the touch when squeezed. Discard any sprouted or aborted seeds. The latter are typically misshapen, flat, and contain little or no endosperm. Clean seed surface in a 2% bleach solution for 5–10 minutes or treat with a fungicide according to the manufacturer's recommendation. Plant immediately, as seeds are recalcitrant and cannot be dried or chilled. Germination rates are high, close to 100%.

Place seeds in seedling flats in a loose, well drained medium. Plant at a depth twice the width of the seed. Keep moist but not wet. Seeds germinate within 10–14 days. Transplant into 4–8 liter (1–2 gal) pots once the true leaves have hardened. If adding fertilizer (such as balanced 8-8-8), use only sparingly, at a rate of less than half the manufacturer's recommendations. Keep plants in partial shade and weed-free. Seedlings grow quickly, reaching 1 m in approximately 6 months, and are ready to plant into the field in less than a year. Seedlings can also be gathered from beneath trees and transplanted into the nursery. Care must be taken when digging the seedling from the ground, because it is easy to damage or break the delicate roots and injure or kill the seedling.

Establishment in the nursery

Young plants prefer partial shade. If plants are to be planted in full sun, gradually move to full sun conditions in the nursery for 1–2 months to harden them to the site conditions. Young plants should never be allowed to dry out or be exposed to strong wind.

Young dugdug seedlings always have entire leaves (without lobes). PHOTO: D. RAGONE

Outplanting

Outplant when the plants have reached the desired size of approximately 1.25 m tall and 2 cm in stem diameter. The leaves have a large surface area and therefore lose a great deal of water to the air. It is best to reduce the size of the leaves to reduce transpiration. Carefully remove 1/2 to 2/3 of the lower leaves by trimming the blade and leaving only a small section attached to the petiole. Do not remove or damage the growing point of the plant where new leaves develop. Protect from wind and excessive heat during transport. Dig a hole the same depth and twice as wide as the container. Add a small amount of slow-release fertilizer such as 8-8-8 to the bottom of the hole and cover with soil. To prevent injury to the brittle root system, carefully cut off the container rather than pulling the plant out. Place the tree in the hole, add soil no higher than the level of the plant in the pot, top-dress with compost, and water well.

Young plants grow best in partial shade. It is best to plant at the onset of the rainy season, but if the weather is dry, irrigate for the first 1–3 months of establishment. Once established, breadfruit trees can withstand a dry season of 3–4 months, although it prefers moist conditions. Mulching young plants is beneficial by helping keep the soil moist and adding a steady supply of nutrients. It also helps control weeds around the root system. Use of herbicide to control weeds around the base of the tree can damage the tree if it comes in contact with the surface roots or young trunk. Young trees need to be protected from cattle, goats, horses, and pigs, which will eat the bark and tender shoots. Close to 100% success rate can be expected.

DISADVANTAGES

Compared to most varieties of breadfruit, this species produces small, seeded fruits and is not as suited as a backyard tree because of its large size and extensive buttress roots.

Potential for invasiveness

This species has little potential for invasiveness because the seeds quickly lose viability and are not readily spread except by flying foxes. Since populations of flying foxes are seriously declining in many parts of the Pacific, there is little chance that this species will become invasive. In fact, the decline of flying fox populations has been accompanied by a decline in this species throughout its native habitat.

Susceptibility to pests/pathogens

The plant is relatively trouble-free, with disease and pest problems localized. It does not appear to be as susceptible as breadfruit to fruit rots caused by *Phytophthora*, *Colletotrichum* (anthracnose), and *Rhizopus*. *Phellinus noxius*, a root rot, can be a problem, spreading through root contact, especially when trees are planted in areas of native forest that have been recently cleared. It may also be attacked by termites.

Host to crop pests/pathogens

Fruit flies are attracted to ripe fruits on the trees and ground and infest many fruit and vegetable crops.

Other disadvantages or design considerations

The surface roots can interfere with other plants. The soft wood is relatively weak. Canoes built of dugdug are often kept in shaded situations to prevent damage.

AGROFORESTRY/ENVIRONMENTAL PRACTICES

Mulch/organic matter

The leaves of this evergreen species provide abundant mulch for the tree and other plants growing beneath the canopy.

Soil stabilization

Dugdug naturally occurs on steep ridges, cliffs, and shallow calcareous soils.

Crop shade/overstory

Can be interplanted with a wide range of crops and plants such as yam, banana, medicinal plants, aroids, ginger, noni, etc.

Homegardens

Dugdug is ideal for homegardens on atolls because of its adaptability to calcareous soils and saline conditions and especially for the beneficial shade it produces. On deep, fertile soils, the trees grow too large for homegardens.

Animal fodder

All parts—flesh, peel, core, and seeds—of both mature and ripe fruits are edible and are fed to pigs and other livestock. The leaves also are edible.

Native animal/bird food

Breadfruit is an important food source for flying foxes, native doves, and other birds in the Pacific islands.

Host plant trellising

The tree can be used as a trellis for yam (*Dioscorea* spp.).

Bee forage

Honeybees visit male inflorescences and collect pollen and also collect latex that oozes from the fruit surface.

Ornamental

It is an attractive, stately evergreen tree with a rounded canopy.

USES AND PRODUCTS

Staple food

The nutritious fruits are consumed when mature or ripe and are typically roasted or baked. Ripe fruits can be eaten raw but are usually cooked. On Kapingamarangi and in the Marshall Islands fruits were commonly preserved by spreading mashed fruits into thin sheets and sun-drying to make a "fruit leather."

Nut/seed

The seeds are high in protein, low in fat, and a good source of vitamins and minerals. They are cooked in the fruits and eaten, especially on atolls. Cooked sprouted seeds are a delicacy on some atolls.

Medicinal

All parts are used medicinally, especially the latex, leaf tips, and inner bark. The latex is massaged into the skin to treat broken bones and sprains and is plastered on the spine to relieve sciatica. It is commonly used to treat skin ailments and fungus diseases such as "thrush," which is also treated with crushed leaves. Diluted latex is taken internally to treat diarrhea, stomachaches, and dysentery. The sap from the crushed petioles (leaf stalks) is used to treat ear infections or sore eyes. The root is astringent and used as a purgative; when macerated, it is used as a poultice for skin ailments. The bark is also used to treat headaches in several locations.

Timber

The light-weight, flexible wood is easy to work.

Fuelwood

The wood is fast burning, but generally older, less productive trees are used for this purpose.

Craft wood/tools

The wood is easy to work and carve into statues, bowls, fishing floats, and other objects.

Canoe/boat/raft making

The light-weight timber is used to make small canoes.

Fiber/weaving/clothing

The inner bark was once used to make bark cloth (tapa).

Rope/cordage/string

The inner bast was traditionally used to make a strong cordage used for fishing.

Wrapping/parcelization

The flexible leaves are used to wrap foods for cooking in earth ovens, and as plates.

Resin/gum/glue/latex

The sticky white latex is used as a chewing gum and an adhesive. It is still used to caulk canoes.

THE MAGIC BREADFRUIT TREE

Milad, the granddaughter of Latmikaik, lived on the islet of Ngibtal off Babeldaob Island, Palau. A magic breadfruit tree grew on her land. It had a hollow trunk that reached down into the lagoon, and once in a while a large wave would force a large fish up through the trunk and out of a broken branch. People became jealous and cut down the tree. The ocean poured through the cut trunk and flooded the island, which then sank beneath the sea. The sunken island can still be seen to this day. This legend is a popular motif for Palauan storyboards.

Toxin/insecticide/fish poison

Dried male flowers can be burned to repel mosquitoes and other flying insects.

COMMERCIAL PRODUCTS

Dugdug is a natural component of the forests of Palau and the Mariana Islands and is grown as a subsistence crop in Micronesia. It is not as widely used as breadfruit or seedless hybrid varieties due to the small, lumpy fruits with large seeds. It has no commercial use and limited potential. Hybrid seedless varieties receive the same treatment and recommendations as breadfruit (*A. altilis*).

INTERPLANTING/FARM APPLICATIONS

Trees provide shade, mulch, and a beneficial microclimate. It is generally planted as part of a homegarden or mixed agroforestry system with a wide array of useful plants. Widely spaced trees in an orchard can be interplanted with small fruit trees such as citrus and a leguminous cover crop. Short-term fruit crops such as pineapple, banana, and papaya, or field and vegetable crops including taro, tomato, and eggplant can also be grown between breadfruit trees. A leguminous cover crop should replace these intercrops when they begin to interfere with orchard operations.

Example system

Location

Federated States of Micronesia (Pohnpei)

Description

Hybrid varieties of breadfruit are typically grown with yam (*Dioscorea* spp.). The yam vines climb trellises of *Hi-*

Detail of a Palauan storyboard depicting the legend of the "Magic Breadfruit Tree." PHOTO: D. RAGONE

biscus tiliaceus, grow into the canopy of the tree during the non-fruiting period, and are dormant when the fruits are harvested. This allows the fruits to be picked without damaging the yam vines.

PUBLIC ASSISTANCE AND AGROFORESTRY EXTENSION

Extension offices for agroforestry and forestry in the Pacific: http://www.traditionaltree.org/extension.html.

GERMPLASM RESOURCES

The National Tropical Botanical Garden can provide selected varieties from an extensive breadfruit germplasm collection.

The USDA Clonal Germplasm Repository, Waiakea, Hawai'i, can provide selected breadfruit varieties.

INTERNET

The Breadfruit Institute: <http://www.breadfruit.org>.

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traditional tree initiative

Traditional Tree Initiative—Species Profiles for Pacific Island Agroforestry (www.traditionaltree.org)

Artocarpus mariannensis (dugdug)

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Acknowledgments: The authors and publisher thank James Atherton, Robin DeMeo, Dale Evans, Joel Miles, and Art Whistler for their input. The photo contribution by Jim Wiseman is greatly appreciated.

Recommended citation: Ragone, D., and H.I. Manner. 2006. *Artocarpus mariannensis* (dugdug), ver. 2.1. In: Elevitch, C.R. (ed.). Species Profiles for Pacific Island Agroforestry. Permanent Agriculture Resources (PAR), Hōlualoa, Hawai'i. <http://www.traditionaltree.org>.

Sponsors: Publication was made possible by generous support of the United States Department of Agriculture Western Region Sustainable Agriculture Research and Education (USDA-WSARE) Program; SPC/GTZ Pacific-German Regional Forestry Project; USDA Natural Resources Conservation Service (USDA NRCS); State of Hawai'i Department of Land & Natural Resources Division of Forestry & Wildlife; and the USDA Forest Service Forest Lands Enhancement Program. This material is based upon work supported by the Cooperative State Research, Education, and Extension Service, U.S. Department of Agriculture, and Agricultural Experiment Station, Utah State University, under Cooperative Agreement 2002-47001-01327.

Series editor: Craig R. Elevitch

Publisher: Permanent Agriculture Resources (PAR), PO Box 428, Hōlualoa, Hawai'i 96725, USA; Tel: 808-324-4427; Fax: 808-324-4129; E-mail: par@agroforestry.net; Web: <http://www.agroforestry.net>. This institution is an equal opportunity provider.

Acacia koa (koa) and *Acacia koaia* (koai'a)

Fabaceae (legume family)

koa (*Acacia koa*)
koai'a, koai'e (*Acacia koaia*)

Craig R. Elevitch, Kim M. Wilkinson, and J. B. Friday

IN BRIEF

Distribution Endemic to the major Hawaiian islands of Hawai'i, Moloka'i, Maui, Lāna'i, O'ahu, and Kaua'i.

Size Typically attains heights of 15–25 m (50–80 ft) with a canopy spread of 6–12 m (20–40 ft).

Habitat Native to a wide elevation range of 100–2300 m (330–7500 ft) (recommended for planting only above 610 m [2000 ft]), with annual rainfall of 850–5000 mm (34–200 in).

Vegetation Associated with dozens of other native species.

Soils Requires well drained soils. Koa stands on shallow soils are not as productive as those on deep soils and may be short-lived.

Growth rate Can grow faster than 1.5 m (5 ft) per year in height for the first 5 years in favorable environments.

Main agroforestry uses Wildlife habitat, silvopastoral systems, ornamental.

Main products Timber.

Yields Projected yields of 90–180 m^3/ha (6.5–13 mbf/acre) may be possible in pure stands in 30–50 years; much less in open-grown stands in pastures or in mixed stands in natural forests.

Intercropping Difficult to integrate with annual crops due to koa's aggressive surface root system that competes with crops, while also susceptible to damage by human, animal, and machine traffic.

Invasive potential Poses a small risk of being invasive if introduced outside of Hawai'i.

Large koa trees such as this in South Kona, Hawai'i, have mostly disappeared due to logging and land clearing.

INTRODUCTION

Acacia koa, known worldwide as koa, is the largest native tree of the Hawaiian Islands. It can reach heights in excess of 35 m (115 ft), although more commonly trees reach about 15 m (50 ft) in height at maturity. Koa is very important to the ecology, economy, and culture of Hawai'i. Koa trees in natural ecosystems provide habitat for many birds, insects, and plants, some endangered. As a nitrogen-fixing species, koa plays an important role in forest fertility. A key traditional use of koa logs by early Hawaiians was to build canoes. The resurgence of interest in Hawaiian voyaging and racing vessels using traditional materials has led to a greater public awareness of the scarcity of trees suitable for "canoe koa" and the importance of renewing this depleted resource.

Commercially, koa is Hawai'i's premier timber, and currently one of the most expensive woods in the world. It is utilized for furniture, veneer, and crafts. Most commercial koa is harvested from remnant individuals or stands in pasture land. Efforts in the private and public sectors are being made to re-establish koa, either through fostering natural regeneration (through the removal of livestock and occasionally scarifying the ground to expose buried koa seeds), or by planting seedlings. There are many unknowns regarding the cultivation and management of koa for commercial timber. Private landholders sometimes choose to plant koa for the ecosystem and heritage value, while recognizing that as a financial investment the outcome of koa reforestation is highly uncertain.

Koa trees once thrived in areas as low as 90 m (300 ft) in elevation. However, pests and diseases currently limit koa's optimal range to elevations above 610 m (2000 ft). Hawai'i's highly variable climate means that matching an appropriate seed source to the site conditions is important to foster a viable koa planting. Koa is a large, fast-growing tree with an aggressive root system. As such, its uses for interplanting with crops are limited. It is recommended that crops be planted no closer than 10–12 m (33–40 ft) to mature trees. However, many kinds of herbaceous plants can thrive in the dappled shade cast by koa.

The proliferation of this species is desirable within Hawai'i. However, as a fast-growing nitrogen-fixing tree with long-lived seeds and the ability to regenerate after fire, koa may have potential as a problematic invasive species outside its native range.

DISTRIBUTION

Native range

Koa is endemic to all major Hawaiian Islands (Hawai'i, Moloka'i, Maui, Lāna'i, O'ahu, Kaua'i), at 100–2300 m (300–7500 ft) elevation.

Current distribution

Scattered remnants of koa forests are still found on the main Hawaiian Islands, mostly in upland areas. The healthiest and largest populations grow at elevations of 900–1800 m (2950–5900 ft). New plantings are taking place in agricultural and former pasture areas, primarily above 610 m (2000 ft).

BOTANICAL DESCRIPTION

Preferred scientific name

Acacia koa Gray

Family

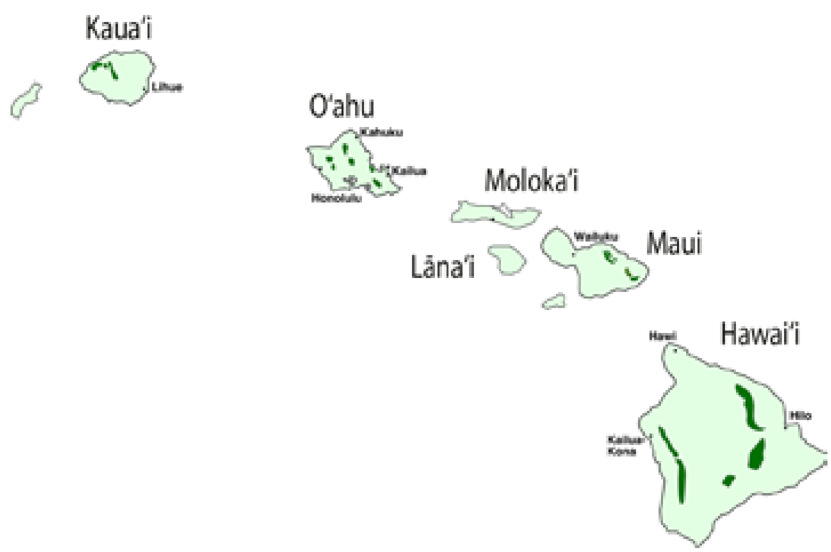
Fabaceae (legume family)

Subfamily

Mimosoideae

Non-preferred scientific names

Acacia hawaiiensis (Rock) Degener & I. Degener
A. heterophylla Willd. var. *latifolia* Benth.
A. kauaiensis Hillebr.
Acacia koaia is a closely related species previously classified as a subspecies of *A. koa* (Wagner et al. 1999)



Current remnant areas of koa (after Whitesell 1990).

Common names

koa (worldwide)

GENERAL DESCRIPTION

Size

Koa can grow to over 35 m (115 ft) in height but more commonly reaches heights of 15–25 m (50–80 ft) with a canopy spread of 6–12 m (20–40 ft). Some populations are much smaller, with a shrub-like form.

Form

The form of trees is highly variable, ranging from an upright, single trunk to low and sprawling with multiple trunks.

Flowers

Pale yellow, borne in axillary racemes with spherical heads about 8.5 mm (0.33 in) in diameter. Flowering peaks in mid to late winter. Flowers are produced throughout the year, starting when the tree is 2–3 years of age.

Leaves

Young seedlings have bipinnately compound true leaves with 12–24 pairs of leaflets. Mature trees have no true leaves, but only sickle-shaped phyllodes (flattened leaf stalks) 7–25 cm (2.8–10 in) long and 0.5–2.5 cm (0.2–1 in) wide.

Seeds

Seeds are contained within a pod (legume) 15–20 cm (6–8 in) long, containing 6–12 seeds.

Rooting habit

Koa has an extensive, shallow, and lateral-spreading root system that can often be seen on the soil surface, just under the leaf mulch. Roots can sucker, particularly when they are damaged or the tree experiences stress.

How to distinguish from similar species/look-alikes

Sickle-shaped phyllodes ("leaves") at maturity distinguish it from "haole koa" (*Leucaena leucocephala*); larger stature, larger phyllodes, and paler yellow and larger flowers distinguish it from Formosan koa (*Acacia confusa*); longer sickle-shaped phyllodes distinguish it from Australian blackwood (*Acacia melanoxylon*), which is also usually a much straighter-stemmed tree; and its much larger stature and larger phyllodes distinguish it from its close rela-

Left [scale: ⅓ size]: Young koa trees have true leaves (on left). At about 6–9 months of age, trees begin producing flattened, elongated leaf stems called phyllodes (on right) instead of true leaves. Right: Flowering branch tip. PHOTOS: C. ELEVITCH

Root suckering (on left) occurs frequently when a tree is severely stressed (on right) or when surface roots are damaged. PHOTO: C. ELEVITCH

tive koaiʻa (*Acacia koaia*). The rare koaiʻa is a shorter tree with a bushy, often gnarled habit, primarily of drier areas of Kauaʻi, Molokaʻi, Lānaʻi, Maui, and Hawaiʻi (see koaiʻa section below).

GENETICS

Variability of species

Koa is a highly variable species in tree form, wood quality, and environmental tolerances. Populations on the island of Hawaiʻi tend to be larger trees with broad (2.5 cm [1 in]) phyllodes and long, straight boles, whereas populations on other islands tend to be shorter trees with narrower and more curved phyllodes. Wood colors vary from blonde to red to deep brown, sometimes showing curl or fiddleback. Growth rates, leaf shape, and bole form have been shown to be highly heritable (Sun 1996). Different populations also vary in water use efficiency, environmental tolerances, and resistance to disease (Daehler et al. 1999, Ares et al. 2000, Shi 2003). Although there are no completed studies on wood quality, anecdotal evidence suggests that populations in some areas tend to have better quality wood than populations in other areas and that wood quality, especially curl, is inherited.

Known varieties

Distinct varieties of koa occur on Hawaiʻi island (*A. koa* var. *latifolia*) and on Kauaʻi (*A. koa* var. *kauaiensis*) (Wagner et al. 1999). *Acacia koa* var. *koa* occurs on all the main islands. Koa trees with characteristics in between *Acacia koa* and *A. koaia* (koaiʻa) occur on Kauaʻi (Wagner et al. 1999). Isozyme studies have shown differences between Hawaiʻi island populations of koa and the populations of the other Hawaiian islands (Conkle 1996).

ASSOCIATED PLANT SPECIES

Koa is the second most important and widespread tree in Hawaiian forests after ʻōhiʻa lehua (*Metrosideros polymorpha*). While koa may occasionally occur in pure stands, usually the species is found in mixed forests where ʻōhiʻa lehua predominates. On mesic sites, the koa canopy may also be shared with aʻe (*Sapindus saponaria*) and naio (*Myoporum sandwicense*). A wide variety of native understory trees are found in koa forests, including naio, ʻōlapa (*Cheirodendron trigynum*), kāwaʻu (*Ilex anomala*), kōlea (*Myrsine lessertiana*), kōpiko (*Psychotria* spp.), ʻiliahi (*Santalum* spp., sandalwood), olopua (*Nestegis sandwicensis*), and pilo (*Coprosma* spp.). In wetter sites, tree ferns (*Cibotium* spp.) may be prominent in the understory, while other species of ferns such as palapalai (*Microlepia strigosa*) and *Dryopteris wallichiana* cover the ground. The native Hawaiian raspberry or ʻākala (*Rubus hawaiensis*) and the shrub māmaki (*Pipturus albidus*) are also common in the understory of koa forests. At higher elevations the forest gradually becomes dominated by māmane (*Sophora chrysophylla*) (Mueller-Dombois and Fosberg 1998). Today, many koa forests consist of scattered old trees in rangelands dominated by kikuyu grass (*Pennisetum clandestinum*).

ʻŌhiʻa lehua, the most common native Hawaiian tree, is almost always found growing with koa. PHOTO: C. ELEVITCH

Koa forests are invaded by many non-native or alien species. On the wet sides of the islands at lower elevations, strawberry guava (*Psidium cattleianum*) is the worst invader. Christmas berry (*Schinus terebinthifolius*) invades dry-side forests. Various species of raspberries (*Rubus* spp.) pose problems in montane forests. The climbing vine banana poka (*Passiflora tarminiana*, syn. *P. mollissima*) posed a severe threat to the koa forests until a few years ago when a successful biocontrol was established (Trujillo et al. 2001). In many koa forests, a dense carpet of the alien meadow ricegrass (*Ehrharta stipoides*) prevents regeneration of native species.

ENVIRONMENTAL PREFERENCES AND TOLERANCES

Environmental tolerances of koa vary by population. Such variation is one reason that seedlings used in reforestation should come from seeds collected from sites near or similar to the planting site. An inherent advantage of relying on natural regeneration is that the genetic stock will already be adapted to the planting site.

Climate

Elevation range

100–2300 m (330–7500 ft). Recommended for planting only above 610 m (2000 ft).

Mean annual rainfall

850–5000 mm (34–200 in)

Rainfall pattern

Koa tolerates a wide range of rainfall patterns including summer, winter, and uniform.

Dry season duration (consecutive months with <40 mm [1.6 in] rainfall)

0–5 months

Mean annual temperature

9–21°C (48–70°F)

Mean maximum temperature of hottest month

14–26°C (57–79°F)

Mean minimum temperature of coldest month

2–16°C (36–61°F)

Minimum temperature tolerated

–4°C (25°F). Koa seedlings may be killed by frost (Scowcroft and Jeffrey 1999).

Soils

Soil texture

Koa prefers loams, sandy clay loams, clays, clay loams, and sandy clays. Koa forests naturally occur on both light, ash-derived soils and on highly weathered clays on the older islands. Organic soils on lava rock (Tropofolists) are common in many koa regions.

Soil drainage

Koa must have freely draining soils.

Soil acidity

Acid to neutral soils are acceptable, pH 4.0–7.4.

Special soil tolerances

Koa can grow well in infertile soils. However, it does not tolerate shallow or saline soils.

Tolerances

Drought

Koa can tolerate drought for 3–5 months, depending on

After an overnight frost, young seedlings may be killed by overly rapid thawing caused by direct sunlight. Here sun screens are placed to shield seedlings from early morning sunlight, giving seedlings time to slowly warm up. Hakalau National Wildlife Refuge, Hawai'i. PHOTO: C. ELEVITCH

Pink nodules on the root system of a koa seedling, indicating active nitrogen fixation. PHOTO: J. B. FRIDAY

soil, competition from weeds, relative humidity, winds, and other factors.

Full sun

Koa is a pioneer species that thrives in full sun.

Shade

Intolerant of shade, the tree grows well only in the sun.

Fire

Koa can re-sprout from the base or roots after fire, but the above-ground parts are not resistant to fire.

Frost

Modest frosts are tolerated by mature trees but can kill young seedlings.

Wind

Although koa can survive steady winds, it will have poor form and slow growth and is therefore not considered highly wind tolerant.

Abilities

Fix nitrogen

Koa is a nitrogen-fixing legume and when successfully inoculated with the appropriate rhizobia bacteria at an early age can grow rapidly without nitrogen fertilizers.

Regenerate rapidly

It establishes quickly in open, favorable environments.

Self-prune

Grown close together, koa readily sheds its lower branches. Pruning is not recommended.

GROWTH AND DEVELOPMENT

Growth rate

Koa is a fast-growing tree. In favorable environments, koa can grow faster than 1.5 m/yr (5 ft/yr) in height for the first 5 years or so. Growth slows thereafter. Stem diameter growth rates depend on stand density (how many trees per hectare or acre). Open-grown trees in fields or pastures may increase up to 3 cm (1.2 in) in stem diameter per year for 10 years on sites with deep soil and adequate rainfall, and well managed plantation trees average 1.7–2.4 cm/yr (0.7–0.9 in/yr) on good sites with enough water and deep soil. Outstanding plantation trees have reached diameters of over 40 cm (16 in) and heights of 15 m (50 ft) in 12 years (Shi 2003). Dominant forest trees may grow 1.7 cm (0.7 in) in diameter per year for up to 25 years, and average trees in a healthy stand on a good site may grow from 0.7 to 1 cm (0.3-0.4 in) in diameter per year. In poor environments with shallow soils, low rainfall, or high elevations above 1525 m (5000 ft), average diameter growth is more typically 0.3–0.5 cm/yr (0.1–0.2 in/yr). In dense, unthinned stands or in stands that thin themselves naturally but only slowly, diameter growth all but ceases.

Flowering and fruiting

Flowering occurs year-round in many areas and is strongly seasonal in other areas. Flowering occurs most heavily from January to March, with seed ripening in August, September, and October, and may start in trees as young as 3 years old.

Reaction to competition

Young seedlings are intolerant of grass competition. Dense grass may also limit natural regeneration. Competition among koa trees in a dense stand is a limiting factor for older saplings (Grace 1995). In very dense stands, most individual trees are hardly growing at all, although a few may be able to emerge from the canopy and overtop their peers.

Diseases, pests, and predators

The major pests affecting koa are fungi (*Fusarium* spp., especially *F. oxysporum* and *F. solani,* and *Calonectria* spp.) and twig borers (*Xylosandrus compactus* and *Xyloborus* spp.). Twig borers damage branches and may kill young seedlings. Livestock readily consume small seedlings and can also quickly cause catastrophic damage to young trees by eating the leaves, stripping the bark, and trampling the extensive surface root systems. Seed predators include seed weevils (*Araecerus levipennis* and *Stator* spp.) and the koa seedworm (*Cryptophlebia illepida*) (Stein 1983). The koa




Top left and right: Damage caused by twig borer. PHOTOS: C. ELEVITCH **Bottom left: Rust on phyllodes.** PHOTO: S. NELSON **Bottom right: Mistletoe (*Korthalsella* spp.).** PHOTO: J. B. FRIDAY

moth (*Scotorythra paludicola*) may cause defoliation and in some cases may kill trees outright (Stein and Scowcroft 1985). Rusts (*Endoraecium* spp. and *Atelocauda* spp.) are common on phyllodes but are usually not serious problems. Koa is sometimes infected with *Armillaria* root rot fungi or mistletoes (*Korthalsella* spp.); older trees are attacked by a number of wood-rotting fungi (Gardner 1996). Banana poka (*Passiflora tarminiana*), a vigorous climbing vine, has overgrown and suppressed stands of koa, particularly on the islands of Hawai'i and Kaua'i, but the recent introduction of biological control agents seems to have lessened the impact of the weed (Trujillo et al. 2001).

PROPAGATION

The only propagation method currently in wide use is from seed. Success of vegetative propagation methods such as air-layers, rooted cuttings, and tissue culture has been limited (Skolmen 1986a, Skolmen and Mapes 1978, Shi 2003). Growing koa seedlings is very similar to many other nitrogen-fixing tree species, requiring pregermination treatment to break through the hard, impermeable seed coat, inoculation with an appropriate rhizobia bacteria, and special nutrient requirements. Koa is susceptible to root-knot nematodes, especially when grown in grassy areas at low elevations.

Propagation by seed

Seed collection

Koa trees are highly variable in size, form, and site performance. Hawai'i's many microclimates mean that local populations are often best adapted to the particular site conditions. For this reason, a quality seed source should be found from a similar environment as close to the planting site as possible. When no natural stands of koa are found nearby, seeds should be collected from areas with similar environments (rainfall, drought period length, pest populations, soil conditions, etc.). Seeds should be collected from straight, healthy, fast-growing individuals, as both form and vigor are strongly inherited (Sun 1996, Sun et al. 1996, Shi 2003). If seedlings are purchased, the buyer should make sure the nursery grower took care in seed collection. It is simplest to collect seeds from short, branchy trees, but doing this ensures that the seedlings will also be short and branchy rather than tall and straight.

For areas without natural koa populations, growers should select seed from known superior populations or provenances, being careful not to introduce diseases (see box on koa wilt.) Koa seed collected from superior trees has been shown to grow up to three times as fast as koa seed collected from slow-growing trees (Sun et al. 1996). Research is still underway to select koa strains that are both fast-growing and disease resistant.

Koa seed pods contain 6–12 seeds. Pods are ready to pick when their color has turned from green to brown or black, and when the seeds inside are dark brown and filled out rather than green, flat, or small. Seeds can also be collected from the ground, although it would be prudent to surface sterilize (e.g., with a weak bleach solution) such seeds if collected in areas prone to koa wilt. Koa can bear seed any time of year, although for some populations seed availability is highly seasonal. The heaviest period for seed maturation is usually August–September.

Seed processing

Pods are dried in the sun until they can be opened easily. Seeds are extracted by hand or by machine threshing. Once extracted from the pods, seeds may be dried more if necessary (ideal moisture content for storage is 6–8%). Koa seed size is highly variable, a kilogram of seed containing 5500–16,500 seeds (2500–7500 seeds/lb). Dried seeds should be stored in an airtight container away from direct sunlight. Properly dried seeds can store at least 12–24 months at room temperature, many years longer in cooler conditions. Germination is usually 70% or higher, but can be lower depending on weather conditions during ripening.

Pre-planting seed treatments

Koa seeds have a hard seed coat that is normally impenetrable to water. To hasten germination, the hard outer layer of the seed needs to be broken ("scarified") to allow water to contact the germ so the seed can sprout.

Two common methods are used to scarify koa seeds:

1. Mechanical scarification involves nicking the seedcoat on an edge away from the point of attachment to the pod. Nail clippers work best, although a knife, file, or even sandpaper may also be used for this purpose. The nick should be shallow, just deep enough to allow water to penetrate. Manual scarification is labor intensive, but very reliable once the technique is learned.
2. Hot water treatment can be used for large seed lots. Near-boiling water (90°C, 195°F) is poured over the seeds in a volume ratio of at least five parts water to one part seed. Seeds are then soaked in the hot water


Left: Breaking seed coat dormancy through scarification is important to ensure fast and uniform germination; the nicking method is shown here. Right: Seedlings that were not inoculated with rhizobia (on left) were pale and less vigorous than their same-age, inoculated counterparts (on right). PHOTOS: C. ELEVITCH

COMMON PLANTING PITFALLS AND REMEDIES

- Overwatering and overfertilization cause stress which often exhibits itself as yellowing of the leaves. Decreasing irrigation and eliminating nitrogen fertilizer can reverse the problem.
- Weed whacking the bark at the base of the tree can ruin the tree in a fraction of a second. It's best to control weeds only by hand cutting and mulching near the tree.
- Piling mulch against the trunk can cause rotting. Leave a few inches breathing room.
- Planting a seedling too deep will cause the part of the stem that is underground to rot, and the tree will effectively be girdled. Seedlings should be planted with the top of the planting medium even with the soil surface.
- Without adequate soil contact, newly planted seedlings can be severely set back or die of water stress within a few days of planting. When planting seedlings, especially those grown in forestry tubes, the soil should be firmed right up against the seedling's root system.
- Failure to inoculate seedlings with rhizobia bacteria in the nursery will result in trees that are not vigorous. Trees should be inoculated in the nursery within 4 weeks of germination.
- Root-bound seedlings that have become stunted in their containers will never return to being vigorous, healthy trees. Seedlings should always be planted when they are ready, and seedlings that are root-bound discarded.
- Growing in lawns stresses young koa and koai'a trees. Grass competes with the trees for water and nutrients, and trees are likely to be injured when cutting the lawn. Grass should be kept away from trees, ideally at a radius equal to the height of the tree or more, although many kinds of herbaceous plants can be grown underneath koa.
- Windy or shady conditions are not conducive to rapid growth. Trees should be protected from wind and given full sun most of the day.
- Grazing animals such as cattle, goats, sheep, and pigs can ruin a field of young seedlings in a matter of minutes or hours. These animals should be kept away from koa seedlings for the first few years, and preferably for the life of the trees. Horses have been grazed successfully under koa in some instances but have destroyed plantations in other situations. Pigs do not usually browse seedlings but will uproot new plantings and rub against seedlings, damaging the bark.
- When planting dense stands of koa, failure to thin out trees on time will cause growth to stagnate. Stands should be thinned at the first sign of loss of vigor.

for 1–3 minutes, followed immediately by a cooling in tepid water. The hot water weakens the seed coat, allowing water to penetrate.

Whichever of these methods is used, it is best to start with a small trial to make sure the seeds germinate and are not harmed. To start the germination process and to test if scarification was successful, scarified seeds should be soaked in cool water overnight to allow water to be absorbed into the seed before planting. Scarified seeds swell with water, while seeds that remain unscarified will not take on water. Healthy, successfully scarified seeds germinate in 2–7 days.

Growing area

Koa is relatively easy to grow in the nursery. In most environments of Hawai'i, koa seedlings can be grown outdoors in an uncovered growing area and no special greenhouse area is needed. If available, some cover (greenhouse or temporary cover) is ideal for the first 2 weeks after germination to protect sprouts from hard rains and seed-eating birds. Rodents also eat koa seeds and should be excluded from the nursery area. Root-training forestry containers are best for koa. Tubes or open-ended suspended pots available from forestry suppliers are usually used. These containers have ribbing on the inside walls to train the roots to grow straight down without spiraling or wrapping around each other. Containers can be filled with any kind of commercial well drained potting media. Potting media should also be inoculated with mycorrhizal fungi, available from commercial suppliers and garden centers.

Seedling establishment phase

Seeds are planted into forestry containers that have been pre-filled with media. Shallowly cover the seed with potting media, followed by a thin mulch layer, such as finely sifted black cinder or #2 poultry grit (available from feed stores and farm supply centers). Seeds should be buried about as deep as they are wide, and no deeper. Water with a fine-headed sprayer to keep the medium moist. Full sun is best. Daily watering is usually necessary, by hand or with an automated system.

Scarified seeds will germinate in 2–7 days. After 1–2 weeks of growth, seedlings should be inoculated with rhizobia

Damage with a power weed cutter happens in an instant and seedlings usually never recover. PHOTO: C. ELEVITCH

bacteria selected for this species (available from commercial suppliers or from nodules collected from the roots of healthy forest trees). Strains of rhizobia selected by researchers are best for optimum nodulation and nitrogen fixation.

Active growth phase

As the seedlings develop, they should be watered as needed and never allowed to dry out. Watering in the morning is typical for nurseries that grow koa. Hot, dry days may necessitate a second watering in the early afternoon. Late afternoon and evening watering is not recommended, as it can lead to disease problems such as sooty mold. After about 6 weeks, seedlings should be double-spaced in their trays to ensure that each seedling receives full sunlight and to facilitate strong stem development. Depending on seed lot, about 10% of the seedlings will be stunted or poorly formed, and these should be culled. The remaining seedlings should be monitored for pests, but predators are generally not problematic once the seedlings are taller than 8 cm (3 in). If any weeds enter the soil-free media, they should be removed. No fertilizer application is necessary if seedlings were inoculated with rhizobia bacteria and mycorrhizal fungi. No pruning should be done. After 10–16 weeks, seedlings may be hardened for a few weeks by gradually reducing watering frequency to introduce seedlings to temporary, moderate water stress. The target size ranges from 15–30 cm (6–12 in), depending on the container size. When seedlings have reached target size, they may be delivered to the planting site.

Plantation establishment

Site preparation is a crucial part of koa establishment. The area must be fenced to exclude any grazing animals (domesticated or feral), and competitive vegetation should be removed from around the planting holes. As discussed above, genetic quality is a crucial aspect of koa growth and the seed source must be carefully considered and matched for the outplanting site. Koa planted at low elevations often succumbs to introduced pests or diseases such as black twig borer or fungi such as *Fusarium* spp. For areas with a pronounced dry season, outplanting is typically scheduled at the onset of the rainy season. For areas that receive sufficient rainfall throughout the year, the spring (March or April) is an optimal time for outplanting.

At planting time, seedlings should be carefully removed from their containers and planted at the correct depth, with the ground even with the root collar. Soil should be firmed around the tree. Watering for the first few weeks after planting may be necessary if rainfall is insufficient. If possible, a weed barrier/mulch around the tree (kept several inches from the trunk) can aid in koa establishment. Koa is a hardy pioneer species, and survival is usually over 90% after outplanting on well prepared sites.

Spacing

Spacing for koa timber production is a much-debated topic, and no firm guidelines have been established. Mature, pure stands in plantations might support 100 trees/ha (40 trees/acre, equivalent to 10 x 10 m [33 x 33 ft] spacing). Plantations should be initially planted at a much denser spacing of 2 x 3 or 3 x 3 m (6.6 x 10 or 10 x 10 ft) to promote upright form and self-pruning of lower branches. Drawbacks to denser plantations are that they require earlier thinnings to maintain rapid tree growth and require a greater initial investment in seedlings. Mixed plantings of koa and slower-growing native trees such as ʻōhiʻa lehua and naio may promote self-pruning in the koa while avoiding the need for early thinnings.

Management objectives

Koa may be managed simultaneously for timber and wildlife habitat, watershed protection, and native forest restoration. Understory plantings with economically valuable

KOA WILT

Koa wilt is a common, fatal disease of koa and koaiʻa that is of major concern to growers. Leaves in the upper crown on affected trees rapidly wilt, turn yellow, and die while still on the tree. Occasionally only one branch will be affected, while at other times the entire tree will show symptoms. Sapwood of infected branches and roots usually shows a characteristic dark staining, and the roots may be killed. The tree's bark may develop cankers as the disease progresses. Defoliation of the crown progresses downward until the entire tree is killed, and small trees may succumb to the disease in as little as a few weeks. Koa wilt has been associated with infection of the vascular fungus *Fusarium oxysporum* f. sp. *koae* (Gardner 1980), although other species of *Fusarium* may also play a role. Infection by the fungus spreads upward from the roots and blocks conducting vessels in the branches and trunks of the trees, leading to canopy loss and death.

Planted stands at elevations below 760 m (2500 ft) are the most frequently affected, although koa wilt has been observed as high as 1650 m (5400 ft) (Anderson et al. 2002). Trees less than 15 years old are most often affected. Symptoms of the disease often become more severe after a period of environmental stress, such as drought. In some planted low elevation stands, 90% of the trees have died. The disease is found on Hawaiʻi, Maui, Oʻahu, and Kauaʻi.

The koa wilt fungus is probably a recent introduction to Hawaiʻi in the past few decades, and the future effects of the disease are difficult to predict. Field control of the disease with fungicides would probably be impractical. Some families of koa have shown less susceptibility to the disease than others, and research is underway to select resistant varieties for planting in disease-prone areas (J. Brewbaker, pers. comm.). Current recommendations for the grower are to avoid planting seed or seedlings from infected areas, as the fungus is seed-borne and soil-borne. Use of seed from select trees from nearby, natural stands of koa is probably the best way to avoid the disease. Seedlings should be raised in soilless media, and soil from infected areas should not be brought to the planting site. Shoes, tires, and tools should be well cleaned after leaving an infected area to remove any infected soil. Tools such as saws and machetes used in infected stands should be sterilized before being used elsewhere. Growers who plant koa in highly disease-prone areas (lands below 760 m [2500 ft] in elevation) should be prepared for high losses. In areas with no local koa populations, planting trees from several different seed sources may increase the likelihood of finding resistant trees. The presence of the pathogen will not necessarily cause disease. However, if conditions for infection are right and the pathogen is present, disease may occur.

Left: Crown of a tree infected with koa wilt, showing leaf yellowing and loss. PHOTO: S. NELSON **Right: Koa wilt attacking an experimental plantation and cut stem of an infected tree showing staining of the sapwood and cankers on the bark.** PHOTOS: J. B. FRIDAY

Left: Muriel and Kent Lighter show trees that were planted in circles of six to eight seedlings. After 5 years there are about 400 trees/acre, and the best trees will be released by thinning out the poorer trees. PHOTO: C. ELEVITCH **Right: Koa trees self-prune when grown in dense stands.** PHOTO: J. B. FRIDAY

native plants such as palapalai (*Microlepia strigosa*, an ornamental fern used in the hula), maile (*Alyxia oliviformis*, a scented vine), māmaki (*Pipturus albidus*, a native nettle used to make a medicinal tea), and pepeiao (*Auricularia*, an edible fungus) show promise. Koa plantations allow light to penetrate the canopy and usually support a grass understory, which may be grazed occasionally by livestock if care is taken to avoid damage to the trees (see section on silvopasture, below).

Plantation design considerations

Pests and diseases generally limit commercial koa plantings to higher elevations (above 600 m, 2000 ft) and mesic to wet sites. The tree does not do well in extremely wet sites (>5000 mm [200 in] precipitation) or on shallow or poorly drained soils. In Hawai'i, koa performs better on deep ash-derived soils than on lava soils, and better on 'a'ā (rough) lava soils than soils over pāhoehoe (sheet) lava. On mesic sites koa productivity is tied to water availability. Koa is an extremely variable species and it is crucial to obtain seed from superior trees for planting stock. Since populations are adapted to local environments, it is best to use locally obtained seed when available. Young koa plantations need to be protected from weeds, livestock, fire, and wind. As koa is a nitrogen-fixer, young koa stands do not respond to nitrogen fertilization but have in some cases responded to fertilization with phosphorus. Older koa stands may benefit from complete fertilizers.

Natural regeneration

Koa is both a rapidly growing, light-demanding pioneer tree that quickly colonizes open sites, and a long-lived tree that is part of mature forests. Koa naturally regenerates from buried "seed banks," seeds that have been buried in the soil for years or even decades. These germinate when the soil is exposed to sunlight and warmth, by natural means such as fire or windthrow of large trees, or artificial means such as scarifying or scraping the surface soil with a bulldozer (Scowcroft and Nelson 1976, Scowcroft and Wood 1976). Seed banks thus exposed will germinate rapidly but may only produce a single crop of seedlings if the scarification exhausts that seed bank. If seedlings regenerated from a seed bank are destroyed, there are often no more viable seeds left in the soil. In some cases, however, seedlings regenerated after a fire have been destroyed, but subsequent bulldozer scarification has resulted in additional regeneration. Seed banks may not exist in very old pastures or may be viable only under the canopy of scattered overstory koa trees. Koa also regenerates from root sprouts, especially where shallow roots have been damaged by livestock.

Travis Idol observes koa root sprouts springing up after removal of cattle, Mauna Loa. PHOTO: J. B. FRIDAY

Natural forest management

Naturally regenerated stands of pure koa may have as many as 20,000 seedlings/ha (8100 seedlings/ac). These grow quickly, and the young seedlings may close canopy and form a solid stand in less than 10 years. Growth of individual trees slows thereafter, as the trees compete for growing space. Such "dog-hair" thickets of koa should be thinned and the best trees selected and released from competition. Young, vigorous trees with full crowns respond best to such release, but even trees as old as 25 years with some crown loss have grown faster after thinning (P. Scowcroft, P. Baker, pers. comm.) In order to avoid generating overly dense stands, some landowners have tried partial scarification in old pastures, only scraping the soil in lines or in patches across the landscape. "Row thinning," or mechanically clearing lines in dense stands, might also help to release the remaining trees.

Pure stands of koa that have developed on lava soils in wet sites at low elevations have sometimes briefly flourished but then ceased growing altogether and died out after 20 to 25 years.

Mature native forests contain diverse tree species and may have only a few koa trees per hectare. Koa will not regenerate in forest shade or even under its own sparse canopy, nor is it able to grow up through the canopy of other trees. Once a koa tree is overtopped by another tree, its growth ceases. In natural forests with only a few very large koa per hectare, koa probably depends on large tree-fall gaps to regenerate. Stands of young koa can be seen growing up adjacent to large ancient stumps left over from logging or huge stems that were toppled by storms. Silvicultural systems for koa forest regeneration can rely on natural regeneration through the seed bank, but enough light must reach the forest floor for young koa trees to grow. Harvesting systems in dense mixed-species forests where single trees are selected and cut are likely to result in "high-grading" or the removal of the koa from the forest rather than the regeneration of a healthy koa forest. "Group selection" systems where small patches of forest are cut so that enough light reaches the forest floor for koa to grow might be a way to regenerate koa forests without causing large-scale disturbances, but guidelines for using such systems in koa forests have not yet been developed. It is not known how large a gap must be created in order to regenerate healthy koa. Koa is also susceptible to wounding, and loggers need to work carefully to avoid injuring future crop trees. Larger clearcuts will regenerate dense stands of koa, but single-species, single-age stands that might be susceptible to insects and disease need to be thinned, as described above, if timber production is desired.

Alien invasive plant species can take over koa forests and prevent the regeneration of koa. Tropical ash (*Fraxinus uhdei*) in particular thrives in the same environment as koa and outcompetes the native trees for sunlight (Ares and Fownes 2001). Banana poka (*Passiflora tarminiana*) vines can smother young koa trees, but the weed is less of a threat since the introduction of a leaf spot fungus (Trujillo et al. 2001). At elevations below 1000 m (3300 ft), strawberry guava (*Psidium cattleianum*) completely occupies the understory of many forests and prevents regeneration. Strawberry guava also rapidly colonizes any gaps created by logging. Any sustainable harvesting plan for koa forests must include a plan to deal with the invasive species that will compete with koa. Loose cattle and sheep browse young koa seedlings, and most koa logging in Hawai'i has historically not resulted in healthy regeneration because herbivores have continually eaten the seedlings as they appear.

Yields

Koa does not yield large volumes of timber per unit area, but low volumes may be made up for by the high value of the wood. Rotation ages for koa have been estimated at 30 to 50 years (and up to 80 years for veneer quality timber), although no one has managed koa stands from regeneration through to harvest, so these estimates of rotation age may be overly optimistic. It is not known how tree age or growth rate affects wood quality. Stem diameter increment may be up 0.7–1 cm (0.3–0.4 in) at first, although the diameter increment of individual stems slows drastically once the crowns close and individual trees compete with one another. In overly dense stands, diameter growth all but ceases. Dominant trees, those whose canopies are above their neighbors, may grow more than 1.7 cm (0.7 in) in diameter per year. Silvicultural treatments, including thinning, fertilizing, and controlling competing vegetation, should allow managers to maintain tree growth at high levels for a longer period. Pure stands on deep ash-derived or ʻaʻā soils with adequate rainfall might yield 90–180 m^3/ha (6.5–13 mbf/acre), while stands developed on shallow pāhoehoe soils and in areas with little rainfall would yield substantially less. Most koa, however, has been and continues to be harvested from mixed-species native forest or from large scattered trees in pastures, both of which yield much less timber per unit area than pure stands.

DISADVANTAGES

Potential for invasiveness

Koa is not generally planted outside its native range. However, as a fast-growing nitrogen-fixing tree, the potential for invasiveness outside Hawaiʻi may be high. There are a number of traits that mitigate against its invasive potential. It would probably not invade intact forests elsewhere in the tropics because it: 1) is very shade intolerant, 2) has no known dispersal agent except wind, 3) is not itself tolerant of fire, 4) is fed on by many vertebrate and invertebrate herbivores, and 5) is susceptible to diseases common to the tropics (Scowcroft, pers. comm.). It would not survive in temperate regions due to freezing temperatures or low rainfall.

Susceptibility to pests/pathogens

Many diseases and pests affect koa, particularly at elevations below 610 m (2000 ft). In lowland areas where koa has been planted, there has been up to 80–100% mortality due to various pests and pathogens, particularly fungi. Animals such as horses, cattle, goats, and pigs are also a very common source of high seedling losses and damage to trees less than 10 years old.

Host to crop pests/pathogens

Koa hosts black twig borer (*Xylosandrus compactus*), a pest that also affects coffee, citrus, cacao, mango, macadamia, and other crop and timber trees such as mahogany and eucalyptus species.

Other disadvantages or design considerations

Koa's aggressive surface root system can compete with crops and disrupt underground utility lines. Shallow root systems are also easily damaged by machinery or foot traffic. Koa trees must be given a wide berth, a minimum of 10–12 m (33–39 ft) for mature trees.

AGROFORESTRY/ENVIRONMENTAL PRACTICES

Soil stabilization

Koa establishes quickly on degraded sites and its extensive root systems aid in soil stabilization.

Crop shade/overstory

Koa casts a light shade that is compatible with many herbaceous understory plants. However, due to koa's extensive surface root system, this tree is preferably planted on borders of other plantings, where competition and root damage to the koa trees are minimized.

Improved fallow

As a nitrogen-fixing tree, koa is a good candidate for improving fallow land.

Windbreaks

Koa tolerates wind poorly but can be planted as part of a multi-row windbreak. Because it has a very sparse crown and is easily deformed by wind, it is recommended that very wind-tolerant species be planted in rows on either side of a row of koa.

Silvopasture

Koa leaves are highly palatable to livestock, and browsing can injure and kill trees. Weaning calves or horses may be temporarily grazed under koa if there is a good grass crop; however, the animals must be closely supervised to ensure they do not damage the koa trees. Mature cows will push down small koa trees to consume their leaves. If livestock are left too long in pastures with koa or left in during dry periods, they may strip the bark from the trees to get at its moisture. Livestock also easily damage roots of koa, especially in shallow soils. Horses have proven less damaging to koa, although some horses relish the taste of koa leaves and bark. Grazing under koa may help lessen the competition from the grass for water and nutrients and may lessen the fuel buildup and the chance of fire.

Animal fodder

Prunings have been used as cut-and-carry fodder for horses, although this might not be advisable because horses develop a taste for the leaves, twigs, and bark. Horses with a taste for koa will quickly eradicate any seedlings or saplings in areas to which they have access.

Native animal/bird food

Koa is considered to be an important habitat for insects that are food for native birds. Native (and exotic) insects feed on koa flower nectar, flower parts, foliage, cambial tissue, seeds, and probably other tissues as well.

Wildlife habitat

Many native Hawaiian birds depend on koa forests directly or indirectly for habitat. Large old trees provide important nest sites. Commonly seen birds include the red ʻapapane (*Himatione sanguinea*) and ʻiʻiwi (*Vestiaria coccinea*), the yellow ʻamakihi (*Loxops virens*), and the inquisitive ʻelepaio

Koa casts a light shade (23-year-old koa trees at Keauhou Ranch, Kaʻū, Hawaiʻi). PHOTO: J. B. FRIDAY

Dying and dead koa trees in pasture. PHOTO: C. ELEVITCH

(*Chasiempis sandwichensis*). The endangered ʻakiapōlāʻau (*Hemignathus munroi*), a species of honeycreeper, eats insects found in the bark and rotting wood of koa trees and is found in both young and old koa stands. Koa forests are also the home of the endangered Hawaiʻi ʻākepa (*Loxops coccinea*) and the Hawaiʻi creeper (*Oreomystis mana*). In 1985, the Hakalau Forest National Wildlife Refuge was established on the slopes of Mauna Kea on the island of Hawaiʻi primarily to protect habitat for native forest birds. The refuge has been reforesting former cattle pasture since then and has planted hundreds of thousands of koa seedlings.

Bee forage

Koa flowers provide pollen and nectar for bees.

Ornamental

Koa makes a spectacular ornamental, although there are pest and disease concerns below 610 m (2000 ft).

ʻAkiapolaʻau on koa branch. PHOTO: J. JEFFREY

Modern day koa racing canoe (outrigger detached on right) named Lanakila Mau O Ka Lōkahi. PHOTO: J. B. FRIDAY

USES AND PRODUCTS

Medicinal

The leaves and ashes have been used medicinally by Hawaiians (Krauss 1993).

Timber

Koa is an extremely important timber tree in Hawaiʻi. For more information, see the "Wood quality" sidebar.

Fuelwood

Formerly, before its timber value was recognized and supplies became scarce, koa was used as firewood.

Craft wood/tools

Ancient Hawaiians used koa for calabashes (ʻumeke lāʻau), canoe paddles, spears, and surfboards (Krauss 1993, Abbott 1992). Koa was not the preferred wood for calabashes to be used for food because it imparted a bitter taste. Today, koa wood is the basis of a flourishing crafts industry in Hawaiʻi.

Canoe/boat/raft

Koa was traditionally used for canoes (waʻa), from one-person fishing canoes to the huge voyaging canoes that could sail between islands and across vast expanses of ocean. In ancient times, the cutting of a forest giant with stone tools to make a canoe was an undertaking of several days for many men, involving many ceremonies and prayers. When a log was felled, it is said that the men watched for a sign from the ʻelepaio bird. If the bird landed on the log and pecked at it, the log would be abandoned. Today, large "canoe koa" have all but disappeared. A single koa log large enough for a traditional Hawaiian voyaging canoe should be 10–14 m (35–45 ft) long and 120 cm (48 in) in diameter along the entire length of the log. Shorter logs may be spliced together to make larger canoes. Smaller logs of 75–90 cm (2.5–3 ft) in diameter are used for racing or fishing canoes. Canoe carving is a living tradition in Hawaiʻi and koa canoes are still used in races, especially on the island of Hawai‘i.

Tannin/dye

Tannin from koa bark has been used to make a red dye for kapa cloth (traditional bark cloth) (Krauss 1993).

Ceremonial/religious importance

The name “koa” also means “warrior” in Hawaiian and the tree is very important in Hawaiian culture.

URBAN AND COMMUNITY FORESTRY

A treasured Hawaiian tree, koa can be grown in home and public landscapes with large open spaces. At lower elevations, or sites with limited space, koa’s close relative koai‘a is often a more suitable alternative.

Size in an urban environment

In a landscape koa generally grows to 6–15 m (20–50 ft) in height. When grown in the open, the canopy spread is often wide, about half the height of the tree. In other words, a large open area is required. For small areas, koai‘a is an excellent alternative, with its more compact form.

Rate of growth in a landscape

Koa growth can be very rapid, greater than 3 m (10 ft) in the first year and more than 1.5 m (5 ft) for the next few years, considering the following measures are taken.

- Only healthy, rapidly growing seedlings should be planted, not root-bound trees whose growth has been slowed by the container size.
- Seedlings should have been inoculated with rhizobia bacteria within 4 weeks of germination.
- Koa should be planted well away from grassy areas, including lawns.

Left: Damage to surface roots and trunk causes undue stress. Right: In the right conditions, and with proper care, koa trees can live many years in a landscape, Volcanoes National Park, Hawai‘i island. PHOTOS: C. ELEVITCH

- Grass and weeds should be suppressed within the seedling's root zone, preferably by hand-weeding and mulching.
- Foot and machine traffic near the tree should be avoided.
- Common maintenance pitfalls such as weed whacking the bark of the tree or spraying herbicide on the leaves or exposed surface roots should be strictly avoided.

Root system

The surface roots are often partially exposed, especially in rocky soils. Foot and machine traffic can easily damage the roots and cause the tree to suffer over the long term. It is best to plant the trees in marginal areas (slopes, buffer areas, etc.), where there is no traffic. When the roots are injured or the tree is cut down, some trees send up suckers from the root system within a wide ring around the tree. Although the surface roots are unlikely to lift concrete pathways or other human structures, koa's intrusive root system may be damaging to underground utilities.

Products commonly used in a Pacific island household

Wood is the primary product derived from koa trees. A mature healthy tree in a landscape can be quite valuable for its wood if allowed to grow for 30 years or longer.

Light requirements

Although small seedlings can tolerate light shade, best health and vigor is attained with full sunlight for the life of the tree.

Water/soil requirements

Koa requires freely draining soils. Standing water or waterlogging is detrimental to tree health. Overwatering should be avoided.

Expected life span in a homegarden

Since most people in Hawai'i live below the minimum recommended elevation of 610 m (2000 ft) for koa, homegarden plantings of koa are often subject to various pests and diseases that can greatly shorten their lives. It is common for koa trees to die at an age of 5–20 years, or even younger in areas where koa wilt is present. Risks can be minimized if measures are taken to support tree health (see "Rate of growth in the landscape" above).

Varieties favored for use in homegardens

It is best to plant trees grown from seeds that were collected from the nearest natural population. This gives reasonable assurance that the trees are adapted to the local climate and soils, while also conserving local native germplasm.

HAWAIIAN SAYINGS (PUKUI 1983)

E ola koa.
"Live like a koa tree."
(Live a long time, like a koa tree in the forest.)

Ka ulu koa i kai o Oneawa.
"The koa grove down at Oneawa."
(From the legend of Hi'iaka. Canoes are sometimes referred to as the koa grove at sea.)

Seasonality of leaf flush, flowering, fruiting

In many areas, koa flushes with new growth nearly year-round, slowing during dry or cool periods. Flowering takes places throughout the year in some areas and is strongly seasonal in others.

Transformation of bark from smooth to rough. PHOTO: C. ELEVITCH

Exceptional ornamental values

Silver-green foliage distinguishes koa in the landscape. Its light yellow "puff-ball" flowers (inflorescences) are borne in sprays that are modestly showy. The bark of young trees is smooth, and often covered with an attractive bright orange-red lichen (harmless to the tree). At an age of about 8–10 years, the bark becomes fissured, rough, light to dark brown, and often hosts silvery lichens (also harmless).

Use as living fence, hedge or visual/noise barrier

Koa is not suitable as a living fence, as this would require attaching fencing to the trunk, which injures the tree and greatly diminishes any future timber value (due to pieces of metal potentially left in the wood). Koa does not tolerate trimming well, which would be required for a hedge.

Birds/wildlife

Koa flowers provide pollen and nectar for various insects, including bees. In or near native forest, koa hosts numerous native Hawaiian insects and birds.

Maintenance requirements

Mulching with leafy materials such as grass clippings, hedge trimmings, chipped tree trimmings, etc. is highly recommended to suppress weeds, conserve soil moisture, and protect koa's surface roots. Because of its association with nitrogen-fixing bacteria, koa does not benefit from nitrogen fertilizer; however, applying phosphorous fertilizer can be beneficial. Pruning is not recommended, as limb cuts provide easy access to fungi and borers.

Special considerations regarding leaf, branch, and fruit drop

The tree can grow tall, so it should not be planted near overhead utility lines or structures.

Nuisance and hazards

None.

Common pest problems

Common pests include pathogenic fungi and twig borers. Avoiding overwatering and damage to roots, trunk, and branches may reduce the risk of attack by pathogenic fungi. Twig borers tend to attack seasonally, usually during dry periods, and healthy trees recover. Trees also can recover from light seasonal damage by whitefly, beetles, thrips, scale insects, Chinese rose beetle, and mites. Leafhoppers that cause defoliation and stippling of the leaves can be treated with soapy water.

Cabinet of curly koa by Marian Yasuda. PHOTO: H. LUM

Other comments about this species in urban environments

Because of koa's particular susceptibility to pests and diseases below 610 m (2000 ft) elevation, it may die prematurely. Even though most people in Hawai'i live below its recommended minimum elevation, koa's fast growth and beauty make it well worth growing in landscapes. The benefits of growing this highly valued Hawaiian tree far outweigh the risks, even if the tree only lives a few years in a particular location. Most people in Hawai'i never see koa trees, and even young koa trees planted in local communities and urban settings give people an opportunity to become familiar with one of the most important trees of the Hawaiian forest.

WOOD QUALITY

(by C. Barton Potter)

Koa wood variability

Koa is Hawai'i's premier timber tree. From area to area and tree to tree, koa wood varies mechanically in density, specific gravity, drying and machining qualities, and many other characteristics. Koa is not a particularly dense wood, with specific gravity averaging 0.55 for wood air-dried to 12% moisture content and a density of 609 kg/m^3 (38 lb/ft^3) (Skolmen 1974). Visually, the wood is strikingly variable across a spectrum of color and figure. A strong correlation exists between economic value and visual attractiveness.

A native Hawaiian timber

Koa wood is revered and valued as much for its strong association with its native Hawai'i as for its appearance. Koa's status as the largest and second most common native tree has ensured its use by people in a wide number of applications. However, many decades of land management favoring agriculture and livestock, exacerbated by the success of numerous competitive alien species, has displaced koa and hindered it from naturally regenerating in much of its native range. While logging has contributed to diminishing koa populations, the state of koa resources today is primarily due to the lack of regeneration. High-quality logs have become scarce on the market, which has elevated the value of the wood and put practical limits on wood applications. The best logs are being directed to high-yield, high-return applications such as veneers, high-end furniture, and musical instruments. Makers of products that consume large volumes of wood, such as solid koa furniture or canoes, are finding it increasingly challenging to locate affordable koa wood. A market thrives for craft items made from small-dimension wood such as branches, stumps, and cutoffs.

Chatoyance

Koa wood is generally known for its red to brown color and for its light-refractive characteristics, known as chatoyance. This attribute can lend a hologram-like effect to finished wood surfaces, adding to the visual allure of koa items.

Kiln drying

Because it shrinks nearly equally in radial and tangential directions, koa can be kiln dried more easily than many other types of wood. Boards with runout (end-grain on the face of the board), pith defect, rot, and other anomalies can warp, cup, or twist if drying is too rapid. Best results are always obtained when a single species is dried at a time, allowing the kiln schedule to be tailored specifically to the wood being dried. In other words, koa wood should be dried by itself in the kiln.

Milling, cutting, and sanding

When green, koa wood cuts readily with sharp saws or chisels. This is one reason sawmillers prefer to mill logs green and bowl turners prefer to turn the wood while it is still green—both boards and roughed-out bowls are easier to season properly than whole logs. When dry, koa wood is not unusually dulling to hand tools, but it does contain tannins that under the tip of all but the sharpest of high speed tools can cause blackening or burning of the surface being cut. The tannic exudate can build up just behind the tool tip, increasing friction and drag, resulting in charring that can be hard to sand out. The sharper the tool, the less this happens; therefore, sharpness is a must when cutting with high-speed tools. The same can be said for sanding: the sandpaper must be clean and the grit sharp or a charring effect may occur that is easier to avoid than to remove by sanding a second time. Koa planes easily, although there can be problems with tearout of curly grain. Sanding versus planing is the preferred method of reducing the thickness of a board that has curly grain.




Left to right: Blister figure, curl with color banding, dark light curl, plain with light flame. PHOTOS: C. B. POTTER

COMMERCIAL PRODUCTS

Processing required

Milling is required for production of koa wood products such as lumber, veneer, molding, or flooring. Because of the high value of koa wood, small-scale milling in the field with a portable mill is often feasible and economically viable, although it typically yields a smaller percentage of usable wood than large, fixed mills.

Markets

Markets exist in Hawai'i, the mainland United States, and the Far East. Koa veneer is produced in California from wood shipped from Hawai'i. Koa stumpage (the amount paid to a landowner for the right to harvest trees) in Hawai'i was approximately $700–840/m³ ($2500–3000/mbf) in the late 1990s and early 2000s, up from less than a tenth of that a decade previously. Finished koa lumber in Hawai'i retails at prices from $4.50 per board foot for yellow, straight-grained wood (#2 common) to $65.00 and up per board foot for finely figured, curly, dark red wood.

Furniture made from koa is the main product of Hawai'i's $30 million/year forest industry (Yanagida et al. 2004) Gradual, sustained harvest of koa helps maintain Hawai'i's local furniture and craft industry, while harvesting large quantities for export has led to rapid boom and bust cycles.

INTERPLANTING/FARM APPLICATIONS

For many reasons, koa is a difficult tree to integrate with other crops, livestock, or farm activities. However, in certain situations and with careful planning and management, it can form a component in a diverse farm system.

Despite massive planting efforts in the 1920s and 1930s, when over a million koa trees were planted in the forest reserves (Nelson 1965), there are few successful koa plantations today. None have been grown through to harvest, nor has much natural koa forest been managed for timber. Interest in koa forest management increased greatly with the skyrocketing of koa prices in the 1990s, and now many landowners are again experimenting with plantations and forest management plans.

Potential drawbacks of interplanting

Koa's aggressive surface root system is very competitive with crops. Trees become large, and must be afforded plenty of light and space. The area must be fenced to preclude losses from cattle, sheep, goats, and pigs. Due to pests and diseases, koa is generally only suitable for areas with higher elevation than where most crops are grown.

Example system 1

Location

Honokōhau, Kona, Hawai'i (1380–1830 m [4500–6000 ft]).

Description

Downed and sickly trees were harvested for their timber in a cattle pasture. After the harvest, the cattle were removed, and koa regenerated prolifically from the buried seed bank, particularly in areas where the machinery used for harvest operations disturbed the soil surface.

Yields/benefits

After koa seedlings began growing in thickly, weaning calves were introduced to thin the dense, regenerating stands during the first 2 years of establishment. The calves were carefully monitored by an experienced rancher so they did not run short of low-growing seedlings and begin consuming larger seedlings. After several years of growth, cattle and horses have been allowed into the area for brief periods to graze the undergrowth.

Spacing

The initial density of regrown koa seedlings was 1200–5000 trees/ha (500–2000 trees/acre), which will be reduced to a final density of less than 125 trees/ha (50 trees/acre).

Honokōhau koa with understory maintained for brief periods by cattle and horses. PHOTO: C. ELEVITCH

Left: Koa boundary for coffee orchard. Right: 23-year-old koa regeneration at Keauhou Ranch, Hawai'i. PHOTOS: C. ELEVITCH

Example system 2

Location

Hōlualoa, Kona, Hawai'i (640 m [2100 ft]).

Description

In a newly planted coffee plantation, koa was planted in marginal areas such as on rocky and steep slopes, and along boundaries where coffee cultivation was untenable.

Yields/benefits

The koa is a long-term timber in areas that have marginal value for crops requiring intensive cultivation.

Spacing

Single rows have a spacing of about 3 m (10 ft) between trees, with about 9 m (30 ft) spacing from coffee trees.

Example system 3

Location

Keauhou Ranch, Volcano, Hawai'i (1600 m [5250 ft]).

Description

Degraded forest with remnant large koa was logged, and residual vegetation was bulldozed to scarify the soil in 1978. Grazing animals were kept out, but no other management was done. Koa regeneration from the buried seed bank was prolific. After 23 years, a pure koa overstory of basal area 26 m^2/ha and 17 m (56 ft) height had developed, with the best trees reaching 20–30 cm (8–12 in) dbh. Nine other native tree species had established from seed spread from nearby native forest.

Spacing

Initial densities of 20,000 seedlings/ha (8100 seedlings/ac) were observed. Trees naturally thinned to 1000 stems per ha (400/acre) after 23 years. The target spacing of eventual crop trees is 10 x 10 m (33 x 33 ft), or 100 trees/ha (40 trees/acre).

Acacia koaia (koaiʻa)

Koaiʻa (*Acacia koaia*) is a close relative of koa that is native to the islands of Kauaʻi, Molokaʻi, Lānaʻi, Maui, and Hawaiʻi. Koaiʻa and koa are so closely related that there is controversy among taxonomists as to whether they are different species. For the purposes of this discussion they are treated as distinct species. Koaiʻa is much more compact in size than koa, often having a bushy, gnarled, or even horizontal growth habit. Koaiʻa grows well in harsher conditions than koa: dry, windy, and open. The tree's size and tolerance for harsher conditions make it more suitable for most urban environments than koa.

Characteristics

Koaiʻa is a small tree, rarely taller than 5 m (16 ft), with a domed canopy that is usually about as wide as the tree is tall when grown in the open. The phyllodes (mature "leaves") are generally narrower, shorter, and straighter than those of koa, although there is tremendous variation. The inflorescence is similar to koa, but the seedpods are narrower with seeds longitudinally arranged instead of transversely as in koa. Seeds are similar in appearance to koa seeds, although they are considerably smaller than seeds produced by most koa trees. The wood is harder, denser, and more finely grained than koa wood.

Propagation

Koaiʻa is propagated from seed, using methods identical to those used for koa.

URBAN AND COMMUNITY FORESTRY

Koaiʻa makes a wonderful addition to urban and public landscapes, and should be used instead of koa where a compact tree is needed, or in harsher, drier environments than are recommended for koa.

Size in an urban environment

In a landscape koaiʻa generally grows to 5 m (16 ft) tall. In the open, the canopy is often wide and domed, often with a diameter as wide or wider than the tree is tall. Some trees have a tendency to spread laterally, with a squat form and horizontal branches.

Rate of growth in a landscape

In an optimal environment koaiʻa can grow rapidly for the first few years. Growth in height of 1–1.5 m (3.3–5 ft) per year for the first 2 years is common. After this, growth in

Top: Remnant koaiʻa trees growing in open, dry area, North Kohala, Hawaiʻi. Middle: Koaiʻa leaves and flowers. Bottom: Koa seeds are arranged transversely in the seedpod (above), while koaiʻa seeds are arranged longitudinally (below). This is one of the identifying traits of koaiʻa. PHOTOS: C. ELEVITCH height slows down, the canopy broadens, and the stem(s) increase in diameter. Cautions for proper care of koaiʻa in the landscape are the same as for koa.

Root system

As with koa, koaiʻa has a strong lateral root system, which is often partially exposed on the surface, especially in rocky soils. Any kind of traffic can injure the roots and stress the plant. It is best to plant the tree in areas with limited or no traffic. Herbicide use under the tree should be avoided, as it could make direct contact with exposed roots and be taken up by the tree. Instead, mulching or a living ground cover of herbaceous plants are ideal for use under koaiʻa trees.

Products commonly used in a Pacific island household

The wood is much harder than koa and was used by Hawaiians for tools, fishhooks, spears, and canoe parts. When the trees were readily available, they were used for durable fence posts. Today, the rare wood is used for gun stocks, knife handles, bowls, and artwork.

Light requirements

Full sun is best for rapid growth and plant vigor. However, trees that receive light shade during part of the day can grow well.

Water/soil requirements

As with koa, koaiʻa requires freely draining soils. Standing water, waterlogging, and over-watering are also detrimental.

Expected life span in a homegarden

In optimal conditions, koaiʻa trees can be expected to grow many decades. Although koaiʻa is more tolerant of harsh conditions than koa, there have been reports of trees dying at an age of 10–12 years from unknown causes, and at 4 years due to koa wilt.

Varieties favored for use in homegardens

There are no varieties described. For native plants such as koaiʻa, it is best to use seeds that were collected from the nearest natural population. This means that residents of Molokaʻi, Lānaʻi, Maui, and Hawaiʻi should use seeds originating from natural stands on their islands.

Seasonality of leaf flush, flowering, fruiting

The tree grows continually except during dry periods. Koaiʻa flowers year-round in many areas, with a peak in the fall. However, seed set is sporadic. In wetter climates, seed quality is often very poor, whereas in drier climates the seed quality can be very high.

Exceptional ornamental values

Koaiʻa foliage is somewhat more gray-silver than koa, and

Left: Twelve-year-old koaiʻa tree growing along path at Amy Greenwell Ethnobotanical Garden, Kealakekua, Hawaiʻi. Right: When grown in a lawn, koaiʻa and koa become spindly and stressed. PHOTOS: C. ELEVITCH very attractive in the landscape. Because the tree is short, the yellow flowers are more visible that koa's and can be modestly showy. As with koa, the tree trunk is often covered with an attractive and harmless orange lichen. As the tree ages, a gnarled trunk and network of branches often becomes exposed through gaps in the canopy.

Use as living fence, hedge or visual/noise barrier

With its short size and domed canopy, koaiʻa can be used as a hedge tree. However, there are two caveats. First, koaiʻa trees are highly variable in size, shape, leaf size, and color shade, etc., so a uniform hedge cannot be expected. Second, pruning is not recommended due to the risk of increasing the plant's susceptibility to insect or disease attack. This means that a koaiʻa hedge should not be trimmed to a uniform shape.

Birds/wildlife

Koaiʻa flowers provide pollen and nectar for various insects, including bees.

Maintenance requirements

Maintenance requirements are the same as for koa.

Special considerations regarding leaf, branch, and fruit drop

None.

Hazards and nuisance issues

None.

Common pest problems

The pests that affect koaiʻa are the same as those for koa. It is said that koaiʻa is less susceptible to Chinese rose beetle than koa, although it may be more prone to scale insects and mealybugs.

Top: Gnarled framework of old koaiʻa tree, Puʻu o kali, Maui. PHOTO: FOREST AND KIM STARR **Bottom: Hedge of koaiʻa along property boundary, Kailua-Kona, Hawaiʻi.** PHOTO: C. ELEVITCH

Other comments about this species in urban environments

Koaiʻa is often a better choice than koa in landscaping due to its smaller size and tolerance for harsher, drier conditions. However, as with koa, the tree is susceptible to diseases, including koa wilt, which may shorten its life considerably. Even so, it is well worth planting this rare tree in Hawaiian landscapes.

PUBLIC ASSISTANCE AND AGROFORESTRY EXTENSION

Several government agencies offer assistance with forest establishment and conservation, including the following.

The Cooperative Extension Service (CES) of the University of Hawai'i can assist landowners with questions relating to koa. It has an excellent web site for forestry, including many valuable publications, forestry news, and an extensive list of forestry links for Hawai'i.

Extension Forester
College of Tropical Agriculture and Human Resources
University of Hawai'i at Mānoa
Komohana Agricultural Complex
875 Komohana St., Hilo, HI 96720
Tel: 808-959-9155; Fax: 808-959-3101
Web: http://www.ctahr.hawaii.edu/forestry

The Natural Resources Conservation Service (NRCS), formerly the Soil Conservation Service, provides assistance with conservation practices such as windbreaks and contour plantings. They also support various cost-share programs to increase the supply of timber products from private forest lands and to aid in the establishment of native species. The NRCS has offices throughout the USA, including Hawai'i and the American-affiliated Pacific.

NRCS State Office
P.O. Box 50004
Honolulu, HI 96850-0050
Tel: 808-541-2600
Fax: 808-541-1335 or 541-2652
Web: http://www.hi.nrcs.usda.gov

The Hawai'i Forest Industry Association (HFIA) is dedicated to responsible forest management. It offers an annual woodworking exhibition, sponsors the Hawai'i's Wood trademark, and serves as an advocate for Hawai'i's diverse forest industry—from tree planting and harvesting to creating and selling wood products.

Hawai'i Forest Industry Association (HFIA)
P. O. Box 10216
Hilo Hawai'i 96721
Street address:
162 Kino'ole Street, #101
Hilo, Hawai'i 96720-2816
Tel: 808-933-9411; Fax: 808-933-9140
E-mail: info@hawaii-forest.org
Web: http://www.hawaii-forest.org/

The Forest Stewardship Program is one of many programs offering financial assistance for landowners who are investing in forests. PHOTO: C. ELEVITCH

The University of Hawai'i College of Tropical Agriculture and Human Resources maintains a Hawai'i Forestry Extension Incentive Programs web page entitled, "Government Incentive Programs for Tree-Planting or Forest Management on Private Lands" at: http://www.ctahr.hawaii.edu/forestry/Data/incentives.html

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Acacia koa (koa) and *Acacia koaia* (koai'a)

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Acknowledgments: The authors and publisher thank Patrick Baker, Nick Dudley, Dale Evans, Eileen Herring, Clyde Imada, Heidi Johansen, Scot Nelson, Bart Potter, Michael Robotham, Paul Scowcroft, Peter Simmons, and Art Whistler for their input. We thank Bart Potter heartily for his authorship of the "Wood quality" section and the accompanying photographs. Photo contributions from Jack Jeffrey, Hal Lum, Scot Nelson, and Forest and Kim Starr are greatly appreciated.

Recommended citation: Elevitch, C.R., K.M. Wilkinson, and J.B. Friday. 2006. *Acacia koa* (koa) and *Acacia koaia* (koai'a), ver. 3. In: C.R. Elevitch (ed.). Species Profiles for Pacific Island Agroforestry. Permanent Agriculture Resources (PAR), Hōlualoa, Hawai'i. <http://www.traditionaltree.org>.

Sponsors: Publication was made possible by generous support of the United States Department of Agriculture Western Region Sustainable Agriculture Research and Education (USDA-WSARE) Program; SPC/GTZ Pacific-German Regional Forestry Project; USDA Natural Resources Conservation Service (USDA NRCS); Kaulunani, an Urban Forestry Program of the DLNR Division of Forestry and Wildlife and the USDA Forest Service; State of Hawai'i Department of Land & Natural Resources Division of Forestry & Wildlife; USDA Forest Service Forest Lands Enhancement Program; and Muriel and Kent Lighter. This material is based upon work supported by the Cooperative State Research, Education, and Extension Service, U.S. Department of Agriculture, and Agricultural Experiment Station, Utah State University, under Cooperative Agreement 2002-47001-01327.

Series editor: Craig R. Elevitch

Publisher: Permanent Agriculture Resources (PAR), PO Box 428, Hōlualoa, Hawai'i 96725, USA; Tel: 808-324-4427; Fax: 808-324-4129; E-mail: par@agroforestry.net; Web: <http://www.agroforestry.net>. This institution is an equal opportunity provider.

April 2006
ver. 1.2

Agathis macrophylla (Pacific kauri)

Araucariaceae, araucaria family

***dakua makadre, dakua, takua makadre, makadre, makadri, dakua dina, da'ua* (Fiji); *duro* (Solomon Islands: Vanikolo); *hoe*, *khoe* (Vanuatu: Espiritu Santo); *kauri* (Vanuatu: Bislama); *marabete* (Solomon Islands: Nendo); *nejev* (Vanuatu: Aneiytum); *nendu* (Vanuatu: Erromango); Pacific kauri (English)**

Lex A. J. Thomson

IN BRIEF

Distribution Humid, lowland, and lower montane tropics in the southwestern Pacific.

Size Tall tree typically to about 30–40 m (100–130 ft).

Habitat Lowland subtropical and tropical forests with evenly distributed rainfall of 1900–6000 mm (75–236 in); grows in elevations of 5–1150 m (16–3770 ft).

Vegetation Occurs in association with many different angiosperm and gymnosperm trees; a dominant component of lowland tropical closed forests.

Soils Prefers well structured, friable, and freely drained soils.

Growth rate In favorable conditions, annual growth can reach about 1–1.5 m (3.3–5 ft) in height and 1.5–2 cm (0.6–0.8 in) in trunk diameter.

Main agroforestry uses Crop shade, silvopasture.

Main products Timber.

Yields Production of merchantable timber is conservatively estimated to be 2–3 m^3/ha/yr (29–43 ft^3/ac/yr).

Intercropping Preferably cultivated with a diverse tree/shrub understory.

Invasive potential Not considered to be an invasive species.


PHOTO: L. THOMSON

Seven-year-old Pacific kauri planted underneath moribund *Cordia alliodora* trees at Shark Bay, Santo, Vanuatu.

INTRODUCTION

Pacific kauri (*Agathis macrophylla*) is a forest tree species of major ecological and economic importance in the southwest Pacific region of Melanesia. It is among the largest and longest living tree species found in the region, with individuals reaching up to 40 m (130 ft) in height and 3 m (10 ft) in bole diameter, with an estimated life span of 300–1000 years. The tree occurs naturally in the humid and mesic lowland and lower montane rainforests in the Solomon Islands, Vanuatu, and Fiji. Tropical cyclones occur at periodic intervals in all parts of its range, mainly during the months of November through March. Its ability to withstand strong winds is a major attraction for growing it in cyclone-prone areas. Pacific kauri generally prefers well drained, basalt-derived clay loams and clays with a well developed upper humus layer. The species is a gap opportunist, with seedlings dependent on large gap openings (more than 2–3 trees) in the canopy for establishment and growth. In mature trees the canopy is emergent and constitutes a unique structural element in the forests in which it occurs; i.e., the form/structure of Pacific kauri cannot be replaced by any other species. Hence it has major significance in conservation of the plant communities in which it is a component.

Its finely grained, pale, easily worked, and uniform timber is of major commercial importance with various high value end-uses, including furniture, handicrafts, veneer, boat building, light construction, and paneling. From a plantation viewpoint, Pacific kauri stands apart from most species in the genus because of its ability to grow moderately fast and establish in open, sunny sites.

Pacific kauri has good potential in several agroforestry situations, including interplanting in shifting gardens, improved fallows, boundary plantings, upper-story windbreaks (where space permits), and woodlots. It also has good potential for rehabilitation of degraded and secondary forests through line plantings. Its biological characteristics ensure that it is highly unlikely to become an environmental weed when planted outside of its native habitats.

The main factors limiting its wider re-planting are

- high early maintenance costs, with regular weeding and vine cutting being required during the first 4–5 years, especially in open-grown plantations
- long projected rotation length for timber production, which is expected to be 40–55 years (i.e., longer than for mahogany)
- difficulty in obtaining viable seed of the most desired sources from southern Vanuatu.

DISTRIBUTION

Native range

Pacific kauri naturally occurs as scattered trees and groves in lowland subtropical and tropical forests in the Solomon Islands, Vanuatu, and Fiji. It occurs more frequently on ridge crests. In the Solomon Islands it is found on four islands in the Santa Cruz group, namely Ndende, Vanikolo, Tevai, and Utupua. In Vanuatu it is found in the central-eastern parts of two southern islands, Erromango and Aneityum. In Fiji, the species occurs on the larger islands of Viti Levu, Vanua Levu, Taveuni/Qamea, Ovalau, and Kadavu.

Current distribution

The species is still reasonably abundant throughout its natural range in the southwestern Pacific. It has been recorded as being cultivated in Hawai'i, and it has been planted in small-scale trials in Sarawak, Malaysia (Fahlman 1975) and New Zealand (Beveridge 2002).

BOTANICAL DESCRIPTION

Preferred scientific name

Agathis macrophylla (Lindley) Masters

Family

Araucariaceae (araucaria family)

Non-preferred scientific names

A. obtusa (Lindl.) Masters (for southern Vanuatu populations)

A. vitiensis (Seeman) Benth. & Hook f. ex Drake (for Fijian populations)

Common names

dakua makadre, *dakua*, *takua makadre, makadre, makadri, dakua dina, da'ua* (Fiji)
duro (Solomon Islands: Vanikolo)
hoe, *khoe* (Vanuatu: Espiritu Santo)
kauri (Vanuatu: Bislama)
marabete (Solomon Islands: Nendo)
nejev (Vanuatu: Aneiytum)
nendu (Vanuatu: Erromango)
Pacific kauri (English)

Size

It is a tall tree to about 30–40 m (100–130 ft) height, rarely attaining 45–55 m (150–180 ft). In Fiji mature trees are typically 20–33 m (66–110 ft) tall. Bole diameters of older specimens are around 1.2–1.6 m (4–5.2 ft) the Solomon Islands and up to 3 m (10 ft) in Vanuatu and Fiji.

Form

Tree form varies considerably depending on seed sources (provenance), age, and habitat. The bole is slightly to strongly tapering, without buttresses, and in mature specimens is clear of branches for 9–20 m (30–66 ft). In younger specimens the form of the crown is conical and monopodial. Eventually the canopy becomes broad (diameter to 36 m [120 ft]) and deep (to 24 m [80 ft]) and develops a sympodial form, often asymmetrical and ragged in outline. Branches may be erect to horizontal and massive. When trees are between 30 and 50 cm (12–20 in) dbh, the canopy shape changes from narrow-conical to a spreading crown with upward spreading branches (Beveridge 1975).

Flowers

The tree a gymnosperm, i.e., it produces its male and female reproductive structures in cones and not in flowers. It is monoecious, having separate male and female cones on the same tree. The first female cones begin to be produced at about 10 years old. These take 2 years to mature; at the end of the first year they are egg-shaped, about 5 cm (2 in) long, and 3 cm (1.2 in) in diameter, and at the end of the second year they are more or less round and 8–10 cm (3–4 in) in diameter. In Fiji, very young female cones have been observed in early January.

At maturity, the male cones are cylindrical (20–25 mm [0.8–1 in] long by 8–12 mm [0.3–0.5 in] diameter) with the cupule wider than the cone base. They are borne on short side branches and rather inconspicuous green drying to light orange-brown. The microsporophylls are taxonomically important and a useful character for distinguishing between different *Agathis* species. In *A. macrophylla* the microsporophylls (as seen in the intact cone at anthesis) are strongly overlapping, 1.5–2 mm (0.06–0.08 in) across, margin thin, entire or irregularly incised, head in adaxial view 2(–2.5) mm (0.08[–0.1] in) across by 2 mm (0.08 in) radially, thick center thinning gradually to a narrow margin, stalk joining near head near abaxial edge. There are 6 to 14 pollen sacs.

Leaves

The leaves are leathery, dark green, and shiny above and often glaucous below. The leaf blade is simple, entire, elliptic to lanceolate, about 7–15 cm (2.7–6 in) long and 2–3.5 cm (0.8–1.4 in) wide, with many close inconspicuous parallel veins. The leaves taper to a more or less pointed tip, rounded at the base, with the margins curved down at the edge. Petioles are short, from almost sessile up to 5 mm

Top: Female cone. Bottom: Male cones. PHOTO: GTZ-PACIFIC-GERMAN REGIONAL FORESTRY PROJECT

(0.2 in) long. The leaves are arranged decussately but held in one plane except on vertical growing tips. Juvenile leaves developed in shade are considerably longer than those in the upper canopy. The leaves of Solomon Islands plants are typically larger and broader than plants from drier and cooler parts of its range in Fiji.

Fruit

Female flower cones are much larger than male cones, globular, about 8–13 cm (3–5 in) across, on thick woody stalks, green, slightly glaucous, turning brownish during ripening. Each brown, winged seed is attached to a triangular cone scale about 2.5 cm (1 in) across. About half the seeds are viable, these being located in the central part of the cone. The bulk of the seed crop has usually matured by early to mid-February, with later cones maturing in March, suggesting a maturation period of 12–15 months.

Leaves of a seedling. PHOTO: L. THOMSON

Seeds

The seeds are brown, small, ovoid to globose, flattened, winged (wing about 3.5 cm [1.4 in] long), and attached to a triangular cone scale about 2.5 cm (1 in) across. Seeds are released during disintegration of the cone. Wind dispersal of seed is efficient: dispersal of up to 10 km (6 mi) has been recorded, and long-distance dispersal of tens to hundreds of kilometers is likely during cyclones.

Rooting habit

Mature specimens have wide, spreading root systems that help stabilize soils on ridges and slopes (Beveridge 1975). Seedlings and young specimens have a vigorous taproot with one or more whorls of lateral roots. Roots of young seedlings are infected by the phycomycete *Endogone*, forming vesicular-arbuscular mycorrhizal associations.

Similar or look-a-like species

Agathis silbae De Laub. (endemic to west coast Santo, Vanuatu)

Agathis robusta (C. Moore ex F. Muell) F.M. Bailey (endemic to Australia and Papua New Guinea and planted in some Pacific islands, especially Tonga)

How to distinguish from similar species/look-a-likes

The main defining feature of *A. silbae* is the male cone: male strobili are cylindrical, oblong, somewhat broadened on the upper half, coppery-brown to red-brown, with a peduncle 3.5–4 mm (0.14–0.16 in) long. Pollen cones 37–55 by 15–18 mm (1.5–2.2 by 0.6–0.7 in), linear with the upper expanded part of the microsporophyll 2–2.5 mm (0.08–0.1 in) long and wide, with a 5–6-sided raised boss at the apical end. Between the raised area (which crowds against those of the surrounding microsporophylls on immature cones) and the pendant pollen sacs is a broad raised area with a ridge along the centre, narrow where two sides of the raised area meet at its upper end and lanceolate (starting as wide as the adjacent side of the raised area) where one of those sides is located in the centre of the expanded part of the microsporophyll. Other differences in flower and fruit characters of *A. silbae* compared with *A. macrophylla* include the longer, more slender penducles on the female cones of *A. silbae*, typically 6–9 cm (2.4–3.6 in), compared with 1–2 cm (0.4–0.8 in), and the typically longer male cones of *A. silbae*, about 4–5.5 cm (1.6–2.2 in) long compared with 2–5 cm (0.8–2 in) in *A. macrophylla*.

In *A. macrophylla* the microsporophyll head is more or less abruptly joined to the stalk, whereas in *A. robusta* the head narrows gradually into the stalk. In *A. macrophylla* the male flower cones (at anthesis) are shorter, about 2–5 cm (0.8–2 in) long compared with 5–10 cm (2–4 in) in A. *robusta*. The mature female cones of *A. macrophylla* are rounded (to 10 cm [4 in] diameter), whereas *A. robusta* has ovoid female cones (to 13 cm [5 in] long).

GENETICS

Variability of species

The populations of Pacific kauri from the Santa Cruz Group, Vanuatu, and Fiji exhibit considerable morphological differences in bole form, bark, and foliage, but they are nevertheless considered to comprise a single species. Whether the three geographic forms should be recognized as different subspecies is an open question. Even within one region, different varieties have been reported. For example, on the basis of differences in leaf characters and stem form, morphologically distinct forms have been recognized on Erromango and Aneityum in Vanuatu.

Within the species there is considerable variation in other traits of economic importance, especially self-pruning. Trees from the Santa Cruz Islands exhibit heavy branching and poor self-pruning. Southern Vanuatu provenances (formerly known as *A. obtusa*) combine moderately fast growth, especially in more open-grown situations, with good form and self-pruning and are considered to be among the most promising seed sources in the *Agathis* genus for use in plantation development.

Known varieties

At Anelghowat (Aneityum, Vanuatu), villagers recognize three variants,

- nejev ahei, the most common type with white bark,
- nejev yang, with yellowish bark and timber, and,
- nejev apeng, with blackish bark and branches.

In Fiji, two different forms have been reported, one taller with fewer branches known as dakua balavu, and the other, dakua leka, shorter and more branched.

ASSOCIATED PLANT SPECIES

In the Santa Cruz Islands (Solomon Islands) Pacific kauri is a dominant component of the lowland tropical closed forests, occurring as an emergent above a dense unstratified forest. The species is largely absent from early secondary forests, where it cannot compete with spreading, fast growing, secondary forest species. In Vanuatu the species occurs as scattered individuals or in small groups as an emergent or upper canopy tree, in various closed forest associations. In Fiji, it occurs in several forest associations, especially in moist montane closed forests and lower montane closed forests in the intermediate rainfall zone.

Associated species of native habitats

Pacific kauri occurs in association with many different angiosperm and gymnosperm trees. In the Santa Cruz Islands it grows with *Campnosperma brevipetiolata*, *Fagraea* spp., and *Hernandia* spp.

Associates in Vanuatu include *Cryptocarya turbinata*, *Calophyllum neo-ebudicum*, *Garcinia vitiensis*, *Hernandia cordigera*, *Ilex vitiensis*, *Palaquium* spp., and *Podocarpus* spp. In Fiji some of the common associates are *Calophyllum vitiense*, *Dacrydium nidulum* and *D. nausoriense*, *Endospermum macrophyllum*, *Fagraea berteroana*, *Garcinia* spp., *Gymnostoma vitiense*, *Myristica* spp., *Palaquium hornei*, *Podocarpus* spp., *Retrophyllum vitiense*, and *Syzygium* spp.

ENVIRONMENTAL PREFERENCES AND TOLERANCES

Climate

The tree occurs naturally in the humid, lowland, and lower montane tropics. Tropical cyclones occur at periodic intervals in all parts of its range, mainly during the months of November through March. In the Santa Cruz Islands (Solomon Islands) Pacific kauri occurs from near sea level to 600 m (1970 ft). The climate is very wet (4500–6000 mm [180 in]) with no dry season and warm to hot throughout the year. In Vanuatu, the species is most frequent on ridges or steep, often exposed slopes, but also occurs on flat to undulating terrain. Rainfall on Erromango and Aneityum is around 2200–2600 mm (87–102 in) per year with a short dry season from June to October but may reach 4000 mm (157 in) in wetter parts of Erromango. In Fiji, Pacific kauri is a component of lowland and lower montane subtropical rain forest from near sea level to 1150 m (3770 ft), mostly from 600 to 900 m (1970–2950 ft) elevation. Temperatures are warm to hot throughout the year. Annual rainfall is 2100–3600 mm (83–142 in) with a weak to pronounced dry season from June to October.

Elevation range

5–1150 m (16–3770 ft)

Mean annual rainfall

1900–6000 mm (75–236 in)

Rainfall pattern

Pacific kauri prefers climates with summer or uniform rainfall patterns.

Dry season duration (consecutive months with <40 mm [1.6 in] rainfall)

0–1 months. While there is a distinct dry season of several months in Fiji and Vanuatu, the average monthly rainfall in the driest months still exceeds 40 mm (1.6 in).

Mean annual temperature

25–28°C (77–82°F)

Mean maximum temperature of hottest month

29–31°C (84–88°F)

Mean minimum temperature of coldest month

17–23°C (63–73°F)

Minimum temperature tolerated

7°C (45°F) (Nadarivatu, western Viti Levu, Fiji)

Soils

Pacific kauri generally prefers basalt-derived clay loams and clays with a well developed upper humus layer. It has also been reported on coral limestone terraces and bordering mangrove vegetation. Tree growth is poor on compacted and waterlogged soils, and the species is most commonly found on well structured, friable, and freely drained soils.

On Ndendo (Santa Cruz Islands) the stands are located on deep friable clays (Oxisols) derived from basalt, although the edges of the stands may occur on calcareous sandstones and siltstones. On Vanikolo trees grow over basalt on a latosolic soil without appreciable accumulation of humus and no sign of podsolization. It has been found that the total Ca^{2+} and Mg^{2+} levels are lower in soil samples obtained from below individuals of Pacific kauri than from samples obtained below individuals of *Calophyllum neo-ebudicum*. Although this data suggest that more extensive leaching of cations occurs under Pacific kauri, the species does not appear to promote podsolization to the same extent as some other species of *Agathis*.

In Vanuatu the species also generally occurs on clayey soils with a well developed upper humus layer. On Erromango the species grows on deeply weathered, well structured clays (Oxisols) derived from basalt. In Fiji the species occurs on various heavier soil types, including deep, friable, chocolate-brown clay over basalt, humic Latosols and red-yellow podzolics.

Soil texture

The tree grows in heavy soils (sandy clays, clay loams, and clays).

Soil drainage

Freely draining soils are required.

Soil acidity

It grows in acid to neutral soils (pH 4.0–7.4).

Tolerances

Drought

It is likely to be tolerant only of short dry periods (e.g., 3–5 months) once established.

Full sun

The tree grows most rapidly in well lit situations, but trees grown in full sun may have poorer self-pruning of side branches and heavier lateral branching compared with those grown under light, even shade (about 25% overhead shade).

Shade

In lightly shaded situations plants may elongate moderately fast (sometimes faster than in full sun), but under heavy shade they grow very slowly (until such time as they are exposed to stronger sunlight). However, seedlings are able to endure heavy shade (up to 75%) for many years.

Fire

Fires can kill mature trees; susceptibility to fire damage reportedly increases in over-mature specimens.

Frost

Frosts are unknown in its native habitats, and accordingly the species is likely to be tolerant only of the mildest frosts at infrequent intervals.

Waterlogging

The tree is generally intolerant of waterlogging but might be able to tolerate short periods of waterlogging in lighter, well aerated soil types.

Salt spray

Pacific kauri occurs in near-coastal situations and is tolerant of light salt spray.

Wind

Trees are well adapted to growing in windy locations and cyclones.

Abilities

Regenerate rapidly

Seed production is sufficient to maintain occasional to moderately common and reasonably widespread populations of very slow growing seedlings. When large gaps in the canopy appear (>2–3 trees), the seedlings are released and can grow reasonably rapidly to become emergent trees.

Self-prune

The extent of self-pruning is substantially affected by both environmental and genetic factors. In the Santa Cruz Islands open-grown trees develop persistent, heavy limbs that showed no sign of self-pruning during the first 10 years. However, mature plantations self-prune well, and pruning is not practiced in the Solomon Islands. Trees from Vanuatu exhibit much better self-pruning and branching characteristics than those from the Santa Cruz Islands (Fijian populations are intermediate).

Coppice

Unknown for *A. macrophylla*. Some species of *Agathis*, including *A. borneensis* in Malaysia, will coppice when sapling size plants are cut.

GROWTH AND DEVELOPMENT

Pacific kauri is reported to be among the fastest growing species in the genus (Bowen and Whitmore 1980a). However, annual diameter increment is variable and affected by several factors. The major factor appears to be the degree of exposure of the tree canopy to sunlight. The species is exceptionally long-lived with an estimated life span of 300–1000 years.

Growth rate
In open and lightly shaded areas, with good weed control, the mean annual increment is about 1–1.5 m (3.3–5 ft) in height and 1.5–2 cm (0.6–0.8 in) in trunk diameter (Marten 1970, Neil 1990). Trees in undisturbed, native forest grow very slowly, e.g., 2.5–3.7 mm (0.1–0.15 in) per year and take more than 200 years to reach a dbh of 75 cm (30 in) (Ash 1985).

Reaction to competition
Pacific kauri is very tolerant of shading, but growth rates are greatly reduced at higher levels of shading. It is reasonably tolerant of root competition, but seedlings/ saplings should be kept free of competition from grasses.

PROPAGATION
The species is readily grown from freshly collected seed, and this is the recommended propagation method. Plants can also be propagated vegetatively using both main stem and lateral cuttings from 12-month-old seedlings. Lateral cuttings tend to retain a plagiotropic growth habit and should not be used for planting stock for timber plantation purposes.

Propagation by seed

Seed collection
Heavy cone crops are produced on older trees with massive, spreading crowns, although the larvae of *Agathiphaga* moths can cause major seed damage and loss (see "Pests and diseases"). The recommended collection technique is climbing (using appropriate safety equipment, ropes, harnesses, and spikes) into the upper canopy and using long-handled hooks to break off mature cones. Seed is most abundant in the early months of the year: February–April (Santa Cruz Islands), February–March and June (Vanuatu), and January–March (Fiji). Collection of recently matured cones will result in greater seed viability and longevity, but it is difficult to assess when the cone is fully mature, and it shatters shortly afterward.

Propagule processing
Precautions have to be taken in seed collection, extraction, and handling to avoid damage due to lethal combinations of temperature or moisture content. Cones should be air dried in an open location, and seed should be extracted as soon as possible after collection to minimize fungal damage and/or germination in the cone. On average about half the seeds are viable; these are located in the central part of the cone. However, there is a very large variation in numbers of viable seeds per cone, from a few up to about 100. Freshly collected seed has about 5000–6000 viable seeds/kg (2270–2730 seeds/lb).

Seed storage
Pacific kauri may be classed as intermediate in its seed storage characteristics. Its seeds are very sensitive to a range of conditions including drying, chilling damage, and carbon dioxide/oxygen balance. Seed storage life is affected by complex relationships among moisture content, temperature, and drying rate. For long-term storage, seed should be dried to around 9–13% moisture content and kept as cold as possible, preferably at –13°C (11°F). Drying below 7% moisture content reduces viability.

Pre-planting treatments
In order to avoid reduction in viability during storage, it is recommended that dewinged seeds be sown immediately following collection and processing. No pretreatment is required, and fresh, undamaged seeds germinate rapidly, commencing within 2–7 days (at 26°C [79°F]) and completed by 14 days.

Growing area
It is recommended that plants be germinated under shelter with about 50% shade.

Germination
Sow seeds into potting medium in germination trays. The seeds are sown in a vertical position with wing end up and just covered by sand or potting mix. Seedlings are transplanted into individual pots at the two-leaf or cotyledon stage.

Media
A standard potting medium with good draining properties is recommended. For introduction into areas outside of its natural range, it is likely to be advantageous to inoculate seedlings with appropriate mycorrhizal fungi.

Time to outplanting
Seedlings reach a plantable size after about 6–12 months in the nursery.

Approximate size
Seedlings are suitable for field planting when they have reached 25–30 cm (10–12 in) in height. However, larger seedlings grown in larger, deeper pots may be desirable in order to reduce the period of high-maintenance weeding following outplanting. If necessary, seedlings may be safely held in the nursery for a considerable period, e.g., up to 2 years, by transferring them into more shaded conditions.

Guidelines for outplanting

Survival is expected to be very high (>95%) for larger seedlings that are planted into reasonably sunny sites and weeded at regular intervals, on an as-needed basis, during the first 4–5 years. It is important to cut away and cut down fast-growing climbers such as *Merremia peltata* and mile-a-minute (*Mikania micrantha*). These can quickly weigh down, bend over, and damage younger kauri plants. For grassy/weedy sites, pre-planting spraying of site with glyphosate herbicide is recommended.

DISADVANTAGES

The main disadvantage is the high early maintenance cost, with regular weeding being required during the first 4–5 years, especially in open-grown plantations. Pacific kauri should not be planted in areas with heavy infestations of weedy climbers.

There may also be difficulties in obtaining planting stock, due to problems of collecting, maintaining, and/or procuring viable seed.

Potential for invasiveness

The biological characteristics of the species ensure that it has a low weediness risk.

Diseases and pests

The species has low susceptibility to termite attack and beetle larvae, but old trees are sometimes affected by these insect pests. Pink disease, caused by *Corticum salmonicolor*, and root fungi may be lethal to the plant but are usually restricted to waterlogged sites. Other pests and diseases include foliage blight (*Cylindrocladium macrosporum*), necrotic bark, leaf gall, canker, hollow butt, and *Phellinus noxius*. Plantations in the western Solomon Islands (outside the species' natural range) have been affected by a coreid bug (*Amblypelta cocophaga*). The most serious recorded pests are larvae of the primitive moth *Agathiphaga vitiense*. Attack by these caterpillar larvae may greatly reduce the amount of viable seed produced, with up to 95% of seed in a cone being destroyed. Plants may suffer from dieback especially when grown on soils of poor structure.

Host to crop pests/pathogens

Unknown.

Other disadvantages or design considerations

The nursery period is of a long duration for a tropical tree species, increasing the cost of seedling propagation and risk of seedling death from water stress.

In open-grown situations, trees of Santa Cruz Islands and Fiji origin showed no sign of self-pruning during the first 10 years and exhibited a tendency to form several leading shoots.

AGROFORESTRY/ENVIRONMENTAL PRACTICES

Soil stabilization

It is not suitable for situations where rapid soil protection and binding is needed, but it may be very useful for longer-term stabilization of less stable soil profiles.

Crop shade/overstory

The tree is mainly suitable as a long-term or permanent overstory tree for more shade-tolerant understory crops; however, wide-spaced plantings of less dense forms of Pacific kauri (such as from Fiji) may provide light shade for a wider variety of crops.

Alley cropping

It is not well suited to alley cropping in permanent agroforestry systems due to its eventual large stature and spread. It could be included in alleys in shifting gardens (which are then left to revert back to forest.

Homegardens

The tree is usually not appropriate for homegardens due to its large size, but it could be included as a "landmark" tree (with high stability during cyclones). Because of its traditional and commercial importance, as well as its long life span and increasing rarity, the plant is ideal for planting in village and schoolyards.

Improved fallows

It could be planted in shifting garden situations, but long rotations mitigate against its use for this purpose.

Boundary markers

In certain situations it is suited as boundary marker, due to size and longevity, but it may shade neighboring crops.

Windbreaks

Where space permits, Pacific kauri is an excellent upper story in a mixed-species windbreak (including faster growing species).

Silvopasture

Pacific kauri is well suited to inclusion as a tree component in silvopastoral systems, being long-lived and providing high shade for cattle.

Woodlot

It is suited only to woodlot plantings in which early financial returns are not required.

Wildlife habitat

It is a very useful wildlife habitat tree, especially for birds, and provides a unique structural element in SW Pacific forest ecosystems.

Ornamental

One of the most impressive trees in the Pacific islands, it deserves to be more widely planted in large public spaces, including along roads and as a landmark tree.

USES AND PRODUCTS

Pacific kauri is of great importance to local people throughout its natural range in Melanesia. In a survey of 18 villages on the major islands in the Fiji Group, 41 of 42 respondent groups named the species as an important timber tree. Traditional uses for the tree are similar in different parts of its range. The timber is utilized for house and other construction, furniture, canoe making, and carving, while its resin is used for glazing pots, canoe caulk, lighting fire, glue, and in torches. The smoke of the resin is also used as a dye for hair and tattoos and to paint native clothes black. In some areas Pacific kauri may also have spiritual significance. For example, in Fiji it is the totem tree of several family clans, villages, and districts.

Pacific kauri is a highly valued commercial timber species, often generating much needed cash income for local communities through logging royalties.

Medicinal

The young leaves and bark of the related *A. silbae* are used in traditional medicines on Santo, Vanuatu (Siwatibau et al. 1998).

Timber

The wood is an important commercial timber with many end-uses, both for local and export markets (see "Commercial products"). It produces a finely textured, straight grained, pale, and uniform timber that is easily worked and glued and has excellent physical, mechanical, working, and veneering properties. The timber is valued for handicrafts, furniture, veneer, boat building, light construction, and paneling. It is not suitable for use in ground contact, as its natural durability class is rated as 3 or 4 (depending on source), indicating a service life in ground contact of about 5–10 years. The timber is amenable to preservative treatment, but its high value would normally preclude its use for general construction purposes. The species is currently being commercially exploited in Fiji, mainly on the large islands of Vanua Levu and Viti Levu. The species is protected on Erromango, Vanuatu, in a Kauri Reserve: it is expected that this measure will generate ecotourism revenue for local communities. The species is not currently logged in Santa Cruz Islands, and exports of logs are prohibited.

Fuelwood

The wood can be used as fuel, but is better suited to other purposes.

Craft wood/tools

The wood is traditionally used for carving in Vanuatu.

Canoe/boat/raft making

The wood has traditionally been used for making canoes in Vanuatu; the whole trunk is used, carved out to make canoe.

Resin/gum/glue/latex

Manila copal produced from the living inner bark was an important component of many varnishes (Chaplin 1993) and is still used mixed with synthetics. Commercial export of the resin was formerly practiced in Fiji but was prohibited in 1941, as no method could be found for tapping an economic yield of gum without endangering the life of the tree. In Vanuatu *Agathis* resin is traditionally used as canoe caulk, and the resin soot was used for tattoos. In Fiji the resin was formerly used for glazing pots.

Tannin/dye

Smoke residues of the burnt resin were traditionally used as a dye for hair.

Illumination/torches

Resin from the inner bark was traditionally used for lighting and torches in Fiji and Vanuatu.

Ceremonial/religious importance

In some areas the tree has spiritual significance. For example, in Fiji it is the totem tree of several family clans, villages, and districts.

COMMERCIAL PRODUCTS

Pacific kauri is a highly valued commercial timber species. It has good peeling and gluing properties and is highly sought after for surface veneer. The pale cream to gold brown lustrous heartwood and straw yellow to pale brown sapwood are well known and highly appreciated in the timber industry. Damage from pinhole borers may occur in standing trees, while drywood termites and *Anobium* borers may cause damage in service.

The wood is readily kiln dried with a medium shrinkage value. The air-dry density is 540 kg/m^3 (34 lb/ft^3). In service the timber is very stable. The timber is suitable for a wide range of end-uses including laboratory bench tops, vats, sauna baths, battery separators, weatherboards, bowls, novelties, handles, furniture, veneer, and boat building.

The use of selected, superior seed provenances (notably from Vanuatu) and good silviculture will enable the commercial production of timber and veneer in plantations on a 40–55-year rotation period.

Spacing

Selection of spacing regime will depend on the environment in which the plantation will be established:

- in secondary or logged forest, enrichment planting with a spacing of 2–3 m (6.6–10 ft) in lines 9–10 m (30–33 ft) apart
- in cleared areas a spacing of 4–5 x 4–5 m (13–16 x 13–16 ft) in association with agricultural intercrops for several years to reduce weeding costs.

Management objectives

The overall management objective is to produce a high stocking of well formed stems. Accordingly, implementation of a thorough weeding regime in early years is essential, including regular removal of climbers and singling of any multi-stemmed seedlings/saplings.

An initial density of 400–500 stems/ha (160–200 stems/ac) is recommended, reducing to a final density of about 150 stems/ha (60 stems/ac) through mortality and one selective, non-commercial thinning at about half the rotation length, i.e., about 20–25 years.

In native forests it is recommended that natural regeneration be periodically tended, mainly release from vines and climbers, following opening up of the canopy through logging.

Design considerations

The wood is valuable, and accordingly plantations do not necessarily have to located especially close to markets but should preferably be located within economic range of processing facilities. Excessive delays in processing may diminish log quality due to sap stain and/or borer attack (including toredo, a type of marine borer, if exposed to the sea).

CONSERVATION OF PACIFIC KAURI

The high-quality timber of Pacific kauri has led to heavy post-European exploitation, and it remains a species highly preferred by logging companies. Former extensive logging of the species has left just a few more-or-less pristine stands remaining in Vanuatu and Fiji, and some of these have some level of protection. Although under no imminent threat, which is indicated by its "near threatened" (LR/nt) listing in the International Union for Conservation of Nature and Natural Resources (IUCN) "red list," it is an open question whether present conservation efforts are sufficient to maintain the remaining genetic resources of the species in the long term. An intensification of commercial timber harvesting may lead to a CITES listing for the Fijian populations.

Yields

No data is available for older plantations of *A. macrophylla*. In the Santa Cruz Islands, Marten (1970) envisaged a 45–55-year rotation with a final crop of 60–80 stems/ha (24–32 stems/ac) with each stem yielding 2 m^3 (140 ft^3). This equates to a growth increment for merchantable timber in the final crop of only 2–3 m^3/ha/yr (29–43 ft^3/ac/yr). Higher growth rates have been observed for other *Agathis s*pecies, and Marten's estimates appear conservative. Whitmore (1980) recommended that *A. dammara* be grown on a 50-year rotation on Java (Indonesia) for a total predicted yield of 22–28 m^3/ha/yr (315–400 ft^3/ac/yr) (volume increment, including thinnings, at 30 years of age was 23–32 m^3/ha/yr [329–458 ft^3/ac/yr]). *Agathis robusta*, another faster growing species in the genus, exhibited a merchantable wood increment of 11 m^3/ha/yr (157 ft^3/ac/yr) at age 22 years on a sub-optimal site in southern Queensland, Australia (Whitmore 1980).

Market

The timber and veneer of the species has good local and export market prospects. Because of its deservedly high reputation in the timber trade and the multiple uses to which its timber can be put, demand and prices will remain solid for the indefinite future. In former times an annual output of around 10,000 m^3/yr (35,300 ft^3/yr) from the Solomon Islands was considered necessary to meet Australian demand and return a profit. There is currently no production, but there is estimated to be about 450,000 m^3 (15,900,000 ft^3/yr) available, and logging may resume in near future.

INTERPLANTING/FARM APPLICATIONS

Pacific kauri appears to be suitable for growing in monocultures but is preferably cultivated with a diverse tree/shrub understory.

Example system

Location

Shark Bay, Espiritu Santo, Vanuatu.

Description

New system: Seedlings are underplanted as an understory in a moribund (stagnant growth with some deaths from *Phellinus*) *Cordia subcordata* plantation, commenced in about 1997 on trial basis.

Yields/benefits

The trees have grown moderately fast, about 1–1.5 m (3.3–5 ft) per year, and have very good stem form.

Spacing

Spacing of *Agathis* trees is 5 x 5 m (16 x 16 ft).

PUBLIC ASSISTANCE

See general extension links at: <http://www.traditionaltree.org/extension.html>.

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Species Profiles for Pacific Island Agroforestry (www.traditionaltree.org)

Agathis macrophylla (Pacific kauri)

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Acknowledgments: The author and publisher thank Tony Beveridge, Dale Evans, Gunnar Keppel, and Mike Wilcox for their input. Photo contributions by Tony Beveridge and the GTZ-Pacific-German Regional Forestry Project are greatly appreciated.

Recommended citation: Thomson, L.A.J. 2006. *Agathis macrophylla* (Pacific kauri), ver. 1.2. In: Elevitch, C.R. (ed.). Species Profiles for Pacific Island Agroforestry. Permanent Agriculture Resources (PAR), Hōlualoa, Hawai'i. <http://www.traditionaltree.org>.

Sponsors: Publication was made possible by generous support of the United States Department of Agriculture Western Region Sustainable Agriculture Research and Education (USDA-WSARE) Program; SPC/GTZ Pacific-German Regional Forestry Project; USDA Natural Resources Conservation Service (USDA NRCS); State of Hawai'i Department of Land & Natural Resources Division of Forestry & Wildlife; and the USDA Forest Service Forest Lands Enhancement Program. This material is based upon work supported by the Cooperative State Research, Education, and Extension Service, U.S. Department of Agriculture, and Agricultural Experiment Station, Utah State University, under Cooperative Agreement 2002-47001-01327.

Series editor: Craig R. Elevitch

Publisher: Permanent Agriculture Resources (PAR), PO Box 428, Hōlualoa, Hawai'i 96725, USA; Tel: 808-324-4427; Fax: 808-324-4129; E-mail: par@agroforestry.net; Web: <http://www.agroforestry.net>. This institution is an equal opportunity provider.

April 2006
ver. 2.1

Aleurites moluccana (kukui)

Euphorbiaceae (spurge family)

‘*ama* (Marquesas); candlenut, candleberry, varnish tree, Indian or Belgaum walnut (English); *kukui, kuikui* (Hawai‘i); *lama* (Samoa); *lauci, nggerenggere, sikeci, sikeli, sikethi, toto, tuitui, tutui, waiwai* (Fiji); *lumbang* (Guam); *raguar* (Caroline Islands); *rama* (Mangareva); *sakan* (Palau); *sakan, shakan* (Pohnpei); *tahii, tahiri, tiairi, ti‘a‘iri, tutui* (Moorea [French Polynesia]); *tuitui* (Mangaia [Cook Islands], Futuna, Makatea, Niue, Tonga, Tubuai, Uvea); *tutu‘i, ti‘a‘iri* (Society Islands); *tutui* (Rimatara, Rurutu, Tahiti)

Craig R. Elevitch and Harley I. Manner

PHOTO: C. ELEVITCH

A gathering place under kukui.

IN BRIEF

Distribution Widespread throughout the tropics.

Size Typically reaches 10–15 m (33–50 ft), with similar crown diameter.

Habitat Subtropical dry to wet and tropical very dry to wet forest climates. Typically 0–700 m (0–2300 ft) with rainfall of 640–4290 mm (25–170 in).

Vegetation Associated with a wide variety of cultivated plants.

Soils Prefers light and medium textured soils; grows even on basalt, red loams, stony clay ground, sand, and limestone.

Growth rate Moderately fast growing in favorable conditions, growing 0.5–1.5 m (1.6–5 ft) per year.

Main agroforestry uses Windbreak, screen/hedge, soil stabilization, homegardens.

Main products Oil from seed, nut shells for leis.

Yields 80 kg (176 lb) seeds per tree/year in cultivation.

Intercropping Planted as a boundary or windbreak tree.

Invasive potential Moderate, has naturalized in many areas. Rarely considered a pest.

INTRODUCTION

Kukui is one of the great domesticated multipurpose trees of the world. It is one of the most useful trees introduced by the aboriginal people of the Pacific islands. A tall, spreading tree in open areas, it commonly attains heights of 10 m (33 ft) and a canopy diameter about as wide as the tree is tall. Kukui grows in homegardens, in and around farms, and naturalized along streams, gulches, and valley slopes. It is easily recognized by its characteristic silvery gray-green foliage, which is particularly ornamental.

Kukui is native to the Indo-Malaysia region and was introduced in ancient times throughout the Pacific islands. It can grow in a wide range of dry to wet tropical and subtropical habitats but is most at home in the moist tropics with annual rainfall of 2000 mm (80 in) or greater. Kukui tolerates drought and wind and grows readily on poor soils as well as steep slopes. Due to its many traditional uses and its role in ecosystems, kukui is recognized as the official state tree of Hawai'i.

The traditional uses of kukui are extensive. Throughout Polynesia kukui is known in local languages by names whose root means "light," referring to the traditional use of seeds and oil which were burned for illumination. Many parts of the plant including the seeds, leaves, flowers, and bark were used in traditional medicine. Caution is advised in using the plant medicinally or for consumption, as all parts of the tree are toxic. Dyes extracted from various plant parts were used to color tapa cloth and canoes, as well as in tattooing. Today, in addition to its traditional uses, kukui has found commercial uses, particularly in the cosmetics industry.

In urban areas, kukui makes a lovely shade tree or visual screen. In agricultural systems it can be integrated for use in windbreaks, shade, soil stabilization, and improved fallow. Kukui can regenerate and naturalize where planted, and it has been described as a moderate invader in certain areas. However, it is rarely considered invasive or problematic.

DISTRIBUTION

Native range

Kukui is native to Indo-Malaysia. It thrives in moist tropical regions up to 1200 m (3940 ft) elevation.

Current distribution

Kukui is today widespread throughout the tropics. It was introduced aboriginally throughout the Pacific islands and is now a common tree of the Pacific at elevations up to 700 m (2300 ft). In Hawai'i, kukui has naturalized in forests on all the main islands and is commonly found in cultivation. It is particularly at home in moderately moist valleys, where it has become a conspicuous part of the landscape.

Elsewhere in the Pacific, it is primarily found in cultivation in villages and plantations or in secondary growth following cultivation or along stream banks. The tree is also found in Puerto Rico, the Virgin Islands, Malagasy, Sri Lanka, southern India, Bangladesh, Brazil, the West Indies, and the Gulf Coast of the United States.

BOTANICAL DESCRIPTION

Preferred scientific name

Aleurites moluccana (L.) Willd.

Family Euphorbiaceae (spurge family)

Non-preferred scientific names

Synonyms no longer in use include:

Aleurites javanica Gand.
Aleurites remyi Sherff
Aleurites triloba Forster & Forster f.
Camirium moluccanum (L.) Ktze.
Croton moluccanus L.
Jatropha moluccana L.

Common names

Candlenut, candleberry, varnish tree, Indian or Belgaum walnut (English)

The roots of the Polynesian names below mean "light," referring to the ancient use of burning the nuts or oil extracted from the nuts to provide illumination:

'ama (Marquesas)
kukui, *kuikui* (Hawai'i)
lama (Samoa)
rama (Mangareva)
tahii, *tahiri*, *tiairi*, *ti'a'iri*, *tutui* (Moorea, French Polynesia)
tuitui (Mangaia [Cook Islands], Futuna, Makatea, Niue, Tonga, Tubuai, Uvea)
tutu'i, *ti'a'iri* (Society Islands)
tutui (Rimatara, Rurutu, Tahiti)

Other common names from the Pacific include:

lauci, *nggerenggere*, *sikeci*, *sikeli*, *sikethi*, *toto*, *tuitui*, *tutui*, *waiwai* (Fiji)
lumbang (Guam)
raguar (Caroline Islands)
sakan (Palau)
sakan, *shakan* (Pohnpei)

Names from other world regions include:

Left: Kukui often is found in the regrowth of abandoned agricultural sites, such as here in American Samoa. (pictured: Tuipuavai Tago) Right: The distinctive canopy often stands out in the landscape, such as here on the slopes of Waipi'o Valley, Hawai'i. PHOTOS: C. ELEVITCH

arbol llorón, *avellano*, *avellano criollo*, *nogal de la India*, *nuez* (Spanish)
bancoulier, *noyer de bancoul*, *noyer des Moluques*, *aleurites*, *noisette*, *noix*, *noyer*, *noyer des Indes* (French)
calumbàn, *noz da India* (Portuguese)
kamiri (Indonesian)
kandeltri (Bislama, Vanuatu)
Kerzennussbaum, *Lichtnussbaum* (German)
le noix de Bancoul (French, Vanuatu)
lèrit, *nwa*, *nwazèt* (Creole)
ragaur (Carolinian)
tung (trade name)

Size and form

Kukui is a large spreading tree that can reach 20 m (66 ft) in height and 0.9 m (3 ft) trunk diameter, although it typically reaches 10–15 m (33–50 ft) when growing in the open. Crooked trunks and irregular, wide, spreading or pendulous side branches are typical. In narrow valleys kukui usually has a branchless trunk and achieves its greatest height. Dense clusters of kukui are often seen in areas favorable to its growth, with the inner trees having tall trunks with relatively few side branches and trees on the edge having outer side branches and foliage often down to the ground.

Flowers

Kukui is monoecious (having both male and female flowers on the same plant). The greenish-white, fragrant flowers are arranged in a 10–15 cm (4–6 in) terminal panicled cyme, with many small male flowers surrounding the female flowers. The corolla is whitish with five free petals, dingy white to creamy in color, oblong in shape and up to 1.3 cm (0.5 in) in length. The ovary is pubescent, superior, and two-celled, each with one ovule. Staminate flowers are longer and thinner than pistillate flowers.

The plant typically flowers in the spring, although flowers can be found nearly any time of year in many areas.

Leaves

This tree is easily discernible by its very distinctive leaves, which are three- to five-nerved from the base, alternate, and simple, with entire, wavy margins. The leaf blades are 10–20 cm (4–8 in) long with two glands at the junction of the




Upper left: The scientific name for kukui, *Aleurites*, comes from the Greek word for "floury," referring to the dusted-flour appearance of young leaves and flower buds. Upper right: Trees often flower nearly continuously. Lower right: Ripe fruit in tree. Lower left: Bark is smooth and light gray in color, often with lichen growth in moist areas. PHOTOS: C. ELEVITCH

leaf base and petiole that secrete a sweetish sap. Leaves of young plants and those of the lower branches are three- to five-lobed with a rounded, heart-shaped base (subcordate), while the apex is acute (sharp). Younger leaves are usually simple and deltoid to ovate in shape. The upper surface of young leaves is whitish with a silvery gloss, becoming dark green with age. The underside is rusty stellate-pubescent when young (having a hairy glossy indument).

Fruit

The green to brownish fruit is a laterally compressed, ovoid to globose indehiscent drupe 5–6 cm (2–2.4 in) long by 5–7 cm (2–2.8 in) wide. It has also been described as being "round, hard apple-shaped" with fleshy to leathery husks. The nuts contain an oil similar to tung oil from *Aleurites fordii*.

Seeds

The seeds are contained within a hard, black, rough shell elliptical in shape and about 2.5–3.5 (1–1.4 in) cm long. The shells are similar in shape and texture to walnuts, although smaller and thicker. There are about 100–120 seeds (with shells on, but with husks removed) per kilogram (45–55 seeds/lb).

Similar species

Aleurites trisperma Blanco is a small tree similar to kukui (*A. moluccana*). Unlike kukui, *A. trisperma* has unlobed leaves and prominently ridged three-seeded fruits.

GENETICS

Variability

There is great variability in kukui, particularly in the leaves, which can vary tremendously in size, shape, color, and texture, even on a single tree. For example, leaves of young plants and of the lower branches are three- to five-lobed while older leaves and those of the upper branches are usually simple and deltoid to ovate in shape. Fruits can range in size up to 4 cm (1.6 in) in diameter.

Known varieties

The variety aulanii is named for small-fruited plants from Waipi'o Valley, Hawai'i (Wagner et al. 1999). The variety katoi (mango-leafed kukui) has "narrow, lanceolate leaves with lateral lobes obscure or absent" (Stuppy et al. undated). The remyi variety, also the probable result of aboriginal Hawaiian selection, has "lengthened, simple lanceolate leaves (with or without obscure lobes) or deeply lobed leaves with the lateral lobes very narrow and the terminal lobe much elongated," while a cultivar from New Caledonia has orbicular leaves (Stuppy et al. undated). A variety found in Vanuatu (Maewo) has seeds which can be eaten without any apparent toxic effect (Walter and Sam 2002).

Culturally important related species

In China, tung oil is produced from *Aleurites fordii* (Stone 1970). In Japan, *A. cordata* is used for the same purpose, while other related species are *A. montana* and *A. trisperma* (Anon. undated [2]).

ASSOCIATED PLANT SPECIES

As kukui is an aboriginal introduction to the Pacific islands, it is generally found in disturbed mesic (moderately moist) forest habitats. In Hawai'i, it is very conspicuous along stream valleys and ravines. However, it can also be found in association with native species. It is found in cultivated forest remnants in the Marquesas and other high volcanic islands of the Pacific.

Associated native species commonly found

On Mangaia (Cook Islands), kukui is found in "disturbed native" mixed-species forest dominated by the native tree species *Elaeocarpus floridanus* and *Hernandia moerenhoutiana* (Merlin 1991). Introduced species associated with kukui include *Cocos nucifera*, *Morinda citrifolia*, *Hibiscus tiliaceus*, and *Psidium guajava*.

In Pahole Gulch, O'ahu, Hawai'i, kukui is a dominant species in a forest composed of *Diospyros hillebrandii, D. sandwicensis*, *Pisonia umbellifera*, and *P. brunoniana* (Mueller-Dombois and Fosberg 1998). Kukui is also a dominant in non-native forests of the Pahole Gulch Natural Area, composed of *Syzygium cumini*, *Psidium* spp., *Schinus terebinthifolius*, and *Eucalyptus* (Mueller-Dombois and Fosberg 1998).

Hawaiian sayings (Pukui 1983)

He kumu kukui i he'e ka pīlali.
"A kukui tree oozing with gum."
(A prosperous person.)

Ka malu hālau loa o ke kukui.
"The long shelter of the kukui trees."
(A kukui grove shelters like a house.)

Pupuhi kukui—malino ke kai.
"Spewed kukui nuts—calm sea."
(Pour oil on troubled waters.)

On Moorea (Fr. Polynesia), kukui, *Hibiscus tiliaceus*, *Rhus taitensis*, and other trees are found on the sides of valleys. On rocky slopes, kukui is found in association with indigenous species such as *Pisonia umbellifera*, *Boehmeria virgata*, *Pandanus* sp., *Freycinetia impavida*, *Hernandia* sp., *Cyclophyllum barbatum*, *Macaranga* sp., *Weinmannia parviflora*, *Glocihdion* sp., *Neonauclea forsteri*, *Ixora moorensis*, and *Tarenna sambucina* (Mueller-Dombois and Fosberg 1998).

Species commonly associated as aboriginal introduction in Pacific islands

In Tahiti, kukui is found in the submontane rain and valley forests in association with native species along with breadfruit (*Artocarpus altilis*), mango (*Mangifera indica*), and coconut (*Cocos nucifera*) (Mueller-Dombois and Fosberg 1998).

In the Marquesas, this species is found in formerly cultivated valley bottomlands. The vegetation here has been described as a mesophytic (medium moisture) forest composed largely of food and other useful plants such as *Artocarpus*, *Annona*, *Ceiba*, *Cocos*, *Citrus*, *Coffea*, *Syzygium*, *Inga*, *Inocarpus*, *Mangifera*, *Pandanus*, *Persea*, *Psidium*, *Pometia*, and *Spondias* (Mueller-Dombois and Fosberg 1998, Decker 1992). On Eiao Island (Marquesas), kukui is found in the gulches with *Pisonia grandis*, *Hibiscus tiliaceus*, *Thespesia populnea*, *Dodonea viscosa*, and *Annona squamosa* (Mueller-Dombois and Fosberg 1998).

ENVIRONMENTAL PREFERENCES AND TOLERANCES

Climate

This species has a large geographical distribution. Climatically it is found in subtropical dry and wet climates and tropical very dry to wet forest climates. In Hawai'i, the species is found between 0 and 700 m (0–2300 ft) (Wagner et al. 1999). Near the equator, the tree is reported to grow on a variety of soils up to 2000 m (6560 ft), although it is more likely that it has an upper limit of about 1200 m (3940 ft).

Elevation range
0–700 m (0–2300 ft) (Hawai'i), but can grow up to 1200 m (3940 ft) closer to equator.

Mean annual rainfall
640–4290 mm (25–170 in) (mean of 14 cases, 1940 mm [76 in]) (Duke 1983)

Rainfall pattern
Kukui grows in climates with summer, winter, bimodal, and uniform rainfall patterns.

Dry season duration (consecutive months with <40 mm [1.6 in] rainfall)
3–5 months or longer, as the species is often found along streams that may have subsurface water even after longer dry spells

Mean annual temperature
19–27°C (66–81°F)

Mean maximum temperature of hottest month
26–30°C (79–86°F)

Mean minimum temperature of coldest month
8–13°C (46–55°F)

Minimum temperature tolerated
8°C (46°F) (estimate)

Soils
Said to occur on a variety of soils, including red loams, stony clay ground, sand, and limestone. As evidenced by its relative absence in Northern Guam (which is underlain by limestone), kukui does not seem to prefer alkaline soils. However, its presence on Mangaia, which has Makatea soils with some limestone, suggests a tolerance of neutral to slightly alkaline soils. The species is dominant on moist, well drained acidic soils (perhaps Inceptisols and Andosols) of the high volcanic islands of the Pacific Basin.

Soil texture
The tree prefers light and medium texture soils (sands, sandy loams, loams, and sandy clay loams).

Soil drainage
It requires free drainage.

Soil acidity
It grows in lightly acidic to alkaline soils (pH 5–8).

Special soil tolerances
Kukui tolerates infertile soils.

Tolerances

Drought
Kukui is quite drought tolerant once well established. However, it flourishes in moist environments.

Full sun
The tree prefers full sun and can grow as a pioneer species in open areas with suitable rainfall.

Shade
Kukui can grow in a modest amount of shade, up to 25%.

Fire
The species is probably intolerant of fire.

Frost
It is probably intolerant of frost, as it is generally confined to the lower slopes of pali (steep slopes) that do not experience frost (up to about 700 m [2300 ft] in Hawai'i).

Waterlogging
Although the species is an indicator of stream courses, it favors well drained, moist soils.

Salt spray
Kukui tolerates a modest amount of salt spray and is occasionally found growing near the coast.

Wind
It tolerates both steady and storm winds and makes a suitable windbreak tree, especially in a multi-row windbreak.

Abilities

Regenerate rapidly
The tree can grow well even on relatively poor sites, provided ample soil moisture is available, particularly during establishment.

Coppice
Kukui regrows very well even after severe pruning, although it has a tendency to die after two or more prunings

in quick succession.

Other

Kukui is known for its ability to grow well on slopes, even steep gulches and cliffs.

GROWTH AND DEVELOPMENT

There is little direct information on the growth and development of kukui. It is said that the tree is quick growing and readily colonizes disturbed gaps and forest margins. Given these characteristics, kukui probably has growth rates comparable to other common secondary forest tree species. The tree requires little attention once it is established.

Flowering and fruiting

Flowering and fruiting begins at 3–4 years old. In many places flowering and fruiting take place almost continuously, frequently with flowers and fruits of all stages of ripeness occurring on each tree.

Reaction to competition

Kukui can hold its own even in the presence of grasses and other herbaceous weeds.

PROPAGATION

Propagation of kukui seedlings is easily done by seed. Although the seeds can take up to 3–4 months to germinate, they are large and quickly grow into strong, stout seedlings ready for field planting. Seedlings are not finicky about growing location (tolerating sun or partial shade), nor do they require special growing medium or watering regimes. Due to the quick growth of germinating seeds into seedlings, seeds lend themselves to either being direct-seeded in the field or pregerminated in the nursery, then direct-seeded. Kukui can also be propagated by cuttings, but this is uncommon and may not yield a plant that grows as vigorously as a seedling.

Ripe fruit can often be collected from underneath the lower canopy (top), or seeds can be collected from the ground under trees with the husk already deteriorated (bottom). PHOTOS: C. ELEVITCH

Seed collection

Kukui flowers and fruits intermittently throughout the year. Mature fruits can be picked from the tree or collected from the ground.

Seed processing

If the fruits are fresh, they are allowed to decay a few days in a moist area, which facilitates peeling off the thick, leathery outer husk. This exposes the hard shell that encloses the seed. There are about 100–120 seeds per kg (45–55 seeds/lb) with husk removed and shells on. Typically, germination is about 80% over the course of several months.

To improve the germination rate, bad seeds can be floated off in water.

Seed storage

Seeds can be stored for several months when dried to 10–12% moisture content. Often seeds lying on the ground under trees are viable and can be used successfully.

Pre-planting treatments

Untreated seeds germinate in about 4 months. Sun warming of a moist medium is thought to hasten and improve germination. Cracking the seed coat (shell) and soaking overnight in water may also hasten germination. Fungi growing on the seed coat may become a problem for germinating seeds, so treating the seeds with a fungicide prior to sowing may be helpful in reducing fungal problems. Seed scarification with acid does not benefit germination.

Growing area

Kukui seeds can grow in moderate shade, but full sun also works and may hasten germination.

Germination

Seeds can be direct-seeded in containers or pregerminated in beds. When seeds are pregerminated in a bed, it is best to transplant the seeds just as they begin to germinate when the seed cracks open. Pregerminated seeds can either be planted in nursery containers or direct-sown in the field.

Media

Because kukui germinants have a large, thick taproot, it is recommended that seedlings are grown in 2–4 liter (1/2–1 gallon) root-training containers. Use a well drained potting medium such as 50% peat moss, 25% perlite, and 25% vermiculite, amended with a little compost, dolomite lime, gypsum, and 14–14–14 slow-release fertilizer. Potting media should also be inoculated with mycorrhizal fungi from a reputable commercial source, particularly if the trees will be planted in degraded soils.

Time to outplanting

After germination, plants are ready to be transplanted into the field after about 3–4 months.

Approximate size for outplanting

Trees are ready to outplant when they have attained a height of about 25 cm (10 in) and stem diameter of 12 mm (0.5 in).

Guidelines for outplanting

It has been reported that 200–300 seedlings are planted per hectare for oil seed production. In windbreaks, kukui can be planted 3–4 m (10–13 ft) apart in the row.

DISADVANTAGES

There are very few disadvantages to planting the widely adapted and multipurpose kukui tree. Perhaps the biggest commercial disadvantage is that no large markets exist for any kukui products. Also, it is so easy to grow in many environments that there is no clear commercial advantage to growing it in any specific place. For example, any kukui product that can be produced in Hawai‘i can be easily reproduced in other tropical regions where the costs of land and labor are cheaper.

Potential for invasiveness

Kukui has naturalized in several Pacific islands, particularly in Hawai‘i, and has the potential to become established outside of cultivation. Despite this, kukui is rarely considered a harmful invasive or pest species.

Susceptibility to pests/pathogens

The following fungi are known to attack kukui: *Cephalosporium* sp., *Clitocybe tabescens*, *Fomes hawaiensis*, *Gloeosporium aleuriticum*, *Physalospora rhodina*, *Polyporus gilvus*, *Pythium ultimum*, *Sclerotium rolfsii*, *Sphaeronema reinkingii*, *Trametes corrugata*, *Xylaria curta*, *Ustulina deusta*. Nematodes include *Meloidogyne* sp. (Duke 1983).

AGROFORESTRY/ENVIRONMENTAL PRACTICES

Mulch/organic matter

Kukui leaves make a good mulch. To preserve the health of the tree and encourage rapid regrowth, only a small percentage of the leaves (less than 20%) should be removed at any one time.

Soil stabilization

Kukui grows well on steep slopes and in gulches. Along with koa (*Acacia koa*), kukui was one of the first trees planted by the Hawai‘i Division of Forestry for watershed rehabilitation.

Crop shade/overstory

Although not considered overly competitive with other plants, kukui’s dense shade limits its use as shade for light-demanding crops.

Alley cropping

Although kukui will regrow after severe pruning, its moderate growth rate makes it unsuitable for frequent pruning for mulch in an alley cropping system.

Homegardens

Because of its usefulness and beauty, kukui is grown in homegardens throughout the Pacific and elsewhere in the tropics.

Living fences/visual screen/boundary markers

It is often used as a living fence or boundary marker in Tonga, Hawai'i, and elsewhere. Planted densely as a double row on 2 x 2 m (6.5 x 6.5 ft) or 3 x 3 m (10 x 10 ft) spacing, kukui makes a wonderful visual screen.

Windbreaks

Kukui makes a good windbreak component, particularly in a multi-row windbreak.

Ornamental

Kukui is widely used as an ornamental tree for its thick silvery-green foliage. This is perhaps its most common use in cultivation.

Kukui makes an excellent screen along roads and boundaries. Top: Privacy hedge along driveway. Bottom: Boundary hedge next to coffee plantation.
PHOTOS: C. ELEVITCH

USES AND PRODUCTS

With its innumerable uses, kukui was disseminated aboriginally throughout the Pacific islands. Virtually all parts of the tree—leaves, fruits, bark, wood, roots, sap, flowers, etc.—were useful for medicine, illumination, housing, dyes, food, ornamentation, and many other uses. Even today, many of kukui's traditional applications are still in use. During the 19th century kukui oil was a commercial export of Hawai'i, and it has recently been revitalized as a commercial product there and elsewhere in the Pacific.

Nut/seed

The raw seeds are toxic and have a strong purgative effect, but cooked seeds can be eaten sparingly, especially as a condiment. Some varieties, such one found in Vanuatu (Maewo), have no apparent toxic effect (Walter and Sam 2002).

Medicinal

Folk remedies are reported for general weakness due to stomach or bowel disorder in children, asthma, bad breath, skin sores or ulcers, "swollen womb," and rejuvenating the body after poisoning (Kaaiakamanu and Akina 1922). Kukui nut oil makes a strong laxative and is sometimes used like castor oil. The leaves have been used for poultices for deep contusions and swellings.

Flavoring/spice

Hawaiians have traditionally used the roasted, pounded kukui seed kernel mixed with salt and seaweed or chili peppers as a condiment called 'inamona.

> Kukui is the official tree of the State of Hawai‘i because of "the multiplicity of its uses to the ancient Hawaiians for light, fuel, medicine, dye, and ornament, as well as the distinctive beauty of its light-green foliage which embellishes many of the slopes of our beloved mountains." (Neal 1965)

Animal fodder

After removal of the oil, the remaining seed cake has been used for cattle fodder.

Timber

The wood is straw colored and very light weight (sp. gr. 0.35). Because it is not resistant to decay or insect attack, it is rarely utilized for timber. The wood is readily colonized by fungi and has been used successfully as a substrate for growing mushrooms, particularly the ear fungus (*Auricularia* sp.) known in Hawai‘i as pepeiao. After heavy rains, deadwood under kukui trees often has large quantities of edible fungus.

Fuelwood

The wood can be burned as a low-quality fuel.

Canoe/boat/raft making

The Hawaiians used the easily worked wood for short-lived, light-weight canoes and fishnet floats.

Rope/cordage/string

A bark infusion with water was used by Hawaiians to preserve fishnets.

Resin/gum/glue/latex

The whitish sap was painted on tapa cloth to make it more durable and waterproof.

Body ornamentation/garlands

The empty shells are strung to make a popular lei. The mature black seeds and immature white to brown seeds are commonly used in lei making, polished and unpolished. The shells, which can be polished to a high luster, are fashioned into earrings and other costume jewelry. The leaves with or without the flower clusters are woven into impressive leis.

Tannin/dye

Hawaiians used the seed husk to make a black dye for tattooing and the root bark to make a dye to paint canoes. The soot from burned seed kernels (traditionally used for illumination) is used for an indelible black dye in tattooing and tapa cloth, particularly in Samoa and Tonga (Whistler 1991).

Toxin/insecticide/fish poison

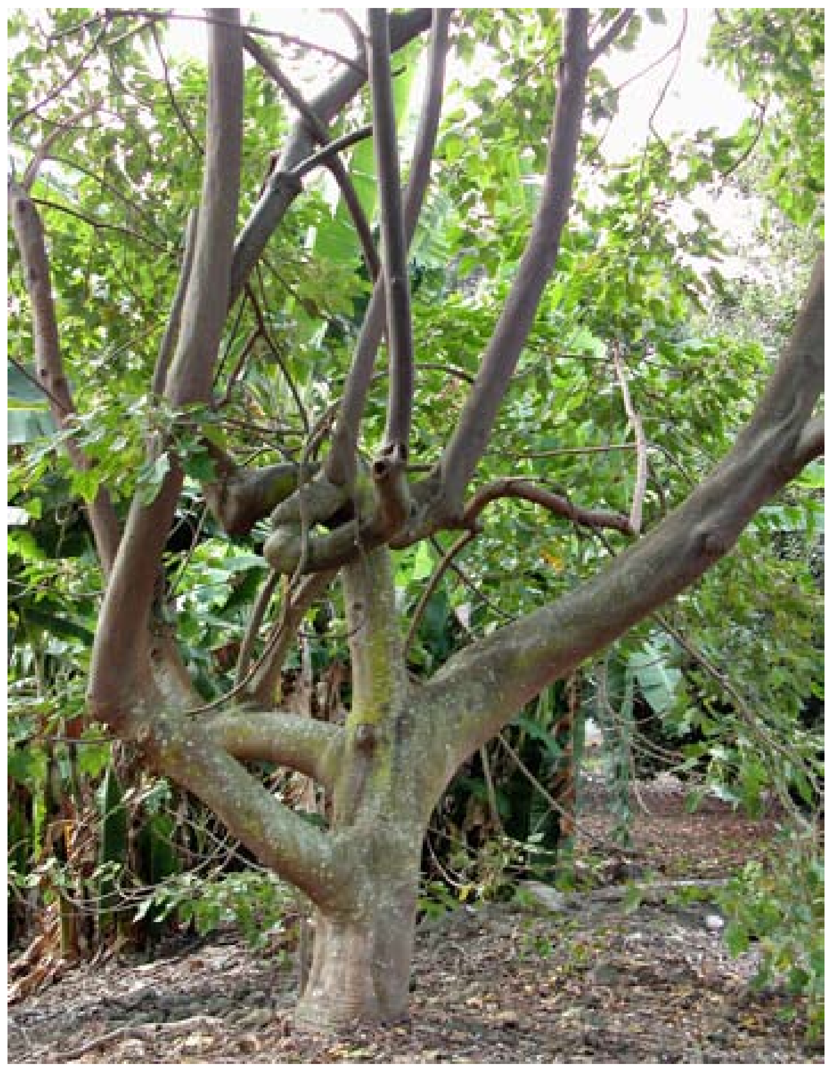
Kukui oil can protect cotton bolls from the boll weevil and prevent feeding by the striped cucumber beetle.

Cosmetic/soap/perfume

Oil extracted from the seed can be made into soap. Chewed seeds are used as a soap substitute. Refined kukui oil is today widely sold in the cosmetic industry and may currently be kukui's primary commercial product.

Fertilizer

After removal of the oil, the remaining seed cake has been used for fertilizer.



Due to its light weight, poor durability, and crooked form, the wood is rarely used for timber. PHOTO: C. ELEVITCH

Oil/lubricant

Oil extracted from the seeds was traditionally used by Hawaiians as a preservative for surfboards. The oil can also be used as a basis for paint or varnish, burned as an illuminant, made into soap, and used for waterproofing paper. Today kukui nut oil is marketed as a skin moisturizer and protectant. With chemical modification the oil can also be burned as fuel in diesel engines.

Illumination/torches

The oily kernels are dried and strung on a skewer such as a coconut leaf midrib. Each nut in the string burns for about 3 minutes and emits a somewhat fragrant smoke.

Ceremonial/religious importance

The likeness of a pig's head carved from kukui wood is set on an altar for the Hawaiian festival of Makahiki (Kamehameha Schools 1994).

Other

The seeds have been used as toys such as marbles and tops. The crushed seeds have been used mixed with other ingredients as fish bait (Abbot 1992).

URBAN AND COMMUNITY FORESTRY

Kukui is found in homegardens and community areas throughout the tropics. It has many traditional products for home use such as a condiment, medicines, dye, and utility wood. The tree is also highly prized for its amenity services including shade, living fence, and ornament.

Size in an urban environment

Kukui typically reaches 10–15 m (33–50 ft) tall with a broad canopy when grown in the open, with dense foliage often growing down to the ground. When grown in the shade of nearby trees, kukui grows more upright, with a dominant main stem and little side foliage. Trunk diameter at maturity can reach 1.5 m (5 ft). The tree tolerates pruning very well and can be controlled in size and shape as desired.

Rate of growth in a landscape

In favorable conditions young trees can grow 1–2

Top: The kukui kernel has numerous uses including medicine, condiment, and a basis for oil and soap. Bottom: The sap which wells up at the stem attachment just after harvesting young kukui fruits is used traditionally by Hawaiians to treat cuts and skin sores. PHOTOS: C. ELEVITCH m/yr (3.3–6.6 ft) in height. As trees grow older, the rate of growth declines.

Root system

There is no indication of the root system interfering with other plants, pipes, or structures.

Products commonly used in a Pacific island household

The flavorful but somewhat toxic kernels are consumed to varying degrees throughout the Pacific. In Hawai'i the seeds are traditionally roasted and crushed together with sea salt to prepare a condiment called 'inamona. The crushed, roasted kernel is frequently used in small quantities in Indonesian and Malaysian cuisine. In Samoa the kernels are eaten by children, although more than 2–3 kernels can cause nausea, vomiting, abdominal pains, or diarrhea.

Various parts of the plants are used in traditional medicine throughout Oceania (Thaman and Whistler 1996, Whistler 2000, Walter and Sam 2002). A black dye used to dye tapa cloth is made from the fruit, bark, or roots. Leaves, flowers, and seeds are used in making leis in Hawai'i. The leaves and young branches are considered to be an excellent mulch material and were formerly used to mulch taro in Hawai'i. Many more uses are listed in "Uses and products" above.

Light requirements

Kukui prefers full sun and grows more upright and spindly in partial shade.

Water/soil requirements

The tree grows in a wide variety of soils, including infertile soils. It requires free drainage.

Life span

There is no data available, but kukui trees are estimated to live 40–60 years.

Varieties favored for use in homegardens or public areas

There are many forms found regionally (see "Variability" above). These selections would be favored for home and village gardens.

Seasonality of leaf flush, flowering, fruiting

In optimal conditions with ample moisture available, leaf flush, flowering, and fruiting are nearly continuous.

Exceptional ornamental values

The silver-gray foliage stands out in the landscape. Kukui is also recognizable by its domed and dense canopy. Trees are often in flower; the white to cream-colored flowers are attractive and slightly fragrant.

Use as living fence, hedge or visual/noise barrier

Given ample sunlight and space, kukui's dense crown makes a very good visual barrier, particularly since foliage tends to extend down to the ground. A row of trees planted 3–5 m (10–16 ft) apart forms a solid canopy.

Birds/wildlife

Many types of birds find shelter in the kukui canopy.

Left: In open areas, the foliage usually extends down to the ground. Right: When pruned up, the area under the canopy makes a wonderful sitting area. PHOTOS: C. ELEVITCH

Maintenance requirements

Young seedlings benefit from regular weeding and irrigation if necessary. Once established, trees require little care. Kukui does not require fertilizer except in the most infertile soils. It tolerates drought but will grow best in consistently moist conditions. The dense canopy tends to suppress weed growth within the drip line. The tree regrows well after pruning. If desired, lower branches can be pruned up along the perimeter to open a view underneath the canopy. The tree can also be pollarded to control the height and canopy diameter (Salim et al. nd). In pollarding, a framework of several stems is formed at a desired height by pruning the tree during its early development. These stems are then pruned back heavily every 2–3 years.

Special considerations regarding leaf, branch, and fruit drop

Kukui holds its branches very well in normal conditions and even in storms. The ground beneath the trees is often covered with fruits and seeds.

Nuisance issues

None.

Hazards

Newly fallen fruits are hard and round, about the size of golf balls. They present a real danger on streets or sidewalks where people could easy slip on them.

Common pest problems

Pests or diseases rarely seriously affect kukui. There are no pests of economic importance (Siemonsma 1999).

COMMERCIAL CULTIVATION

The widespread cultivation of kukui has traditionally been for its many non-commercial uses. At one time the seed oil was used as a basis for varnishes and paint, although the oil derived from tung (*Aleurites fordii*) is superior for these uses. In more recent times, the primary commercial product derived from kukui is the oil extracted from the seed for the cosmetic industry. The oil is rich in polyunsaturated oils (linolenic, oleic, and various linoleic acids), and is said to have a high penetrability and soothing effect on dry or sunburned skin and other skin maladies such as psoriasis, acne, and eczema. Most oil produced in India, Sri Lanka, and other places is consumed locally and does not find its way into international trade.

Spacing

A suggested spacing for oil production is 200 trees/ha, which can be achieved with a spacing of about 7 x 7 m (23 x 23 ft) or 6 x 8 m (20 x 26 ft).

Management objectives and design considerations

Seeds can be harvested from the ground, although the heavy leaf mulch usually found under kukui trees hinders harvesting the fallen seeds. Picking seeds from the trees is often impractical due to the height and the difficulty of judging maturity of the ripening fruit. The propensity of kukui to grow well on steep slopes may be used to some advantage, as the large spherical fruits can roll to collection areas if designed properly.

Yields

For tropical plantations with trees spaced at 200 trees/ha (81 trees/acre), nut yields were reported as 80 kg/tree (176 lb/tree), or 16 mt/ha/yr (7.1 t/ac/yr), of which 3 mt (3.3 t) would be oil Given a spacing of 200 trees/ha and an expected yield of approximately 80 kg of seeds per tree per year, about 16 mt/ha/yr can be produced. About 20% of this yield can be extracted as oil, which is equivalent to 3.2 mt/ha (1.5 t/ac) of unrefined oil per year. The current retail value (year end 2003) of kukui nut oil is about $43/kg ($19.50/lb). This represents a considerable potential retail value per hectare for the processed oil, and an incentive to investigate value-added processing methods. The residues can be converted to alcohol. Fruit yields range between 4 and 20 mt/ha/yr (1.8–8.9 t/ac/yr) and an oil yield of 3100 kg/ha (2760 lb/ac) has been reported (suitable, with modification, for diesel uses) (Duke 1983).

On-farm processing methods

Removing the outer husk and drying to ca. 12–15% moisture should be carried out on-farm. This stabilizes the seeds (prevents fungal growth and insect infestation) and prepares them for pressing.

Markets

Kukui nut oil is marketed widely through health food stores and on the Internet. Market volumes are not known.

INTERPLANTING/FARM APPLICATIONS

Some interplanting systems include:

Example 1

Location

Keauhou, North Kona, Hawai‘i.

Description

This project is a 2.4 ha (6 ac) orchard planted in 1993. The elevation is 230 m (700 ft) and rainfall ca. 1040 mm (45 in) annually. The purpose is a visual screen.

Crop/tree interactions

The interior of the property was planted with avocados, mango, and sapodilla trees. The kukui afforded modest protection from the periodic storm winds.

Spacing/density of species

The outer boundary was planted with a double row of kukui trees 2.6 m (8 ft) apart within rows and 2.6 m (8 ft) between rows.

Example 2

Location

Located at the Moloka‘i Research and Demonstration Farm in the Ho‘olehua Ag Park, Moloka‘i, Hawai‘i. The project is planted on 0.15 ha (0.36 ac).

Description

This project is called, "A Demonstration of a Multi-Cropping System in Establishing and Producing Native Trees" (Arce 2003). Five rows of trees were planted in a north-south orientation with six kukui trees in each row. There is 4.6 m (15 ft) between rows to accommodate the tractor for mowing the area between rows. In addition to the growth rate of the kukui and other trees, the project measured the performance of understory crops such as alfalfa, ginger and anthuriums for cut flowers, kava, edible fungus, and cacao. Alfalfa was successfully grown during the early years, before the kukui trees shaded the surrounding area too much. Kukui's natural habit of dropping its branches and many falling nuts posed a hazard to understory crops such as the flowers. Ear fungus, a popular edible fungus known in Hawaiian as *pepeiao*, was introduced to kukui logs which were set in piles between the trees. Small amounts of edible fungus were produced, which could probably be increased by improved mycoculture techniques.

Spacing

Trees were planted at 3 m (10 ft) between trees, 4.6 m (15 ft) between rows.

Kali Arce shows her kukui trees in an agroforestry demonstration project in Ho‘olehua, Moloka‘i, Hawai‘i. PHOTO: J. B. FRIDAY

PUBLIC ASSISTANCE AND AGROFORESTRY EXTENSION

Extension offices for agroforestry and forestry in the Pacific: http://www.traditionaltree.org/extension.html

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Traditional Tree Initiative—Species Profiles for Pacific Island Agroforestry (www.traditionaltree.org)

Aleurites moluccana (kukui)

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Acknowledgments: The authors and publisher thank Kali Arce, Dale Evans, Heidi Johansen, Scott Peterson, Diane Ragone, Art Whistler, and Kim Wilkinson for their input. The photo contribution by J. B. Friday is greatly appreciated.

Recommended citation: Elevitch, C.R., and H.I. Manner. 2006. *Aleurites moluccana* (kukui), ver. 2.1. In: Elevitch, C.R. (ed.). Species Profiles for Pacific Island Agroforestry. Permanent Agriculture Resources (PAR), Hōlualoa, Hawai'i. <http://www.traditionaltree.org>.

Sponsors: Publication was made possible by generous support of the United States Department of Agriculture Western Region Sustainable Agriculture Research and Education (USDA-WSARE) Program; SPC/GTZ Pacific-German Regional Forestry Project; USDA Natural Resources Conservation Service (USDA NRCS); Kaulunani, an Urban Forestry Program of the DLNR Division of Forestry and Wildlife and the USDA Forest Service; State of Hawai'i Department of Land & Natural Resources Division of Forestry & Wildlife; USDA Forest Service Forest Lands Enhancement Program; and Muriel and Kent Lighter. This material is based upon work supported by the Cooperative State Research, Education, and Extension Service, U.S. Department of Agriculture, and Agricultural Experiment Station, Utah State University, under Cooperative Agreement 2002-47001-01327.

Series editor: Craig R. Elevitch

Publisher: Permanent Agriculture Resources (PAR), PO Box 428, Hōlualoa, Hawai'i 96725, USA; Tel: 808-324-4427; Fax: 808-324-4129; E-mail: par@agroforestry.net; Web: <http://www.agroforestry.net>. This institution is an equal opportunity provider.

April 2006
ver. 2.1

Alphitonia zizyphoides (toi)

Rhamnaceae (buckthorn family)

***doi*, *doi damu*, *doi selawa* (Fiji); *navasvas* (Vanuatu); *toi* (Samoa, Tonga, Wallis and Futuna, and Niue); *toi*, *manee* (French Polynesia)**

Lex A. J. Thomson and Randolph R. Thaman

IN BRIEF

Distribution Widely distributed and moderately common in the South Pacific islands.

Size Typically 20–25 m (66–82 ft) tall at maturity.

Habitat Tropical, humid, 1800–4000 mm (70–157 in) rainfall, lowland to lower montane forests, 5–700 m (16–2300 ft) elevation.

Vegetation Wide range of tree species of early successional forest.

Soils Very wide range of well drained soil types.

Growth rate On good sites, 2–3 m/yr (6.6–10 ft/yr) during the first 3–4 years, thereafter reducing to 1–2 m/yr (3.3–6.6 ft/yr).

Main agroforestry uses Improved fallow, windbreak, woodlot.

Main products Timber, fuelwood, and traditional medicine.

Yields Timber yields are estimated at 12–16 m^3/ha/yr (172–229 ft^3/ac/yr).

Intercropping Mainly occurs in such systems as a result of natural regeneration.

Invasive potential Potentially invasive outside of its natural range.

PHOTO: L. THOMSON

Natural regeneration of toi (about 2 years old) in mahogany trial plot, Shark Bay, Santo, Vanuatu. It has grown much faster than the planted mahogany and survived two cyclones.

INTRODUCTION

Toi (*Alphitonia zizyphoides*) is a fast growing tree to 20–30 m (66–100 ft) tall. It is native to the South Pacific region from Vanuatu to French Polynesia, where it occurs in lowland and lower montane forest associations, including secondary forests and the margins of closed forests. In these regions, annual rainfall is high, with a distinct summer wet season (November–April) and a cooler dry season (May–October). The species has a very wide edaphic range, with best development on fertile, well drained, medium-heavy, neutral, friable volcanic ash soils overlying limestone.

Locally it is valued in traditional medicines and for its wood, which is excellent for construction, including posts and rafters, for making canoes, and as a hot-burning fuel. It is very widely used in traditional medicine; the bark and bark sap are used to treat various diseases and ailments. Its leaves were formerly used as soap.

Toi is important ecologically as a component of secondary forest developing on disturbed sites, including abandoned garden places. The species has great potential for enrichment planting in fallow areas, and for agroforestry plantings. Its main drawbacks are its typically poor stem form in open-grown situations, its generally small size, and the low durability of its wood when in contact with the ground. It is likely to have a moderately high weed potential due to its pioneer characteristics.

DISTRIBUTION

Native range

The species is widely distributed and moderately common in the South Pacific islands, from Vanuatu in the west, through Fiji, Tonga, Wallis (ʻUvea) and Futuna, Samoa, American Samoa, Niue, Cook Islands to the Society Islands (French Polynesia) in the east. Toi mainly occurs in lowland and lower montane forest associations below 500 m (1640 ft) elevation.

It is found on most high islands and a few atolls throughout the Vanuatu, Fijian, Samoan, and Tongan archipelagoes: Aneityum, Tanna, Erromango, Efate, Paama, Malekula, Espiritu Santo, Pentecost, and the Banks Group (Vanuatu); Viti Levu, Vanua Levu, Taveuni, Ovalau, Kadavu, Beqa, Gau, Yasawa, and the Lau Group including Kabara, Lakeba, Moala, Totoya, Vanua Balavu (Fiji); Savaiʻi, Upolu, Tutuila (Samoa and American Samoa); Vavaʻu, Haʻapai group, Tongatapu, and ʻEua (Tonga). It is now rare but scattered on the Cook Islands, including on Mount Ikurangi (Rarotonga). It is unclear whether the species also occurs in the Solomon Islands.

Current distribution

The species is not known to have been planted outside of its native range.

BOTANICAL DESCRIPTION

Preferred scientific name

Alphitonia zizyphoides (Spreng.) A. Gray

Family

Rhamnaceae (buckthorn family)

The genus *Alphitonia* has not been assigned to any of the tribes of Rhamnaceae, because the relationship with other genera could not be resolved (Richardson 2000). Kellermann (2002) groups it with its most closely related taxon *Granitites intangendus* (F. Muell.) Rye into an "Alphitonioid Clade."

Non-preferred scientific names

Rhamnus zizyphoides Solander ex Forst. f.
Rhamnus zizyphoides Spreng.
Alphitonia excelsa (Fenzl) Benth.

Common names

doi (pronounced ndoi, main name in common use); *doi damu*, *doi selawa* (Fiji)
navasvas (Vanuatu)
toi (Samoa, Tonga, Wallis and Futuna, and Niue)
toi, *manee* (French Polynesia)

Other local names in Vanuatu include: *napoth* (Aneityum), *vilvile* and *nevilvil* (Banks), *aurie* and *vihumeri* (Santo), *neho* (Malekula), *dove* and *ondova* (Pentecost), *reha* (Paama), *nampou* (Erromango), *nafa* and *nahmah* (Tanna).

Size

A medium-sized to large tree, typically 20–25 m (66–82 ft) tall at maturity with a 10–15 m (33–49 ft) crown diameter, although there is an extreme height range of 3–30 m (10–100 ft) in different habitats. The diameter at breast height (dbh) is typically 30–50 cm (12–20 in) in mature specimens, but it can reach up to 65 cm (26 in) above buttresses. The average bole length is 10 m (33 ft), with a maximum of 18 m (59 ft). A stunted form reaching only 1–2 m (3.3–6.6 ft) in height has been reported from harsh sites in Niue. The related *A. franguloides*, which perhaps ought to be considered as a variant or subspecies of toi, develops into a large woody shrub to small tree from 0.5 to 20 m (1.5–66 ft) in height at maturity.

Left: Flowers and leaves, interior of Viti Levu, Fiji. Right: Fruits, Santo, Vanuatu. PHOTOS: L. THOMSON

Form

Canopy and bole form is highly variable depending on the site. In young specimens the crown is monopodial, with spirally arranged, horizontally held branches. In open situations the lower branches persist and canopy form is variable, with low, heavy, spreading branches. In more closely-grown forest situations the lower branches are shed and the bole form is good, reasonably straight, and cylindrical.

Flowers

The flowers are arranged in short, 3–10 cm (1.2–4 in) long, axillary/near-terminally positioned, flat-topped clusters. Individual flowers are bisexual, small, whitish/light green, fragrant, and arranged in fives. The calyx is about 5–6.5 mm (0.2–0.25 in) across. The sepals are light green with fine, silvery hairs, while the petals are white: both sepals and petals are about 2 mm (0.08 in) long. Flowers have been recorded throughout the year in Fiji, but the main season in Vanuatu is January–March. The age to first flowering is unknown but is expected to be 3–4 years.

Leaves

The leaves are simple, alternately arranged, oblong-ovate to lanceolate, 5–18 cm (2–7 in) long by 3–6.5 cm (1.2–2.6 in) wide, shiny dark-bright green on the upper surface, and tomentose light grayish-green below. There are 10–15 pairs of secondary nerves. The leaves are usually rounded at the base (whereas the related *A. franguloides* usually has an acute leaf base). The petioles (1.5–2.5 cm [0.6–1 in] long) are first covered with orange-brown hairs which later turn blackish-green. Specimens from the Cook Islands have more ovate leaves, whereas those from Samoa are more lanceolate.

Fruit

The fruit is a globose to broadly ovoid drupe about 6–9 mm (0.24–0.36 in) in diameter, with a conspicuous ring-like calyx scar; it turns from green to purplish green and then to brown-black at maturity. In fully mature fruits, the spongy exocarp/mesocarp flesh dries and falls away, exposing two arillate seeds, each enclosed by a hard case.

The age to first fruiting is about 4–5 years under good growing conditions. In Vanuatu, the main fruiting season is August–September, but fruits may be collected as early as June. In Samoa, fruits have been mainly collected in September, but some fruits may be collected throughout the year, with old fruits often persisting on the tree.

Seeds

The seeds are smooth, brown, flattened, and oval, about 4 mm (0.2 in) long, and more or less enclosed by a loose, reddish brown aril. The main mode of dissemination is by soft-beaked birds such as pigeons, doves, honeyeaters, silvereyes, and trillers.

Similar species

Alphitonia zizyphoides is part of a species complex that includes *A. excelsa* (Fenzl) Benth. (in Southeast Asia, PNG, and Australia), *A. franguloides* A. Gray (in Fiji), *A. marquesensis* F. Brown (in the Marquesas Islands, French Polynesia), and *A. ponderosa* Hillebr. (in Hawai'i). *A. zizyphoides* and these closely related species are considered by some botanists to represent a single highly variable taxon.

A. excelsa differs from *A. zizyphoides* in its leaf characteristics, including texture (thin compared with distinctly coriaceous or leathery), leaf-base (cuneate to somewhat narrowed compared with rounded-cordate), and shape (lanceolate-oblong to lanceolate compared with ovate-lanceolate).

A. franguloides is only recorded from higher elevation and drier habitats in Fiji. Its range in morphological characters overlaps those of *A. zizyphoides*, but the leaves and flower parts of *A. franguloides* are generally smaller (i.e., the leaf blade is 3–10 x 1.5–4 cm [1.2–4 x 0.6–1.6 in]) and the leaf blade is usually acute at the base.

A. marquesensis is endemic to the Marquesas Islands. It can be distinguished from *A. zizyphoides* by the obtuse subcordate leaf base, acute but not acuminate leaf apex, more persistent tomentum, and larger flowers.

A. ponderosa is a rare but broadly scattered Hawaiian endemic found in dry forests at lower elevation on the six main Hawaiian islands. It differs from *A. zizyphoides* in its larger, indehiscent (or slowly dehiscing) fruits 14–18 mm (0.6–0.7 in) in diameter.

GENETICS

Variability of species

The species displays moderately high levels of morphological variation for vegetative and floral characters. Smaller growing forms have been reported from Niue and Fiji (with the latter described as *A. franguloides*). The genetic structure of populations of the closely related *A. ponderosa* was examined by Kwon and Morden (2002).

Known varieties

No varieties or subspecies have been formally described.

ASSOCIATED PLANT SPECIES

Toi is a pioneer and early secondary species regenerating following disturbance in different forest associations. It is mainly found in secondary forest, but some large individuals can persist for many decades in closed forest types. It is also found in gardens, recently fallowed areas, and mature fallow forests and woodlands/savannas. In Fiji it is reported to be locally abundant in both dense and drier forest types, in scrub thickets, and on reed-covered hills. In the Society Islands it is mainly found in lower montane forests of medium stature.

Associated species commonly found

The species occurs with a wide range of tree species associated with early succession forest.

Vanuatu *Endospermum medullosum*, *Flueggea flexuosa*, *Macaranga* spp.

Fiji *Endospermum macrophylla*


Left: Seedling leaves, Santo, Vanuatu. Right: Seedling, Niue. PHOTOS: L. THOMSON

Tonga *Bischofia javanica*, *Calophyllum neo-ebudicum*, *Canarium harveyi*, *Dendrocnide harveyi*, *Dysoxylum tongense, Elaeocarpus tonganus*, *Elattostachys falcata*, *Fagraea berteroana*, *Ficus* spp., *Maniltoa grandifolia*, *Podocarpus pallidus*, *Pometia pinnata*, *Rhus taitensis*, *Santalum yasi*, *Syzygium dealatum*, and *Tarenna sambucina*.

Samoa *Adenanthera pavonina*, *Bischofia javanica*, *Cananga odorata*, *Dysoxylum* spp., *Elattostachys falcata, Garuga floribunda, Hibiscus tiliaceus, Macaranga stipulosa, Neonauclea forsteri, Rhus taitensis*, and *Terminalia richii*.

Society Islands (French Polynesia) *Hernandia moerenhoutiana*, *Metrosideros collina, Fagraea* spp., *Canthium* spp., and *Wikstroemia* sp.

Wallis and Futuna *Acalypha grandis, Cerbera manghas, Commersonia bartramia, Decaspermum fructicosum, Geniostoma rupestre, Hibiscus tiliaceus, Homolanthus nutans, Macaranga harveyana, Melastoma denticulatum,* and *Morinda citrifolia.*

ENVIRONMENTAL PREFERENCES AND TOLERANCES

Climate

The climate in its native habitats is tropical, lowland to lower montane, and humid. Tropical cyclones of varying intensity, including the most severe categories, occur at periodic intervals in most parts of its range, mainly from November to March. Temperatures are warm to hot throughout the year, and frosts are absent. Rain falls with a distinct summer maximum from November to April. The period from May to October is cooler and drier.

Elevation range

5–700 m (16–2300 ft)

Mean annual rainfall

1800–4000 mm (70–157 in)

Rainfall pattern

It grows in climates with a summer rainfall pattern.

Dry season duration (consecutive months with <40 mm [1.6 in] rainfall)

0–2 months

Mean annual temperature

24–26°C (75–79°F)

Mean maximum temperature of hottest month

29–32°C (84–90°F)

Mean minimum temperature of coldest month

17–24°C (63–75°F)

Minimum temperature tolerated

10°C (50°F)

Soils

The species has a very wide edaphic range, with best development on fertile, well drained, medium-heavy, neutral, friable volcanic ash soils overlying limestone.

Soil texture

Grows in light, medium, and heavy texture soils (sands, sandy loams, loams, sandy clay loams, clays, clay loams, and sandy clays).

Soil drainage

Toi requires free drainage.

Soil acidity

It prefers acid to neutral soils (pH 4.0–7.4).

Tolerances

Drought

It is likely that some populations that have evolved in tougher, lower-rainfall sites and on shallow soils will be tolerant of droughts lasting for several months.

Full sun

The tree is a pioneer species with most rapid growth in full sunlight.

Shade

All age classes grow best in full sunlight, and are tolerant of only light shade (e.g., up to 25% maximum)

Fire

No information available.

Frost

Likely to have limited or no frost tolerance (although the related *A. excelsa* is exposed to several light frosts per year in cooler parts of its Australian distribution).

Waterlogging

The species is not found naturally on waterlogged sites and accordingly is likely to have little tolerance of poor drainage.

Salt spray

It is sometimes found growing near to the sea (e.g., within

Mature specimen showing good self-pruning characteristics in closed forest situation, Niue. PHOTO: L. THOMSON

100 m [330 ft]), and is likely to have moderately high tolerance of salt spray.

Wind

In Vanuatu, both saplings and trees in open areas have been observed to have excellent tolerance of strong cyclonic winds.

Abilities

Regenerate rapidly

The species has the ability to regenerate rapidly on disturbed, open areas, growing quickly in the first few years.

Self-prune

Self-pruning varies with light regime. Trees growing in open areas or on the forest edge usually retain branches near ground level, and these become quite thick with age. In shaded situations and inside plantations the species has excellent self-pruning characteristics.

Coppice

Unknown, but the related *A. excelsa* coppiced poorly in trials in Queensland, Australia.

Pollard

The species is likely to pollard reasonably well.

GROWTH AND DEVELOPMENT

On good sites (fertile soils and high rainfall), toi displays rapid early height and diameter growth.

Growth rate

On good sites height growth rates can reach 2–3 m/yr (6.6–10 ft/yr) in the first 3–4 years, thereafter reducing to 1–2 m/yr (3.3–6.6 ft/yr). On less fertile soils and more exposed coastal sites early growth is about 1 m/yr (3.3 ft/yr). At 8–9 years, toi attained an average height of 16–20.6 m (52–68 ft) and dbh of 20.6–21.7 cm (8.1–8.5 in) with high survival (70–98%) in trial plantings at Shark Bay Research Station, Santo, Vanuatu (Smith 2004).

Yields

The yield of timber/wood is unknown, but is likely to be in the range 12–16 m^3/ha/yr (171.6 ft^3/ac/yr).

Rooting habit

The rooting habit is unknown, but a related species, *A. petriei,* is reported to have a well developed taproot.

PROPAGATION

The main method of propagation is nursery production of seedlings and transplanted wildlings. Cuttings of the closely related *A. excelsa* strike readily, suggesting that vegetative propagation may also provide a useful means of propagating selected germplasm of toi.

Seedlings

Seed collection

The mature dry fruits, with seeds showing, are collected from the tree canopy, typically in August–September. There are 8900 dry fruits per kg (4000 fruits/lb), with two seeds per fruit.

Seed storage

The seed is orthodox and may be successfully stored for many years in hermetically sealed containers under cool, dry conditions.

Seed pretreatment

Soaking in water for 12–24 hours is reported to improve the germination rate in older seed batches (e.g., more than 10 months old). For the closely related *A. ponderosa*, nicking or partial abrasion of the seed coat has been found to speed germination.

Growing area

Seeds may be sown in trays in a protected, well lit or sunny situation. They are covered with a thin (e.g., 2–3 mm [0.08-0.12 in]) layer of sand, loamy soil, or potting medium.

Germination

Germination may commence about 7–16 days after sowing, but some seedlots take several months to germinate. Seedlings should be pricked out and transplanted to individual containers at the cotyledon or four-leaf stage.

Media

Seedlings grow well in a well drained and fertile soil (e.g., loam) or potting media.

Time to outplanting

Seedlings are ready for outplanting after about 16–20 weeks in the nursery and when they are about 25 cm (10 in) tall, with basal stem diameter of about 4–5 mm (0.16–0.2 in).

Guidelines for outplanting

Very good growth (>2 m/yr [6.6 ft/yr]) and high survival (>95%) are expected from well hardened, healthy seedlings planted early in the wet season.

DISADVANTAGES

The main limitations for this species are poor stem form, heavy branching when planted in the open, the potential for weediness, and limited awareness and appreciation of the species in the timber and building industries.

Potential for invasiveness

The species is a potential invasive outside of its natural range. Given that members of the *A. excelsa* group, including *A. zizyphoides*, are widespread throughout the Pacific islands (and neighboring parts of Asia and Australia), there is an opportunity to plant it (or a very similar species) within its area of natural distribution and eliminate any potential hazard as an environmental weed.

Susceptibility to pests/pathogens

There are no records of pests and diseases causing serious damage to plants of toi. Plants frequently suffer minor damage from leaf-eating insects, and leaf-spot fungi may attack younger plants. Recorded diseases and pests include nematodes (*Ditylenchus* sp., *Helicotylenchus mucronatus*, *Meloidogyne* sp., *Paratylenchus tui* and *P. brachyurus*, *Radopholus similis*, *Xiphinema brevicolle*, *Xiphinema ensiculiferum*), arthropods (*Dysmicoccus nesophilus*, *Icerya seychellarum*), and fungi (*Mycovellosiella* sp.).

Host to crop pests/pathogens

It is not known to be a host of any agricultural crop pests or pathogens.

AGROFORESTRY/ENVIRONMENTAL PRACTICES

Mulch/organic matter

Toi has not explicitly been planted to provide mulch, but rapid growth, combined with a fairly quick turnover of leaves in the canopy, would suggest that it has good potential to build organic matter, especially if grown together with legumes.

Weed control

On Santo (Vanuatu), mature stands of toi established at closer spacings (e.g., 1000 stems per ha [405 stems/ac]) have greatly reduced or eliminated, presumably through shading, the rampant native big-leaf vine, *Merremia peltata*.

Crop shade/overstory

The tree casts an intermediate level of shade, which would be too heavy for most crop species but ideal for somewhat shade-tolerant crops such as cardamom, cocoa, coffee, *Morinda,* soursop, and *Xanthosoma.*

Alley cropping

Branches become heavy and wide spreading in open situations, and the species is considered unsuitable for alley cropping systems.

Homegardens

Toi is suitable for inclusion in homegardens, but it mainly occurs in such systems as a result of natural regeneration and not deliberate planting.

Improved fallows

The species has excellent potential for planting or inclusion in improved fallow systems due to its rapid regeneration and biomass production. Its presumed deep rooting habit would help facilitate cycling of mineral nutrients from lower soil profiles.

Living fences

The species is not known to be used for living fences and is not well suited to such a purpose due to its spreading habit (and inability to be grown from large branch cuttings).

Windbreaks

The species has good resistance to cyclones and would be well suited for inclusion as an upper-mid-level layer of mixed-species windbreaks of wide dimensions (e.g., greater than 50 m [164 ft] across).

Silvopasture

The species is likely to grow well in silvopastoral systems but would not have any specific advantages that would favor its use.

Animal fodder

The leaves and young shoots of closely related *Alphitonia* species are consumed by cattle but have been found to have low digestibility and nutritional status.

Woodlot

Toi has good potential for growing in larger woodlots, mainly for production of sawn wood, fuel wood, and traditional medicines. A disadvantage of cultivation in smaller woodlots would be the poor form of edge trees; for small woodlots a different species could be planted for the outer row(s).

Native animal/bird food

The fruits are especially attractive to fruit-eating birds, including pigeons.

Host plant trellising

The species is not planted to provide trellising support for climbing crops.

Bee forage

The related *A. excelsa* is reported to be a good source of nectar for bees.

Fish/marine food chain

The crushed leaves and fruits of the related *A. excelsa* were used as a fish poison by Australian aborigines.

Coastal protection

The species is not generally planted for coastal protection but could be used in mixed plantings for such purposes.

Ornamental

Toi is an attractive, fast-growing, and moderately long-lived tree with good ornamental potential.

Fuelwood plantation trial of toi, Santo, Vanuatu. PHOTO: L. THOMSON

USES AND PRODUCTS

Toi is a widespread, moderately abundant tree that is highly regarded as a source of timber, fuelwood, and traditional medicine, both in former times and today. The timber is used in house construction and for the manufacture of tools, weapons, and handicrafts. Toi is one of the premier fuelwoods of the Pacific islands; its habit of shedding dried, lateral branches provides a convenient source of high-quality fuelwood. It is one of the most important species in traditional medicine, and its bark is widely used in various herbal remedies, often in combination with other species, for treatment of a wide range of ailments. The leaves may be crushed and rubbed in water to provide a soap and shampoo, but this use has been largely supplanted in post-European times with the ready availability of soap and shampoo.

Medicinal

The bark is boiled, often along with the bark of other tree species, to produce a decoction for treating numerous ailments (including stomachaches, constipation, coughs, headaches, menstrual pain, prolapsed rectum in postpartum women). The sap is used to treat earache, swelling, fever, and cancer. A phenolic compound in the bark, alphitol, has been shown to have anti-inflammatory activity.

Bark, Santo, Vanuatu. PHOTO: L. THOMSON

Timber

The wood is used for house construction (including building members, posts, flooring moldings, and paneling) and furniture.

Fuelwood

The wood makes an excellent fuelwood and is a preferred species for such purposes. The naturally shed lateral branches are ideal for burning.

Craft wood/tools

Used throughout Polynesia to make tools (such as tapa mallets and digging sticks), tool handles, weapons (clubs and spears), and carved artifacts (including kava bowls).

Canoe/boat/raft making

The wood was used for making both canoes and canoe paddles.

Cosmetic/soap/perfume

The crushed leaves foam up in water and were commonly used as a soap. The leaves and flowers, together with those of *Colubrina asiatica* and *Citrus macroptera*, were used to make a shampoo in Samoa.

Other

Fruits of the closely related *A. excelsa* are reported to be eaten by Australian aborigines.

COMMERCIAL CULTIVATION

The species is mainly used in the local subsistence economy and is yet to be grown and traded on any large commercial scale. The three commercial products are timber, fuelwood, and bark.

Timber The species produces an attractive, reddish-brown, medium-density hardwood (air-dry density is 610 kg/m^3 [38 lb/ft^3]). The wood has good technical properties, and is easy to saw, finish, and season. The sapwood is immune to *Lyctus* attack, but the heartwood is not durable and is not recommended for use in high-decay situations, including ground contact.

Fuelwood The wood dries quickly and burns moderately quickly, producing good heat. Accordingly the branch wood (and trunk) is a highly preferred fuelwood. In some areas, such as on Santo in Vanuatu, the wood is collected, bundled and sold as fuelwood in local markets.

Bark The bark is cut and peeled from trees and commonly used in traditional medicines throughout it native range. In Tonga the bark is collected from trees on the outer islands, such as 'Eua, for supply and use in traditional medicines on Tongatapu (where the tree is now almost eliminated by overharvesting).

Spacing

For joint production of timber, fuelwood, and medicine, a close, initial spacing is recommended in order to encourage a straight bole form and self-pruning. The area required for semi-commercial production and local home use for timber, fuelwood, and medicine, would be 0.1–1 ha (0.25–2.5 ac). For larger scale commercial production of a general-purpose or utility sawn timber, a much larger plantation area of several hundred to several thousand hectares may be needed to supply a modern sawmill.

Management objectives

Weeding should be undertaken frequently, as needed, in the first 2 years prior to canopy closure. From about age 3–6 years, the smaller or misshapen trees could be commercially thinned to provide fuelwood and the bark stripped, dried, and used/sold for medicine.

Left: Toi plantation, Santo, Vanuatu, showing reasonably good bole form and self pruning of inner rows. Right: A volunteer toi in an agroforestry setting in Samoa growing among root, fruit tree, and timber crops. PHOTOS: L. THOMSON

Growing in polycultures

The species appears to grow well in monocultures. The form of border trees is poor and accordingly it is preferable to plant outside edges with a different species.

Estimated yield

The yield of timber/wood in both monoculture and mixed systems is unknown, but is likely to be in the range 12–16 m^3/ha/yr (172–229 ft^3/ac/yr).

INTERPLANTING/FARM APPLICATIONS

Example system

Location

Various islands of Vanuatu.

Description

In the traditional system of managed natural regeneration, the straightest and best-formed saplings are weeded to keep them free of climbers and occasionally high-pruned to produce clear boles.

Crop/tree interactions

Trees provide some shelter and protection for surrounding crops, including crops such as banana.

Spacing/density of species

Spacing is variable, with 5–50 trees per hectare (2–20 trees/ac).

PUBLIC ASSISTANCE AND AGROFORESTRY EXTENSION

Extension offices for agroforestry and forestry in the Pacific: http://www.traditionaltree.org/extension.html

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Alphitonia zizyphoides (toi)

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Acknowledgments: The authors and publisher thank Dale Evans, Jürgen Kellermann, and Art Whistler for their input.

Recommended citation: Thomson, L.A.J., and R.R. Thaman. 2006. *Alphitonia zizyphoides* (toi), ver. 2.1. In: Elevitch, C.R. (ed.). Species Profiles for Pacific Island Agroforestry. Permanent Agriculture Resources (PAR), Hōlualoa, Hawai'i. <http://www.traditionaltree.org>.

Sponsors: Publication was made possible by generous support of the United States Department of Agriculture Western Region Sustainable Agriculture Research and Education (USDA-WSARE) Program; SPC/GTZ Pacific-German Regional Forestry Project; USDA Natural Resources Conservation Service (USDA NRCS); State of Hawai'i Department of Land & Natural Resources Division of Forestry & Wildlife; and the USDA Forest Service Forest Lands Enhancement Program. This material is based upon work supported by the Cooperative State Research, Education, and Extension Service, U.S. Department of Agriculture, and Agricultural Experiment Station, Utah State University, under Cooperative Agreement 2002-47001-01327.

Series editor: Craig R. Elevitch

Publisher: Permanent Agriculture Resources (PAR), PO Box 428, Hōlualoa, Hawai'i 96725, USA; Tel: 808-324-4427; Fax: 808-324-4129; E-mail: par@agroforestry.net; Web: <http://www.agroforestry.net>. This institution is an equal opportunity provider.

August 2006
ver. 1.3

Areca catechu (betel nut palm)

Arecaceae (Arecoideae), palm family

betel nut palm, areca, areca-nut (English); *pugua* (Guam), *poc* (Pohnpei), *pu* (Chuuk), *bu* (Yap), *bua* (Palau), *buai* (New Ireland: Kuanua), *buei* (New Ireland: Pala), *vua* (New Ireland: Lamekot)

George W. Staples and Robert F. Bevacqua

IN BRIEF

Distribution Widely distributed in East Africa, South Asia, and Pacific islands.

Size Slender palm typically reaching 10–20 m (33–66 ft) tall; can reach 30 m (100 ft).

Habitat Tropical everwet climates with evenly distributed rainfall of 1500–5000 mm (60–200 in); prefers elevations 0–900 m (0–2950 ft).

Vegetation Generally found in cultivation together with other cultivated species or semi-wild together with wet climate flora.

Soils Adapted to a wide range of soil types, although thorough drainage and high moisture-holding capacity are required.

Growth rate Moderate, about 0.5 m/yr (20 in/yr).

Main agroforestry uses Crop shade, homegarden.

Main products Seeds (masticant).

Yields Kernel yield is estimated at 2.5–8 kg per palm (5.5–17.6 lb/palm) annually.

Intercropping Frequently grown together with short- and long-term crops.

Invasive potential Although it can spread by seed, it is not considered to be an invasive species.

PHOTO: M. MERLIN

Betel nut in homegarden near Angkor Wat, Cambodia.

INTRODUCTION

Betel nut (*Areca catechu*) is a slender, single-trunked palm that can grow to 30 m (100 ft). It is cultivated from East Africa and the Arabian Peninsula across tropical Asia and Indonesia to the central Pacific and New Guinea. The "nut" (actually the seed endosperm) is chewed as a stimulant masticatory by 5% of the world's population, making it more popular than chewing gum but not as popular as tobacco. Use of betel nut is often culturally or socially ritualized, and there are elaborate ceremonies attending its use in various Asian and Pacific cultures. At the same time, betel chewing is stigmatized by Western cultures that find the red saliva and blackened teeth resulting from regular use (not to mention the spitting out of the copious red saliva) to be esthetically disgusting.

In the Pacific, betel nut is grown for local consumption and is a significant item in intra- and interisland trade. Pacific-grown betel nut does not, however, reach the large markets of South Asia and for this reason could not be considered a commercial export of international importance.

Chewing betel nut is a popular pastime in some of the Pacific islands such as in Micronesia, Fiji, Solomon Islands, etc. It is an old tradition, enjoyed by islanders of both genders, that provides mild stimulation and a sweetening of the breath.

On the island of Guam, for example, betel nuts are typically gathered from semi-wild trees in ravine forests and distributed through extended families or sold in village stores. Commercial demand for the nuts is increasing as this traditional supply dwindles. This easily grown palm has the potential for being a profitable crop for farmers as well as backyard gardeners.

In India and Pakistan, by comparison, betel nut is consumed in quantities greater than local production can supply, and it is imported in large quantities annually. The annual commercial value (circa mid-1990s) was estimated in the hundreds of millions of dollars. The palms require an environment with evenly distributed rainfall (or irrigation), and even temperatures within 15.5–38°C (55–100°F). The palms are unable to withstand extreme temperatures or wide variance of daily temperature. Betel nut is now grown worldwide: where it is not used as a stimulant, the palms are grown as ornamentals. Although not recommended for use due to health risks, the plant nevertheless has a long history of cultural importance in many parts of the world, and this will likely continue.

DISTRIBUTION

Native range

Unknown in the wild, betel nut is a cultigen that exists only where humans grow it. An origin in the Philippines has been postulated. Many other areas have been suggested as the original homeland, including South or Southeast Asia.

Current distribution

From SE Asia, betel nut was distributed by indigenous peoples throughout tropical Asia as far as East Africa and the Pacific well before the arrival of Europeans in the region. The palm was distributed to the Pacific islands aboard sailing canoes by the prehistoric ancestors of the Micronesians who explored and settled the islands of the western Pacific.

Betel nut is today grown in East Africa, Madagascar, Arabian Peninsula, India, Sri Lanka, Bangladesh, Myanmar, Thailand, Cambodia, Laos, Vietnam, southern China, Malaysia, Indonesia, Taiwan, and the Philippines. In the Pacific Basin it is grown in Papua New Guinea, Solomon Islands, Fiji, Micronesia (Guam, Palau, Pohnpei, Saipan, Tinian, Rota, Chuuk, Yap), and Vanuatu. It can also be found on some atolls such as Mwoakilloa in Pohnpei State. In the CNMI it is also found on Pagan, Agrigan, Alamagan, and Anatahan. It has also been recorded as being present on Jaluit Atoll in the Marshall Islands. In Hawai'i it is grown mainly as an ornamental.

BOTANICAL DESCRIPTION

Preferred scientific name

Areca catechu Linnaeus

Family

Arecaceae (Palmae), palm family

Subfamily

Arecoideae

Non-preferred scientific names (synonyms)

Areca cathecu Burman, *Areca faufel* Gaertner, *Areca hortensis* Loureiro, *Areca himalayana* H. Wendland, *Areca nigra* H. Wendland

Common names

betel nut, areca, or areca-nut palm (English)
pugua (Guam)
poc (Pohnpei)
pu (Chuuk)

bu (Yap)
bua (Palau)
buai (New Ireland: Kuanua)
buei (New Ireland: Pala)
vua (New Ireland: Lamekot)
angiro (Solomon Islands: Kwar'ae)

Several of the common names in the Pacific are derived from the widespread pidgin English name *buai*.

Common names in other regions include:

arec cachou, *Arequier* (French)
Betelnusspalme (German)
boa (Bali)
boá, boñga, *buá, buñga*, *lúyos, takobtob* (Philippines)
palma catechou (Spanish)
pan (India)
puak (Sri Lanka)

Description

Betel nut is a slender, single-trunked, monoecious palm with a prominent crown shaft.

Size

The palm reaches a mature height of 10–20 m (33–66 ft) (exceptionally up to 30 m [100 ft]), with a trunk 25–40 cm (10–16 in) in diameter. Typhoons and tropical storms usually prevent the trees from reaching their maximum height. The canopy is typically 2.5–3 m (8–10 ft) in diameter and consists of 8–12 fronds.

Flowers

Flowers are unisexual, with both male (=staminate) and female (=pistillate) flowers borne in the same inflorescence. Inflorescences are crowded, much-branched panicles borne below the leaves. Each terminal branch has a few female flowers borne at the base and numerous male flowers extending from there out to the branch tip. Flowers of both sexes have six tepals, are stalkless (=sessile), creamy-white, fragrant; male flowers are minute, deciduous, have six stamens, arrowhead-shaped anthers, rudimentary ovary; female flowers are larger (1.2–2 cm [0.5–0.8 in] long), with six small sterile stamens and a three-celled ovary bearing a triangular stigma with three points at the apex.

Leaves

Fronds are even-pinnately compound, 1–1.5 m (3.3–5 ft) long; pinnae (leaflets) 30–50, lanceolate, 30–70 x 3–7 cm (12–28 x 1.2–2.8 in), longest near middle of frond; frond base sheathing, encircling trunk and forming a green crown shaft, ca. 55 x 15 cm (22 x 6 in).

Top: Inflorescence. PHOTO: M. MERLIN **Bottom: New inflorescence showing both female (large) and male (small) flower buds.** PHOTO: E. BURSON

Fruit

A fibrous, ovoid drupe, 5–10 x 3–5 cm (2–4 x 1.2–2 in), yellow to orange or red when ripe; pericarp fibrous, ca. 6 mm thick. Seed usually 1, ovoid, globose, or ellipsoidal, 3–4 x 2–4 cm (1.2–1.6 x 0.8–1.6 in), base sometimes flattened; endosperm ruminate (with hard reddish tissue from inner integument extending horizontally into pale brown endosperm); embryo conical, located at seed base.

How to distinguish from similar species/look-a-likes

Betel nut has a single, slender trunk, green aging to gray, with prominent white leaf scars, bright green crown shaft, pinnately compound fronds, and red-orange fruits.

The Chinese betel nut or Manila palm (*Veitchia merrillii*) is often confused with *Areca catechu*. The Chinese betel nut palm differs from *Areca catechu* in having a thicker trunk and dense clusters of bright red fruits. It is a popular landscaping tree and can be commonly seen in parks, along roadways, and in homegardens. The fruits can be used for chewing when ripe, although they are an inferior substitute for betel nut.

Characteristic leaf scars of betel nut palm trunk. PHOTO: C. ELEVITCH

Ripe fruits with U.S. quarter dollar for scale. PHOTO: R. BAK-

GENETICS

Variability of species

Betel nut shows considerable variation. Several botanical varieties have been described. No breeding work has been done to select for improved cultivated varieties.

Known varieties

In the Pacific islands, betel nut palms are grouped into two cultivars: red and white. In the Northern Marianna Islands and Guam, these two cultivars are called ugam (red) and changnga (or changan) (white). There are similar locally used vernacular names referring to variants in form, size, and color of the nuts throughout the area where betel nut is grown, but no formal cultivar nomenclature exists. The colors refer to the seed kernel colors. Red seed varies from red to deep purple in kernel color. White seed varies from off-white to deep tan kernel color. The roots of white types have a reddish/pinkish tinge beneath the inner root bark. The red is preferred for chewing and commands a higher price in the market. The white is much less desirable. The red and white seeds come from seemingly identical trees, i.e., except for differences in the seed kernel and root sap colors, it is virtually impossible to distinguish between the two types. Growers considering planting of betel nuts for should plant seeds from confirmed red types.

Culturally important related species in the genus

There are more than 50 species of *Areca,* and some produce useful products such as edible palm cabbage, and a number of species are horticulturally valuable. The seeds of many other palms, including at least eight species of *Areca,* are used as inferior substitutes for *Areca catechu*. No other culturally significant species are known in the genus *Areca.*

Genetic resources where collections exist

"The Regional Station of the Central Plantation Crops Institute, Vittal, India, maintains a germplasm collection of *A. catechu* and related species from within the country as well as from Sri Lanka, southern China, Thailand, Malaysia, Singapore, Indonesia, the Philippines, Fiji, Solomon Islands, and Mauritius. Sixteen exotic accessions have been evaluated for yield in a long-term comparative trial, from which three accessions with high yield potential were released. None of the available cultivars has shown tolerance of yellow leaf disease, which makes identification of disease-tolerant genotypes a priority." (Brotonegro et al. 2000).

No germplasm collections have been established for betel nut palm in the Pacific. Little selection or improvement work has been documented. The palms are open-pollinated and rather variable, with most growers selecting seed from trees with desirable qualities for propagation purposes. Efforts at interspecific hybridization (*A. catechu* × *A. triandra*) failed because the hybrid progeny were sterile and it proved impossible to establish forms with desired characteristics of both parent species.

Associated plant species

Betel nut palm was introduced to the Pacific before the advent of Europeans. It is grown around homesteads and farms or in plantations where it is associated with other cultivated plants or those typically found in disturbed sites.

A very important associated species is betel pepper vine (*Piper betle*), which is grown for its leaves. The leaves of the betel vine are used as the wrapper when preparing a quid of betel nut with lime, tobacco, or other ingredients.

ENVIRONMENTAL PREFERENCES AND TOLERANCES

Climate

Betel nut palm is ideally suited for tropical everwet climates (humid tropical lowland, maritime tropical, subtropical wet, tropical wet forest) with high rainfall that is evenly distributed throughout the year. In areas with a seasonal dry period, irrigation must be provided to assure evenly distributed moisture year-round. These palms are unable to

Leaves of betel vine (*Piper betle*). PHOTO: C. ELEVITCH

withstand extreme temperatures or a wide variance of daily temperatures. They thrive best at low altitudes; above 900 m (2950 ft), flowering and fruit production are adversely affected.

Elevation range

0–900 m (0–2950 ft)

Mean annual rainfall

1500–5000 mm (60–200 in)

Rainfall pattern

It prefers uniform distribution of rainfall throughout the year.

Dry season duration (consecutive months with <40 mm [1.6 in] rainfall)

None, it requires uniform moisture year-round.

Mean annual temperature

21–28°C (70–82°F)

Mean maximum temperature of hottest month

38°C (100°F)

Mean minimum temperature of coldest month

16°C (60°F)

Minimum temperature tolerated

Unknown, very cold sensitive

Soils

Betel nut palm grows in many types of soils varying in texture from laterite to loamy, provided the soil has thorough drainage, yet has the ability to retain optimum moisture. It thrives on deep (3 m [10 ft]) clay loams, often in valley bottoms where topsoil accumulates along water courses. Light and sandy soils are unsuitable unless copiously irrigated and manured.

In the Pacific islands, the palm does best in volcanic clays but can also be grown in coralline soils. Natural fertility is not a critical factor. More important is the soil's capacity for thorough drainage during the wet season. The most desirable soils are rich in organic matter.

On Mwoakilloa Atoll, the species is grown in sands heavily mulched with organic matter.

Soil texture

Betel nut palm prefers soils with medium texture, loams and sandy clay loams.

Soil drainage

Thorough drainage with high moisture retention is essential.

Soil acidity

Betel nut palm thrives in a pH range of 5.0–8.0 (mildly acidic to weakly alkaline).

Other soil tolerances

In the Northern Marianna Islands (Saipan, Tinian) betel nut palm is grown in soils as shallow as 30–60 cm (1–2 ft) deep, over solid limestone. While not ideal for growth and nut production, trees will grow and bear if the grower provides adequate moisture, fertilizer, and spacing.

Tolerances

Drought

Betel nut has poor drought tolerance.

Full sun

The palm requires full sun once out of the juvenile phase.

Shade

Seedlings require 50% or more shade to protect from sunburn. Juvenile palms are often planted out under bananas, which provide sun protection until the palms grow taller than the bananas.

Waterlogging

Despite a strong ecological preference for moist to wet environments, betel nut palm does not tolerate waterlogged soils.

Salt spray

Betel nut is not salt tolerant.

Wind

It has low tolerance for wind.

Abilities

Self-prune

Mature fronds are shed after 2 years; betel nut palm is considered a "self-pruning" palm species.

Coppice

Palms are incapable of regeneration: if the terminal bud is cut off, the palm dies.

GROWTH AND DEVELOPMENT

Germination is complete by 90 days after planting seeds; at this time seedlings have the first bifid (forked) leaf and five roots. A 1-year-old seedling has 4 or 5 leaves. Growth rates vary, and it requires 3–24 months (rarely up to 4 years) before seedlings are ready to transplant to nursery beds. A trunk is formed in the third year. An adult palm produces about six new leaves per year, carries a crown of 8–12 leaves, and drops a mature leaf after a life span of about 2 years. The rate of growth in height is about 0.5 m/yr (20 in/yr). The life span of a betel nut palm is 60–100 years.

Flowering and fruiting

Flowering begins at 4–6 years of age; trees begin to bear at 7–8 years, reach full bearing at 10–15 years, continue to yield until ca. 40 years, then persist in a sterile state until death. The first inflorescences may contain only male flowers and consequently do not produce nuts. A mature tree in full bearing can have inflorescences containing up to 644 female and 15–48,000 male flowers (Murthy 1977). The male flowers open first. Their sweet scent attracts honeybees and other insects, but these insects do not frequent the female flowers and thus their role as pollinators is doubtful. Several days after the last male flower is shed, the female flowers open. They are fertilized by pollen that is wind-transported from neighboring trees.

Seasonality of flowering depends on location: in Malesia the palms flower year-round; in India they flower November–February. No data are recorded on seasonality of flowering in the Pacific.

Rooting habit

The root system is dense, fibrous, with most roots concentrated in a 1 m (3.3 ft) radius from the trunk and in the top 60 cm (2 ft) of soil. Primary roots are ca. 1.4 cm (0.6 in) in diameter, turning dark brown with age, and branch to give secondary and tertiary roots. Root hairs are absent; absorption takes place through thin-walled cells behind the root cap. Aerial (adventitious) roots are occasionally produced from the base of the trunk. In plantation culture adventitious ("prop") roots are encouraged by deep-planting seedlings (90 cm [3 ft] below ground level), then gradually adding earth around the base of the palm, inducing root formation at the buried nodes.

Reaction to competition

Newly-planted trees compete poorly with weeds. For this reason, early weed management is extremely important in establishing new plantings.

PROPAGATION

Betel nut palm is only propagated by seed, and while the same basic requirements are involved, the methods depend on the number of palms desired. Large plantations of betel nut palm are grown in India and Taiwan, where mother tree and seed selection are apt to be practiced, and mass propagation is organized. Carefully selected seeds are planted in shaded beds or pits until they germinate, then seedlings are transplanted to nursery areas for growing on. Seedlings with five or more leaves are planted out at an age of 12–24 months. Seedlings require shade initially, so intercropping with banana or other crops is often practiced.

In Indonesia, Malaysia, SE Asia, the Philippines (and presumably most Pacific islands), betel nut is most often cultivated around homesteads in field borders and along irrigation channels. In Indonesia, villagers often collect volunteer seedlings from fruits dropped by bats and squirrels or by digging and transplanting seedlings from around established trees. The same practices may be followed by Pacific islanders growing betel nut palm for home consumption.

Propagation by seed

Seed collection

Betel nut palms are always propagated from mature fruits. The best seed comes from healthy trees with a history of producing desirable nuts. Only the largest, fully-ripened fruits should be planted. It is best to cut open several kernels (endosperm of the seed) to ensure they possess the red flesh preferred for chewing.

Fruits are harvested when bright red or yellow to yellow orange in some regions (such as Guam). Fruits are harvested either by climbing the tree and cutting the fruit cluster off, or by using a long bamboo pole with a sharp knife attached. Fully mature, heavy fruits that float vertically in water with the calyx end upward give a high germination rate and vigorous seedlings. In places where selection is practiced, the choice of mother tree is believed critical, criteria of importance are early and regular bearing, large number of leaves in the crown, short internodes in the trunk, and high fruit set. In Saipan it is critical to avoid mother trees that show any symptoms of bacterial or viral diseases; these can be passed on to offspring through propagation. In southern India and Malaysia, fruits are gathered from 25–30-year-old trees. In some cases the middle bunch of fruits is chosen for seed; in other cases the last bunch of the season is preferred.

Seed processing

Mature seeds of betel nut palm are sown as whole fruits. In some places the whole fruit is planted immediately after harvesting; in others the fruit is dried in sun for 1–2 days; in others the fruits are dried in shade for 3–7 days.

Seed storage

Like many tropical species, betel nut palm seed cannot be stored for more than a few days without losing viability. Planting within 7 days after harvest is the norm.

Pre-planting treatments

No pre-planting treatment is practiced. Fruits are planted whole, with the husk. Drying fruits before planting does not increase seed germination rates. There is no mention in the literature of scarification, hormone treatments, or fungicide use.

Growing area

Betel nut palm is rarely direct-seeded in the ground. The normal practice is to sow seeds in shaded germination areas, then transplant the germinated seedlings into nurseries for 1–2(–4) years before final planting out in the field. Seeds may be sown in groups of 20–50 in shallow pits, 2.5 cm (1 in) apart and covered with sand; in rows 15–22 cm (6–9 in) apart; or tied up in plantain leaves in rich moist soil and germinated.

In Saipan and Tinian the recommended technique is to sow seed in flat boxes sandwiched between layers of coconut husk with daily watering. Once seedling leaves appear above the husk medium, transplant into individual plastic bags using potting soil as a medium. Nursery areas are often located under established bananas, which shade the betel nut seedlings.

Germination

Germination is completed about 90 days after sowing, at which time the seedlings have one bifid (forked) leaf and five roots. The germination rate is usually over 90%.

Left: Seedlings of betel nut palm from Pohnpei Island, Micronesia. Right: Seedlings of betel nut palm with mature betel palms in background, India. PHOTOS: M. MERLIN

Media/containers

Seeds may be sown in sand, coconut husk, or rich moist soil. When planted individually or in small groups, containers made from plantain leaf or plastic bags are used. When mass-sown, beds or pits dug in the ground are more efficient. Seedlings are transplanted after sprouting into nursery beds or individual gallon plastic bags, in soil. Nursery beds are typically 30 x 30 cm (12 x 12 in) wide with three rows per bed.

Time to outplanting

Growth rates of seedlings are variable. Transplanting from nursery bed to field typically takes place at 1–2 years (although this ranges from 3 months to 4 years). Seedlings should be selected for quick germination and vigor; it is best to cull out slow-growing seedlings.

Approximate size at time of outplanting

Seedlings should bear five leaves at the time they are planted out in the field; no trunk is present at this early stage. A ball of earth around the roots is transplanted from nursery bed to field.

Other comments on propagation

Nursery beds may be located under banana, which shade seedlings until they reach a size suitable for planting out. Newly established beds are mulched with leaves, cattle manure, wood ashes, or groundnut (peanut) cake. Likewise in the field, intercropping with banana (or other crops) provides shade; otherwise coconut palm fronds are propped up around the seedlings to protect from sun scorch until they are established. Volunteer seedlings, if available, can be carefully transplanted.

Guidelines for outplanting

At 12–18 months of age, seedlings are transplanted into the field at the start of the wet season. The hole should be at least 50 cm (18 in) deep and 50 cm (18 in) wide. The bottom portion of the hole should be filled with a mixture of 2.3–4.6 kg (5–10 lb) of organic matter in the form of compost or composted chicken manure, one-half pound of fertilizer rich in phosphorus, such as 10:30:10, and top soil. Deep-planting seedlings—at a depth of 90 cm (3 ft)—allows for gradual piling of earth around the trunk base; the covered nodes produce adventitious roots resulting in firmer anchorage and larger root volume.

The desired spacing between palms is 2.7 x 2.7 m (9 x 9 ft) (Bhat 1978) or 2.4 x 3 m (8 x 10 ft) (Shetty 1949). These spacings will result in 1130–1350 palms/ha (538–545 palms/ac). Proper spacing is important, as it allows air circulation between trees, which discourages diseases which can attack the emerging flowers or developing fruits. Young plantings require regular weeding and mulching as well as fertilization with organic matter, compost, or cattle manure. Outplanting is carried out in the rainy season unless irrigation is available to assure a steady water supply during establishment. In windy areas, windbreaks should be planted along orchard boundaries to minimize wind damage and sun scorch.

DISADVANTAGES

Betel nut use as a stimulant presents significant health risks. Growing betel nut as a cash crop instead of food or other commercial crops has been criticized. There are significant problems in matching supply and demand: the greatest consumption of betel nut occurs in India and Pakistan, which are net importers of fresh and processed nuts. Pacific growers have no ready access to this market and probably they cannot fill their own domestic or regional demand.

Potential for invasiveness

Betel nut is not invasive, although it is often spontaneous and occurs in secondary forests, but never far from cultivation or sites where the palms were formerly cultivated. In Sri Lanka it persists in moist valleys near former habitations, where it forms naturalized groves. It does not spread readily, likely due to lack of a suitable dispersal agent for the large fruits and seeds.

Susceptibility to pests/pathogens

Yield is directly linked to the health and number of female flowers. These flowers are very susceptible to insect pests and diseases. The delicate flowers and newly forming fruits are most susceptible in the weeks following pollination. Growers are encouraged to regularly survey emerging flower clusters and to identify the pests and pathogens that threaten them. Minor threats can be tolerated, but serious threats may require the application of insecticides and fungicides.

The two most serious fungal diseases are *Phytophthora arecae* (or *P. omnivorum* var. *arecae*, Koleroga disease, a fruit rot), and *Ganoderma lucidum* (foot rot). Other fungal diseases include *Alternaria tenuis*, *Aspergillus niger arecae*, *Botryodiplodia theobromae*, *Brachysporum arecae*, *Ceratostomella paradoza*, *Colletotrichum acutatum (=C. catechu*, anthracnose), *Coniothyrium arecae*, *Dendryphium catechu*, *Exosporium arecae*, *Gloeosporium catechu*, *Lenzites striata*, *Lichenophoma arecae*, *Melanocomium palmarum*, *Montagnellina catechu*, *Mycosphaerella* sp., *Nigrospora sphaerica*, *Phomopsis* sp., *Phyllosticta arecae*, *Polyporus ostreiformis*, *P. zonalis*, *Stagonospora arecae*, *Theilaviopsis paradoxa*, *Torula herbarum*, *Ustulina zonata.* The bacterium *Xanthsomas vasculorum* attacks betel nut palm. Nematodes that attack betel nut include *Rotylenchus* sp., *Tylenchorhynchus dactylarus*, *Tylenchus* sp., and *Xiphinema insigne.* Insect pests include *Orcytes rhinoceros* (rhinoceros beetle), *Nephantis serinapa* (leaf-eating caterpillar), *Arceerns fasciculatus* (borer), *Rhabdoscelus obscurus* (New Guinea sugarcane borer), *Aspidiotus destructor* (coconut scale), spiraling whitefly, coconut hispine beetle or brontispa beetle, caseworm or bagworm, mealybugs; white ants and mites cause minor damage.

Host to crop pests/pathogens

Several pests of betel nut palm also attack other crop plants, among them coconut rhinoceros beetle (affects coconut palm, date palm, sago palm), coconut scale (banana, papaya, guava, avocado, cacao, cassava, tea, breadfruit, sugarcane, cotton, rubber), and New Guinea sugarcane weevil (sugarcane, coconut, papaya).

Other disadvantages

Heavy use of betel among humans causes serious health problems including permanent discoloration of the teeth, oral leucoplakia, submucous fibrosis, and squamous cell carcinoma (Norton 1997).

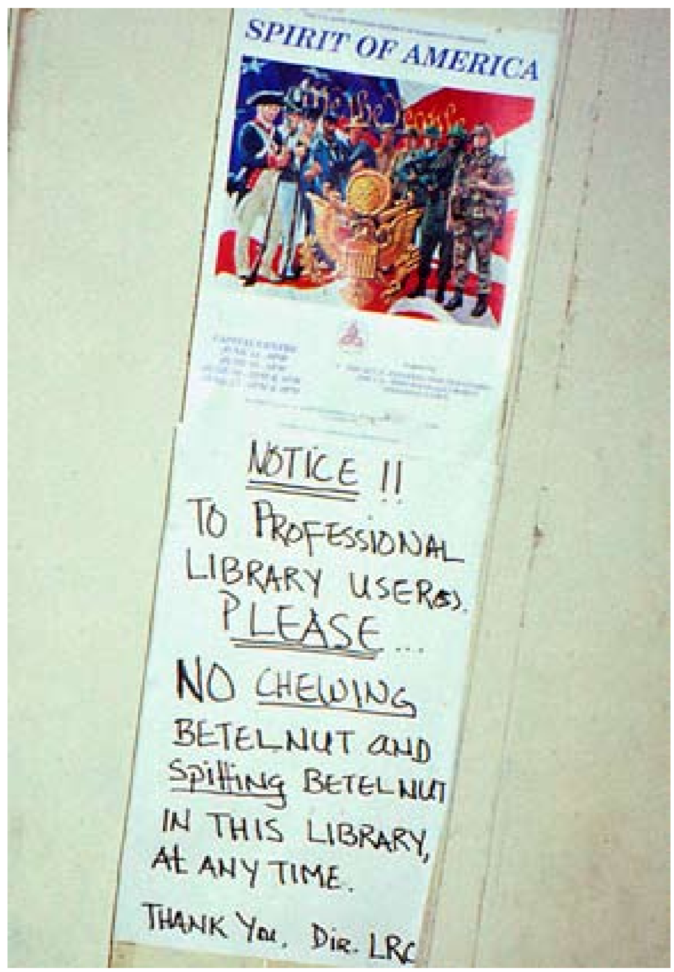
AGROFORESTRY/ENVIRONMENTAL PRACTICES

Mulch/organic matter

In Taiwan fallen, dried fronds and flower spathes are burned in the margin of plantations, where the ashes renew the soil.

Pest control

Betel nut is used as a vermifuge in humans and animals.



Library sign, College of Micronesia Library, Pohnpei. PHOTO: M. MERLIN

Crop shade/overstory

A variety of crops are grown under betel nut palm: annuals and biennials in short-term rotation; cardamom, cacao, banana, and fruit trees in permanent rows between palms. It is customary to interplant betel nut seedlings among 20-year-old palms so that a new generation will replace older palms as they stop bearing; if this practice is repeated several times without thinning, an old plantation may contain as many as 2500 palms/ha (1000 palms/ac).

Homegardens

In many parts of the world betel nut palm is planted around homesteads for home consumption of nuts. It is often interplanted with fruit trees at the margins of fields and along paths and irrigation channels.

Boundary markers

In Sri Lanka betel nut palms are often grown as boundary markers.

Animal fodder

Grasses (e.g., Guinea grass [*Panicum maximum*]) are sometimes interplanted with betel nut palm for animal fodder.

Woodlot

Thinning old betel nut palms provides a source of trunks for fuel and for crude construction.

Host plant trellising

Black pepper (*Piper nigrum*) or betel pepper (*P. betle*) vines are often trained on the trunks of betel nut palms in India.

Bee forage

The male flowers are visited by bees.

Ornamental

In southernmost Florida, Hawai'i, and many tropical places the palms are grown as ornamentals.

Left: Betel nut palms serving as trellis for *Piper betle*. Betel nut palm research center in Kerala, India. PHOTO: M. MERLIN **Right: Young palms growing on the border of a vegetable garden. Kona, Hawai'i.** PHOTO: C. ELEVITCH

USES AND PRODUCTS

Betel nut palm yields diverse products that are used throughout its range. In addition to the well known stimulant properties, the seed is used medicinally in numerous internal and external preparations. The husks, shoots, buds, leaves, and roots also have local medicinal uses. The fibrous fruit husks stripped from the seed have many uses, including as a home fuel source. The trunks of culled trees are used for crude construction; the fallen fronds are used in making alcohol; the spathes and leaf sheaths are used in wrapping, packing, and as hats and sandals. The inflorescences and flowers are used ceremonially in diverse cultures.

Nut/seed

This provides, fresh or dried, ripe or unripe, the betel nut that is chewed as a stimulant narcotic. Betel nut is commercially important in South Asia and locally important in the Pacific and many other tropical Old World areas.

Leaf vegetable

The terminal bud (palm cabbage or palm heart) is edible, although bitter. In Java it is eaten as lalab or made into pickles. In the Philippines the cabbage is eaten raw as salad, or cooked. The tender shoots are eaten after cooking in syrup.

Other vegetable

In the Philippines the flowers are sometimes added to salads.

Medicinal

The nuts, husks, young shoots, buds, leaves, and roots are used in various medicinal preparations.

Masticant/stimulant

The fresh or dried endosperm of the seed is the betel nut of commerce. The betel quid (wad of chewable ingredients) includes the fresh or dried seed of betel nut, a fresh leaf of betel pepper (*Piper betle*), a dab of slaked lime, and various flavorings (cutch, cardamom, clove, tobacco, or gambier). Eight closely related alkaloids are responsible for the stimulant effect; the alkaloid levels are highest in the unripe fruit and this may be why some cultures prefer the unripe nuts for consumption: they give a better buzz. Note that when chewed for the stimulant effect betel quid is never swallowed and the copious saliva resulting is spat out. However, when used medicinally betel nut may be taken internally. One of its effects is a powerful stimulus to intestinal peristalsis; betel nut is used to treat a long list of ailments. The Indian pan (pronounced pon) is a common after-dinner treat, acting against post-meal lethargy and as a digestif.

House made from betel nut palm in grove; all parts of the house are made out of betel nut palm, including trunks for posts and beams. Photo taken at a betel nut palm research center in Kerala, India. PHOTO: M. MERLIN

Beautiful/fragrant flowers

The fragrant flowers are used in weddings and funerals in some SE Asian countries.

Timber

The trunks of culled trees provide a source of construction material. Either split or whole they are used for rafters and for wattle in house construction; they are used in constructing elaborate crematory and temporary structures.

Fuelwood

Fallen fronds, bracts, inflorescences could be used for fuel; culled trees could be used as firewood. In practice, the husks removed from the fruits during processing are used as domestic fuel after drying.

Fiber/weaving/clothing

The tough leaf bases are used in hats, inner soles for slippers, and is an excellent paper pulp source. Husks are used for insulating wool, boards, and for manufacturing furfural (a solvent). In the Philippines the husk is used to make toothbrushes.

Wrapping/parcelization

The leaf sheaths and spathes are used as wrapping and as a substitute for cardboard packing material. In the Philippines the leaf sheaths are used to make book covers. In Sri Lanka the leaf sheaths are used as plates, bags, and for wrapping.

Tannin/dye

Tannins are a by-product of boiling the nuts during processing the commercial product. An extract of betel nut makes black and red dyes.

Oil/lubricant

Fat from the betel nut is used as an extender for cocoa butter.

Ceremonial/religious importance

Betel nut chewing is culturally important in many Asian and Pacific societies, and the literature on the subject is extensive. In the early twentieth century it was postulated that Pacific island societies could be labeled as either kava cultures or betel cultures, based on which substance they consumed (Norton 1998). Betel nut is the preferred stimulant today in the Pacific nations of Papua New Guinea, the Solomon Islands, Fiji, Vanuatu, Palau, Guam, Yap, much of Micronesia, Taiwan, the Philippines, as well as in Malaysia, Indonesia, Thailand, Laos, Cambodia, and Vietnam. Only in Pohnpei, capital of the Federated States of Micronesia, and in Port Moresby, capital of Papua New Guinea, do people use both kava and betel nut regularly (Norton 1998). This is likely due to urban migrations of people from dissimilar rural backgrounds and cultural practices.

Furthermore, the whole inflorescences are used in religious rituals in Sri Lanka and are displayed on the front of vehicles during pilgrimages, to bring good luck. The trunks are used to construct crematory and temporary ceremonial structures in several Asian countries.

COMMERCIAL PRODUCTS

The dried nuts, whole or sliced, are the primary commercial product in international trade. Fresh nuts, either ripe or unripe, are an item in local commerce only, as they do not ship well. The commercial product is prepared from ripe or unripe fruits that are first husked; then the seeds, whole, split, or sliced, are dried in various ways (sunlight, with artificial heat, by smoking). Boiling the nuts before drying reduces the tannin content of the final product. The nuts are boiled in water to which some of the liquid from previous boilings has been added.

Female monk putting quid in her mouth, Ankor Wat, Cambodia. PHOTO: M. MERLIN

In the Pacific islands the ripe, recently harvested nut is the primary item of local commerce. Fresh nuts are consumed in both the fully ripe and unripe stages. In Taiwan the unripe nuts are used in the betel quid. In Indonesia unripe fruits are preferred for home consumption, whereas fully ripe fruits are harvested for local sale. In Guam the fruits of the *changnga* (white) variety are harvested immature and soft; the fruits of the *ugam* (red) variety are preferred at the fully mature and hard stage.

Spacing for commercial production

Minimum spacing is about 2.7 x 2.7 m (9 x 9 ft) on deep, fertile, moisture retentive but well drained soils. On shallower or poorer soils the spacing should be increased to 3.7 m (12 ft) or even more. If interplanted with banana the distance may be 4–5 m (16–20 ft) between rows and 2.7 m (9 ft) between plants in a row.

Management techniques for thinning, pruning, fertilizing, weed control, etc.

Betel nut palms grow best where high rainfall is evenly distributed throughout the year (Sadanandan 1973). Since this weather pattern does not prevail on most Pacific islands, irrigation becomes a critical factor in betel palm husbandry. In dry periods, water deficiency can cause flower abortions even when the inflorescence is still enclosed in the protective boat-shaped spathe. Flower abortions in the dry season reduce yields and limit harvests to certain months. Irrigation is often essential for growers interested in avoiding flower abortions and maintaining vigorous growth and fruit production during the dry months. Where irrigation is required, drip systems are recommended. Backyard growers can water by hand or sprinkler. The ideal is to thoroughly soak the root zone every 3–9 days (Sadanandan 1973).

A recommended fertilizer rate is 0.9 kg (2 lb) of 10:5:22 per palm per year (Mohapatra 1977). One half is applied before the wet season and the other half after.

Dried chicken manure and composted plant remains are prime sources of organic matter and micronutrients, such as iron and zinc. Manures and composts can be applied at rates of 10 kg (22 lb) per palm per year (Sannamrappa et al. 1976).

Mulching with organic materials such as grass or tree prunings can help maintain soil moisture, halt erosion, and slowly add nutrients to the soil.

Design considerations

Some factors to consider in the layout of an orchard are:

- The flower clusters and developing nuts are susceptible to fungal rots and mildews. Thus, the tree spacing should allow air circulation between the trees, discouraging fungal and bacterial diseases.
- The tree has a fibrous root system near the soil surface that extends to the drip line of the canopy. For this reason mechanical cultivation with tractors is not done in the orchard. Hand tools are used to incorporate manures or compost into the soil.
- The tall trees are easily damaged by wind and storms. Windbreaks should be planted to minimize this threat. The palms can also be grown within a framework of wind resistant trees.

In India plantations are closely and evenly spaced, which enables trained harvesters to climb a palm and cut off the fruit clusters, lowering them to the ground with a rope to avoid any damage, then move laterally to the crown of the next palm.

Advantages and disadvantages of growing in polycultures

New betel nut plantings are often intercropped with banana, tapioca, yam, or sweetpotato. Growing a crop of annuals, biennials, or short-lived perennials between rows of betel nut palms increases the per unit area yield by making better use of the land and light and provides revenue while the palms are immature, without decreasing their future yield. The intercrops are usually phased out as the palms come of bearing age.

Yields

Yields can vary considerably depending on the vigor of the trees and absence or presence of pathogens and pests. A palm produces two to six bunches of fruit per year, each bunch with 50–400 fruits. It is estimated that on Guam in 1982 an average palm yielded two to four bunches per year, each containing 50–100 nuts. Larger fruit size is correlated with a lower number of fruits per bunch. Climatic conditions at flowering time affect the percentage of female flowers pollinated in this wind-pollinated species. Yield increases gradually with age until the palms reach full maturity at 10–15 years, then continues until the palms stop bearing at 40(–60) years of age. Soil quality and fertility affect bearing: deeper, water-retentive soils produce higher yield; marginal soils require application of manure, green leaves and twigs, or compost. In India an annual application of 100 g (3.5 oz) N, 40 g (1.8 oz) P_2O_5, and 140 g (5 oz) K_2O is recommended; yield in 1955 was ca. 800 kg (1760 lb) dry nuts per ha; in 1990 this increased to 1200 kg (2640 lb) dry nuts per ha (Brotonegro et al. 2000). Calculated annual mean yield of ripe nuts is about 2.5 kg per palm (5.5 lb/palm), with some farmers recording yields of 8 kg per palm (17.6 lb/palm); the highest yield ever recorded is 30 kg/palm/yr (66 lb/palm/yr) (Brotonegro et al. 2000).

On-farm processing

Processing is generally not practiced in the Pacific islands, as the nut is typically used fresh.

Where processing is practiced, it involves husking fruits, removing embryos, drying nuts in sun or with artificial heat or sometimes smoking. Dried product is graded on stage of harvest, color, shape, and size of nuts. Nuts may first be boiled in water containing concentrated liquid from previous boilings to reduce tannin content of nuts; they are then dried.

Markets

In the Pacific islands, harvested nuts are distributed

Left: Betel nut for sale in main market, Honiara, Guadalcanal, Solomon Islands. PHOTO: M. MERLIN **Right: Fruits for sale, Rayong, Thailand.** PHOTO: C. ELEVITCH

through extended-family networks or sold in village stores or farmer markets.

The primary export market is in South Asia (India, Pakistan, Sri Lanka); India is a net importer of betel nut despite being the world's largest producer (250,000 mt [275,000 t] in 1990). Malaysia, Indonesia (21,800 mt [24,000 t] in 1993), and Thailand (5200 mt [5700 t] in 1991) produce more betel nut than they consume.

URBAN AND COMMUNITY FORESTRY

The majority of betel nut palm grown for nut production is in homegardens, so the species is eminently suitable for this purpose. In fact, like all cultigens, betel nut palm depends on human care for its survival. Where nut consumption is not the primary reason for growing this palm, it is esteemed for its ornamental qualities. There are no special varieties or types favored for use in urban environments.

The betel nut palm, although an attractive tree, is not recommended for landscaping of parks or other public facilities in the Pacific islands where the nut is used. The ripe nuts are of intense interest to chewers, and this can invite theft and other criminal activity. In a survey of betel nut growers on Guam in 1983, security or theft prevention was a high priority for producers. Theft problems begin in the nursery with the propagation of new trees. A good seed for planting is also a good nut for chewing. For the first 12 months in the nursery, the seed can still be uprooted by thieves and chewed, and theft of seedlings for chewing is a major problem in the nursery. Bearing trees whose ownership is not clearly identified can become the subject of disputes over the nuts.

Size considerations

Reaching 10–20 m (33–66 ft), mature betel nut palms are far too tall to be effective ornamentals in today's downsized residential properties. However, young palms are suitable for landscaping and can be replaced every 10–20 years when they grow too tall. Canopy spread is estimated at 3 m (10 ft), which is a good size for landscaping. Juvenile betel nut palms are sometimes used indoors as foliage plants. Also, because of their eventual height, care should be taken regarding planting beneath overhead wires or near a driveway or patio where falling fronds may cause damage or injury.

Rate of growth in a landscape

The growth rate is moderate in landscape settings.

Roots

The fibrous root system rarely presents any problems in an urban setting.

Products commonly used in a household

Aside from the uses outlined above, whole clusters of ripe fruits and leaf sheaths are sometimes used in large floral arrangements.

Special light requirements

Juvenile palms require shade until they grow above the surrounding vegetation, then full sun is necessary.

Life span

The life span is 60–100 years. In homegardens the palm will outgrow the landscape in 10–20 years or be replaced before then by a garden renovation.

Maintenance

Mulching or heaping soil around the trunk base will encourage adventitious root growth, which aids stability and plant vigor. This solitary palm does not branch or require any thinning, and fronds drop as they age, so no pruning is required unless the crown is close to electrical or telephone wires.

Special considerations regarding leaf, branch, and fruit drop

Considered a self-pruning palm, betel nut palm drops old fronds (ca 2 m [6.6 ft] long) throughout the year as new fronds emerge. Falling fronds may damage groundcovers or other plantings beneath the canopy as well as cars, patio furniture, awnings, or people. Storm winds do not normally tear healthy fronds from the crown, but they will dislodge any nearly deciduous old fronds; these may be a hazard in high winds.

Nuisance issues: poisonous parts, thorns/spines, foul smell

None.

Common pest problems

None of significance. Only foot rot fungus (*Ganoderma*) is mentioned as affecting ornamental plantings of betel nut palm.

INTERPLANTING/FARM APPLICATIONS

Crop/tree interactions

Permanent intercropping takes place using bananas, cacao, cardamom, fruit trees (guava, jackfruit, mango, orange, papaya, plantain, coconut), or guinea grass as fodder. In India pepper vines (betel pepper, *Piper betle*) or black pepper (*P. nigrum*) are often trained onto the trunks of betel nut palms.

Betel nut palms in polyculture on Yap Island, Micronesia.
PHOTO: M. MERLIN

Short-term intercropping with annual or biennial crops is also practiced when betel nut plantations are young.

Benefits of interplanting

Intercropping in general makes better use of the land and light by producing an income-generating crop before the palms begin bearing. Intercropping with banana provides shade essential for establishment of young areca palms after they are transplanted from nursery beds to the field. In the Mariana Islands, the banana intercrop improves soil chemistry and soil fertility. When betel pepper is grown together with betel nut palm, the two main ingredients of quid (betel nut and betel pepper leaf) are readily available for consumption or sale. In homegardens, intercropping with fruit trees provides a variety of useful products for home consumption.

Potential drawbacks of interplanting

The main problems of intercropping are competition for nutrients, sunlight, and water between the betel nut palms and the intercrop. Too close spacing is the primary cause of these problems.

Leaf underside. PHOTO: C. ELEVITCH

PUBLIC ASSISTANCE

Central Plantation Crops Research Institute, Kasaragod, Kerala, India, <http://www.bioinfcpcri.org/>.

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Species Profiles for Pacific Island Agroforestry (www.traditionaltree.org)

Areca catechu (betel nut palm)

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Acknowledgments: The authors and publisher thank Dale Evans, Harley Manner, and Mark Merlin for their input. Photo contributions by Ray Baker, Eleanore Burson, and Mark Merlin are greatly appreciated.

Recommended citation: Staples, G.W. and R.F. Bevacqua. 2006. *Areca catechu* (betel nut palm), ver. 1.3. In: Elevitch, C.R. (ed.). Species Profiles for Pacific Island Agroforestry. Permanent Agriculture Resources (PAR), Hōlualoa, Hawai'i. <http://www.traditionaltree.org>.

Sponsors: Publication was made possible by generous support of the United States Department of Agriculture Western Region Sustainable Agriculture Research and Education (USDA-WSARE) Program; SPC/GTZ Pacific-German Regional Forestry Project; USDA Natural Resources Conservation Service (USDA NRCS); State of Hawai'i Department of Land & Natural Resources Division of Forestry & Wildlife; and the USDA Forest Service Forest Lands Enhancement Program. This material is based upon work supported by the Cooperative State Research, Education, and Extension Service, U.S. Department of Agriculture, and Agricultural Experiment Station, Utah State University, under Cooperative Agreement 2002-47001-01327.

Series editor: Craig R. Elevitch

Publisher: Permanent Agriculture Resources (PAR), PO Box 428, Hōlualoa, Hawai'i 96725, USA; Tel: 808-324-4427; Fax: 808-324-4129; E-mail: par@agroforestry.net; Web: <http://www.agroforestry.net>. This institution is an equal opportunity provider.

Bruguiera gymnorrhiza (large-leafed mangrove)

Rhizophoraceae (mangrove family)

denges **(Palau);** ***jon*** **(Marshall Islands); large-leafed mangrove, oriental mangrove (English); orange mangrove (northern Australia);** ***ong*** **(Chuuk);** ***sohmw*** **(Pohnpei);** ***sraol*** **(Kosrae);** ***yangach*** **(Yap Islands)**

James A. Allen and Norman C. Duke

PHOTO: J. A. ALLEN

Forest of large-leafed mangrove.

IN BRIEF

Distribution Found in Micronesia, Samoa, and the southwestern Pacific; widely distributed from the eastern coast of Africa through Asia to subtropical Australia.

Size Reaches 30–35 m (100–115 ft) in height, although commonly much shorter, around 7–20 m (22–62 ft).

Habitat Intertidal zones, 0–2 m (0–6.6 ft), or the elevation range between mean sea level and highest tide, with rainfall of 1000–8000 mm (40–315 in).

Vegetation Common associates on Pacific islands include other mangrove tree species.

Soils Wide range; trees thrive best in river estuaries.

Growth rate Less than 1 m/yr (3.3 ft/yr) in height.

Main agroforestry uses Soil stabilization, coastal protection, wildlife/marine habitat.

Main products Timber, dye, and traditional medicine.

Yields No data available.

Intercropping Recommended for planting together with other mangrove species.

Invasive potential Can be invasive; not recommended for planting outside of its natural range.

INTRODUCTION

Large-leafed mangrove (*Bruguiera gymnorrhiza*) is one of the most important and widespread mangrove species in the Pacific. It is found in intertidal areas of the tropical Pacific region from Southeast Asia to the Ryukyu Islands of southern Japan into Micronesia and Polynesia (Samoa), and southward to subtropical Australia. Large-leafed mangrove thrives under a broad range of intertidal conditions, including salinity levels from near freshwater to full-strength seawater, and tolerates a range of flooding and other soil types. Typically, it is most common in the middle and upper intertidal zones, rather than in the lower intertidal zone or along the seaward edge of mangrove stands.

Some of the value of this species is difficult to separate out from the larger role played by mangrove species as a whole. Mangroves in general are believed to play vitally important roles in shoreline protection, enhancing water quality in nearshore environments (including over coral reefs), providing habitat for juvenile fish and other reef species, and supporting marine food chains through outwelling of carbon. Although the wood is the main part of the tree used in most of the Pacific, numerous uses for other parts of the tree including the propagules, leaves, and bark have been reported in the region.

DISTRIBUTION

Native range

Found in tropical intertidal areas from the eastern coast of Africa through Asia to the Ryukyu Islands of southern Japan, into Micronesia and Polynesia (Samoa), and southward to subtropical Australia (Queensland, New South Wales and Western Australia), it has the largest natural longitudinal range of all mangrove species.

Within the mangrove ecosystem, large-leafed mangrove is most commonly found in the middle and upper intertidal zones, rather than in the lower intertidal areas or outer seaward fringe.

Current distribution

There is little evidence that large-leafed mangrove occurs widely outside of its natural range. It is possible that it occurs in the Hawaiian Islands, but recently the species of *Bruguiera* naturalized on O'ahu was found to be *B. sexangula*, not *B. gymnorrhiza* as previously reported (Allen et al. 2000).

BOTANICAL DESCRIPTION

Preferred scientific name

Bruguiera gymnorrhiza (L.) Lamk.

Family

Rhizophoraceae (mangrove family)

Non-preferred scientific names

Brugiera gymnorrhiza (L.) Lam., Tab. Encycl. 2: 517, t. 397. 1793 ("*gymnorhiza*"). (common misspelling)
Rhizophora gymnorrhiza L., Sp. Pl.: 443. 1753 ("*gymnorhiza*"); G. Forst., Fl. Ins. Austr.: 35, n. 201. 1786.
Bruguiera rheedei Bl., Enum. Pl. Jav.: 92. 1827 (*rheedii*).
Brugiera rumphii Bl., Mus. Bot. Lugd.-Bat. 1: 138. 1850.

Common names

Pacific

denges (Palau)
jon (Marshall Islands)
large-leafed mangrove, oriental mangrove (English)
ong (Chuuk, FSM)
orange mangrove (northern Australia)
sohmw (Pohnpei, FSM)
sraol (Kosrae, FSM)
yangach (Yap, FSM)

Indian Ocean

malkadol, *sirikanda* (Sri Lanka: Sinhala)
thuddu ponna, *uredi* (Andhra Pradesh, India: Telugu)
muia, *mkoko wimbi* (Kenya, Tanzania, and Zanzibar, Mozambique: Kiswahili)

Size

It is a medium to tall tree that may reach 30–35 m (100–115 ft) in height, although it is commonly much shorter. Diameters are commonly about 15–35 cm (6–14 in). Dwarfed stands have been reported for some locations (e.g., Pohnpei).

Form

Large-leafed mangrove is normally a single-stemmed tree with short buttresses and characteristic "knee roots," (horizontal roots that occasionally form above-ground loops, presumably as an aid to gas exchange for the subsurface portions of the roots). It tends to be of shorter stature and more conical in shape on the seaward edge of stands or in areas of high salinity.

Bark is typically pale brown to grey (darker when wet), greater than 2 cm (0.8 in) thick, hard, and rough. Populations on Hainan Island (China) have distinctive bark characteristics with vertical fissures plus large flaky lenticels 2 cm (0.8 in) in diameter.

Flowering

Flowers are perfect. Inflorescence has solitary flower buds, located in leaf axils, usually nodding, positioned at the first (or rarely second) node below the apical shoot. Mature flower bud when closed is 3.0–3.5 cm (1.2–1.4 in) long, 1.5–3.5 cm (0.6–1.4 in) wide. Calyx is typically reddish to almost scarlet, occasionally pale yellow, white or green, characteristically smooth or with grooves above lobe junctures, rarely ribbed, with 12–14 lobes, acutely pointed, narrow. Style is pale green, filiform, 3–4 lobes, about 20 mm (0.8 in) long and 1 mm (0.04 in) wide. Petals are bilobed (one third of total length), with hairy outer margins, creamy-white tend to orange-brown on maturation, number equals the number of calyx lobes, about 15 mm (0.6 in) long and 4 mm (0.16 in) wide. Bristle is between lobes, solitary, straight, up to 4 mm long. Bristles (3–4) are on tips of petal lobes, often curly, 3–4 mm (0.12–0.16 in) long. Stamens are creamy white to golden brown at maturity, about 12 mm (0.5 in) long. Peduncle is smooth, slender, curved, approximately 10 mm (0.4 in) long and 2–3 mm (0.08–0.12 in) wide. The flowering period is chiefly April to August in the southern hemisphere, and October to February in northern hemisphere.

Foliage with flower buds and propagules showing typical red calyx form. Chuuk, Federated States of Micronesia. PHOTO: N.C. DUKE

Leaves

Leaves are opposite, simple, elliptical, dark green, and coriaceous (leathery), aggregated at the tips of apical shoots in clusters of about 12 leaves. Leaves are 8–22 cm (3–8.5 in) long and 5–8 cm (2–3 in) wide, with petioles of 2–4 cm (0.8–1.6 in). Leaf blades are elliptic tending to oblong, about 15 cm (6 in) long and 6 cm (2.4 in) wide, acute tip without mucro, petiole about 4 cm (1.6 in) long. Stipules (leaf sheaths) are green or yellowish, 4–8 cm (1.6–3.2 in) long. Apical shoots are about 6 cm (2.4 in) long. Leaf color, size, and shape enable *B. gymnorrhiza* trees to be distinguished from other *Bruguiera* spp. from a distance. It differs from *Rhizophora* spp. in the lack of mucronate leaf tip, longitudinal fold grooves along blade, and lack of cork wart spots. Leaf emergence occurs mainly from November to March in southern hemisphere, May to September in the northern hemisphere; marked declines in canopy density may occur during these months if rainfall is low. Leaf fall occurs chiefly over the wet summer period from October to March in the southern hemisphere, April to September in the northern hemisphere.

Fruit

Large-leafed mangrove is viviparous, meaning that the species produces seeds that germinate on the parent plant. The dispersal unit, a viviparous seedling, is called a hypocotyl. There is no apparent fruit stage. Instead, a hypocotyl emerges singly from an attached mature calyx. Mature hypocotyls with attached calyx bodies are located at the third to fifth nodes below the apical shoot. The hypocotyl is cylindrical, elongate, stocky, dark green, coriaceous, with longitudinal ribbing giving an angular appearance, the root tip bluntly pointed, mature dimensions 15–25 cm (6–10 in) long and about 2 cm (0.8 in) wide. Expended calyces often remain attached after mature propagules fall from parent trees. "Fruiting," when mature hypocotyls fall, occurs January to February in the southern hemisphere, and July to August in the northern hemisphere.

Seeds

Like all *Bruguiera* species, large-leafed mangrove is viviparous, meaning that the species produces seeds hidden in the mature calyx (post-flowering) that germinate on the parent plant. Just one hypocotyl is usually produced from each mature calyx, although on rare occasions twins may be observed.

Rooting habit

Mature trees have distinctive, sturdy, above-ground knee-roots surrounding the stem base that anchor only shallowly in the sediments, to 1–2 m (3.3–6.6 ft) depth.

Similar species

Large-leafed mangrove is most likely to be confused with other *Bruguiera* species/taxa where distributions overlap in the western Pacific. In particular, *B. gymnorrhiza* might be confused with *B. sexangula*, *B.* × *rhynchopetala*, *B. exaristata*, *B. parviflora*, or *B. cylindrica*.

Mature hypocotyl and calyx attached to branch. Daintree River, NE Australia. PHOTO: N.C. DUKE

B. sexangula Often almost indistinguishable from *B. gymnorrhiza*. it has a solitary flower, calyx orangey-pink, usually ribbed rather than grooved above lobe junctures, like *B. gymnorrhiza*. Propagules tend to be much shorter, 6.5–9.0 cm (2.6–3.5 in). Populations in Hainan Island (China) have distinctive smoother bark with horizontal fissures plus small lenticels about 1 cm (0.4 in) in diameter.

B.* × *rhynchopetala *B. gymnorrhiza* is also reported to hybridize with *B. sexangula*, giving progeny called *B.* × *rhynchopetala*. This hybrid taxon has intermediate and shared characters of *B. sexangula* and *B. gymnorrhiza*, with a solitary flower, calyx green with red blush, variably ribbed or grooved above lobe junctures. Propagules are indistinguishable from parental taxa. Populations in Hainan Island (China) have distinctive intermediate bark with horizontal and vertical fissures plus intermediate-sized lenticels 1–2 cm (0.4–0.8 in) in diameter.

B. exaristata Solitary flowers also, but they are smaller, green never reddish, calyx ribbed with 8–10 spreading lobes compared to 12–13 for *B. gymnorrhiza*. Furthermore, unlike other solitary flower taxa, this species has no spine between petal lobes. Propagule distinctly ribbed, much shorter.

B. parviflora Multiple flowers are in small groups, each having 7–8 short calyx lobes extending down from the narrow, elongate, ribbed calyx. Propagules substantially thinner, with elongate spaghetti-like appearance.

B. cylindrica Multiple flowers occur in groups of two or three and have a greenish-yellow, bulbous calyx with six to nine lobes that fold back against the upper calyx. Propagule narrow, with a rounded cylindrical appearance, no grooves or ribs.

***Rhizophora* species** *Rhizophora* has four calyx lobes, most have cork wart spots on leaf undersurfaces (note: *Bruguiera* species never have cork wart spots), and most Indo–West Pacific *Rhizophora* have prominent mucronate tips at their leaf apices (unlike *R. samoensis* in the southern Pacific islands, and the introduced *R. mangle*).

GENETICS

Variability of species

Some variation in calyx color of the flower occurs, with some trees having flowers described as crimson red, orange, yellowish red, creamy white, or green. Colors may also be mixed red and green, with their red sides often up-



Left: Knee roots with rare instance of sprouting foliage stems. Gazi Bay, Kenya. Top right: Buttress roots and stem base, tree growing on man-made coral rubble platform. Yap, Federated States of Micronesia. Bottom right: Mature hypocotyls comparing a red "albino" form (above) and a normal dark-green form (below). Note also the color variation in calyces, red and red-green, which is independent of propagule color. Moreton Bay, Queensland, Australia. PHOTOS: N.C. DUKE

per-most. Care must be taken to differentiate between calyx color and petal color, as this may at times be defined as flower color. Red coloration of the calyx is definitely more prevalent in sun-affected locations, within single trees and among trees.

Known varieties

In NE Australia, *B. gymnorrhiza* has "albino" forms where some hypocotyls lack green pigment. These propagules are living, but they are non-viable, dying within a year of settlement after depleting reserves, because they cannot photosynthesize. When present, they are easily observed hanging alongside normal green hypocotyls from otherwise normal looking parent trees.

ASSOCIATED PLANT SPECIES

Mangroves commonly occur in relatively distinct zones, which are controlled by factors such as salinity, tidal regime, soil type, and seed predators. Large-leafed mangrove is most commonly found in an intermediate location between the seaward edge of mangrove stands (often dominated by *Rhizophora* spp. and *Sonneratia alba*) and the landward edge, which may be dominated by a diverse mix of mangroves and mangrove associates.

Associated species commonly found

Common associates on Pacific Islands include other mangrove tree species, especially *Rhizophora apiculata*, *R. samoensis*, *Sonneratia alba*, *Xylocarpus granatum*, *Heritiera littoralis*, *Ceriops tagal*, and *Lumnitzera littorea*. Other flora occasionally found with large-leafed mangrove include the mangrove fern (*Acrostichum aureum/speciosum*), nypa palm (*Nypa fruticans*), and a variety of vines (e.g., *Derris* spp.) and epiphytes (e.g., *Hydnophytum* spp.).

ENVIRONMENTAL PREFERENCES AND TOLERANCES

Climate

Large-leafed mangrove is a species of tropical and subtropical environments, which are characterized by moderately high and well distributed rainfall.

Elevation range

0–2 m (0–6.6 ft), which is the elevation range between mean sea level and the highest tide.

Mean annual rainfall

1000–8000 mm (40–315 in)

Rainfall pattern

Grows in climates with a uniform rainfall pattern.

Dry season duration (consecutive months with <40 mm [1.6 in] rainfall)

No specific information is known for large-leafed mangrove. Mangrove plants in general appear to depend on groundwater to sustain optimal growth, especially during drier months. Reduced growth in response to an El Niño event on Kosrae in 1997/1998 was presumably due to a decrease in freshwater input.

Mean annual temperature

20–30°C (68–86°F) (estimate)

Mean maximum temperature of hottest month

32–38°C (90–100°F) (estimate)

Mean minimum temperature of coldest month

0–5°C (32–41°F) (estimate)

Minimum temperature tolerated

-5°C (23°F) (estimate)

Soils

Trees develop greatest stature and columnar growth form in estuaries of larger tropical rivers, characterized by fine clay and black mud sediments with relatively high levels of organic carbon. These soils are often anaerobic, with high concentrations of sulfide. However, these trees also occur at times in sites with more aerobic sediments consisting of fine sands to coarse stones and rocks. In these instances, knee roots are less prominent.

Soil texture

Grows in light, medium, and heavy textured soils (sands, sandy loams, loams, sandy clay loams, clay loams, sandy clays, and clays).

Soil drainage

Grows in soils with free and impeded drainage as well as waterlogged soils.

Soil acidity

Acidic to neutral soils (pH 4.0–7.4).

Special soil tolerances

Grows in saline soils. The optimal salinity range is reported to be 8–26 ppt (parts per thousand), compared with approximately 34–36 ppt for full-strength seawater.

Tolerances

Drought

The tree can tolerate drought periods reasonably well, although growth rate is reduced substantially.

WHAT IS A MANGROVE?

Mangroves form a unique and dominant ecosystem comprised of inter-tidal marine plants, mostly trees, predominantly bordering margins of tropical coastlines around the world. These halophytic (salt tolerant) plants thrive in saline conditions and daily inundations between mean sea level and the highest tides, and they provide vital structure as habitat and food for similarly adapted resident and transient fauna. At low tide, mangrove plants exchange gases from exposed roots using special lenticels, while flooding tides allow uptake of nutrients and seed dispersal, often using especially buoyant propagules. The ecological limits defined by the diurnal tidal range explain the setting and why just 70 species around the world are called true mangroves (Tomlinson 1986, Duke et al. 1998), compared with adjacent rainforests that may have hundreds of tree species per hectare. Specialized morphological and physiological characteristics largely define and characterize mangrove plants, such as buttress trunks and roots providing support in soft sediments, above ground roots allowing vital gas exchange in anaerobic sediments, and physiological adaptations for excluding or expelling salt. Fewer than 22 plant families have developed such attributes, representing independent instances of co-evolution over millions of years to form today's mangrove habitats.

Full sun

It grows well in full sun.

Shade

Large-leafed mangrove is one of the most shade tolerant mangrove species. Seedlings may persist and grow under a full forest canopy (even less than 10% full sunlight).

Fire

It has no tolerance of fire in close proximity.

Frost

The tree is almost certainly not tolerant of sub-freezing temperatures for more than a few hours.

Waterlogging

It can tolerate daily flooding up to depths of at least 1.5 m (5 ft) and even permanently saturated soils.

Salt spray

The tree is highly tolerant of salt spray.

Wind

It is not typically found on the extreme seaward (and most windswept) edges of mangrove forests. Planting in highly wind-prone locations is not recommended.

Abilities

Regenerate rapidly

Large-leafed mangrove regenerates effectively by natural dispersal and seedling establishment, but then tends to grow slowly, depending on freshwater inputs, muddy substrate, and nutrient availability.

Self-prune

Self-prunes well in dense stands but maintains lower branches in more open-grown locations.

Coppice

Does not coppice well but does respond much better to cutting and leaf removal than *Rhizophora* species, with sprouting along larger stems below leafy rosettes.

Pollard

No reports were found of pollarding practices.

GROWTH AND DEVELOPMENT

Growth rates vary with age. Growth in height is rapid shortly after establishment while food reserves are taken up from the hypocotyl. The rate then appears to slow in a sigmoid decline until the tree attains the maximum height obtainable on a particular site—the site maximal canopy height (Duke 2001). After this, trees tend to spread and broaden in canopy diameter rather than get taller.

Growth rate

Large-leafed mangrove generally grows less than 1 m/yr (3.3 ft/yr) in height. Propagules planted in India averaged only 1.19 m (3.9 ft) tall after five growing seasons. Naturally regenerated saplings growing in small gaps on Kosrae have averaged about 10 cm/yr (4 in/yr) over a period of 6 years. Trees in some plantations on the Andamans have reportedly reached a height of 9–12 m (30–39 ft) and a circumference of 25–30 cm (10–12 in) in 15 years. Mean annual diameter increments of 0.17–0.21 cm (0.07–0.08 in) and 0.30 cm (0.12 in) have been reported for Malaysia and Bangladesh, respectively. In Micronesia, large-leafed mangrove growing on Pohnpei had diameter growth rates of 0.26 cm/yr (0.1 in/yr), and on Kosrae, 0.44 cm/yr (0.17 in/yr) (Cole et al. 1999).

A 100-year rotation was recommended for the Andaman Islands, at which time the "exploitable girth" should be around 70 cm (28 in).

Flowering and fruiting

Flowering and "fruiting" occur continuously throughout the year, although distinctly seasonal peaks of hypocotyl production were reported for July–August in northern parts of the range and January–February in southern parts. Trees have notable and long periods of reproductive development, taking 1–2 years from first emergence of flower buds until maturation and drop of mature hypocotyls.

Yields

No data available.

PROPAGATION

Large-leafed mangrove is readily propagated by direct planting of propagules (viviparous seedlings). Although natural regeneration is generally relied upon around the Pacific region, this species is relatively easy to propagate artificially.

Propagation is simple and relies on the special feature of this genus: viviparous propagules. As such, planting simply entails gently pushing the distal end of the 10–15 cm (4–6 in) long hypocotyl one third of its length into the sediment, spaced at about 1 m (3.3 ft) intervals. No holes need to be dug, no nursery preparation, no stakes, and generally low maintenance is required for growing seedlings in sheltered areas.

Propagation by viviparous seedling

Propagule collection

Propagules are available throughout much of the year, with peaks in July–August common in northern parts of the range and January–February in the southern parts. Mature propagules may be collected after they have fallen or directly off the trees. Only healthy looking propagules should be selected. Propagules that are shrunken or desiccated in appearance or that exhibit significant physical damage should be rejected. Although propagules with only minor borer damage may survive and grow, selection of propagules with no signs of borer or crab damage are strongly preferred. Propagules that already have some root or leaf development can be used in most cases but should not be stored for long.

Propagule processing

No processing of mature propagules is required. They can be sown in nursery beds or planted in the field in the form in which they were collected.

Propagule storage

Propagules can be kept viable for at least 6–7 days by storing them in brackish water or by wrapping them in wet burlap bags and storing them out of direct sunlight. It is likely that they can be kept even longer, but storage beyond 2 weeks is not recommended and long-term storage is not feasible.

Propagule pretreatment

No pre-planting treatments are necessary.

Growing area

Large-leafed mangrove can be grown in full sunlight or under a wide range of shade. In Australia, use of 30% shade for *Bruguiera* species is recommended.

Seedling establishment

Leaves and roots may begin to develop within a week or two of sowing.

Media

Although a wide variety of soil media are acceptable, a 50–50 mix of sand and peat has been recommended for Australian mangrove nurseries. Brackish water is recommended, but seedlings have also been successfully propagated using fresh water.

Time to outplanting

Seedlings are ready for outplanting at the six-leaf (three-

Planting mangroves on a storm-damaged site. PHOTO: N. DUKE node) stage if grown in nursery conditions. Older seedlings up to 0.5 m (20 in) tall have also been successfully transplanted. Planting may be undertaken at any time during the year. Direct propagule planting, will, however be restricted by their seasonal availability from parent trees, as they do not keep for extended periods unless planted out in pots.

Guidelines for outplanting

Propagules or nursery-grown seedlings should have excellent survival on sites that have been properly selected and, if appropriate, protected from disturbance. Survival of 90% or greater is not unreasonable in such sites. On the other hand, survival may be zero on sites exposed to excessive wave action, inappropriate hydrologic or salinity regimes, or (rarely) disturbance by grazing animals (such as camels, goats, cattle, and horses).

DISADVANTAGES

In general, large-leafed mangrove poses few significant disadvantages when planted in its native range. It is not especially susceptible to pests or pathogens and has not been reported to host major pests or pathogens of important crop species.

Potential for invasiveness

Although the invasiveness of large-leafed mangrove has not been demonstrated, it is likely to be easily opportunistic due to its shade tolerance and its relatively wide range of tolerance for salinity and soil conditions. Other mangrove species introduced into Hawai'i have clearly demonstrated the general potential for invasiveness of mangroves in areas where they are not native and yet suitable growing conditions exist.

Pests/pathogens

Susceptibility to pests and pathogens is believed to be low, with the exception of grapsid crabs and weevils, which frequently damage propagules and/or leaves.

Host to crop pests/pathogens

No reports were found of large-leafed mangrove serving as the host for a known crop pest or pathogen.

AGROFORESTRY/ENVIRONMENTAL PRACTICES

Large-leafed mangrove is probably of greatest value *in situ*, as this species (and mangroves as a whole) is believed to play a vital role in supporting marine food chains, protecting coastal areas, and improving water quality.

Mulch/organic matter

Mangroves in general have relatively high productivity, including leaf and root production. Mangroves tend to create highly organic soil environments and also export organic matter to nearby marine environments. Large-leafed mangrove foliage may be relatively poor in quality compared to other mangroves such as *Sonneratia alba*, but it still is an effective producer and exporter of organic matter. Mulch in mangrove forests is hidden from view most of the time. If it were not for the small mangrove crabs, fallen leaves would be washed away with each tide. The crabs actively take leaves below ground, where they become underground mulch that can then become available to trees in the forest again.

Soil stabilization

Mangroves in general are effective in stabilizing soils in intertidal areas. They may rapidly colonize newly formed mudflats and other areas of unstable soils within the intertidal zone. Although believed to be useful primarily for gas exchange, the knee roots of large-leafed mangrove may also help trap sediments.

Windbreaks

Large-leafed mangrove has been planted in the Philippines to protect coastal homes from wind and wave action. Mangroves often occur adjacent to agricultural areas and may serve to protect crops from sea spray or storms.

Woodlot

Mangroves adjacent to homes throughout the Pacific frequently serve as informal woodlots, particularly on islands with clear tenure systems that include mangrove areas, such as on Yap, in the Federated States of Micronesia.

Native animal/bird food

Large-leafed mangrove is a largely unknown source of native animal foods. However, several observations demonstrate that the diversity and quantity of the source is likely to be extremely important in mangrove ecosystems. Numerous insects, crabs, and mollusks graze on green leaves in the forest canopy. Sesarmid crabs consume an unknown quantity of fallen leaves and propagules. Organic matter processed by these herbivores is believed to broadly support aquatic food chains in coastal regions. Birds notably feed and depend on floral nectaries of *Bruguiera* species. The relationship with birds is so well developed that this plant-animal relationship has co-evolved to create an unusual explosive pollen-release mechanism in *Bruguiera* plants to disperse pollen to neighboring trees using bird visitors. Few mammals appear to use large-leafed mangrove as a major food source.

Wildlife habitat

In addition to aquatic marine organisms (see Fish/marine food chain), mangroves serve as habitat for a wide range of terrestrial and arboreal wildlife. *Bruguiera* forests provide shelter and food for a number of associated fauna, including birds, small mammals, crustaceans, shellfish, and fish life. Fruit bats may roost in mangroves and are known to pollinate some species (although not large-leafed mangrove). In some cases, rare or endangered species have been documented to use large-leafed mangrove. An example is the nightingale reed-warbler (*Acrocephalus luscinia*), a U.S. federally listed endangered species, which has been found to nest in large-leafed mangrove trees on Saipan.

Bee forage

Bruguiera species have limited nectar (largely consumed by birds), but they do have copious pollen that may be gathered by bees.

Fish/marine food chain

Mangroves in general are believed to play a vitally important role in protecting and supporting marine food chains. Many fish species use mangroves during part of their life cycles, as do species of shrimp and crab. Species such as the mangrove crab (*Scylla serrata*) are common in mangroves with a high component of large-leafed mangrove, and are important sources of food and income on many islands in the region. Populations of some crab species may exceed 10/m^2 (1/ft^2) in parts of the Pacific. Senescent leaves having fallen from *Bruguiera* trees are taken by grapsid (small mangrove) crabs into their burrows. Buried leaves decompose and contribute to nutrient recycling in mangrove forests. Nutrients also feed directly and indirectly to associated estuarine and marine food chains. Mangrove areas with large-leafed mangrove may also serve as habitat for more "charismatic" marine megafauna, such as the saltwater crocodile.

Coastal protection

Mangroves in general play an important role in protection of coastlines, fishponds, and other coastal infrastructure. Mangroves are planted explicitly for coastal or fishpond protection in some areas (e.g., parts of the Philippines) and there are laws in many locations aimed at protecting mangroves in large part because of this important function.

Ornamental

Large-leafed mangrove is not widely used as an ornamental, although its dark green leaves, generally attractive form, and reddish-scarlet flowers do make it an attractive tree. Packaged plants (sprouting hypocotyls) are sold in the Okinawan Islands (Japan) as an ornamental plant at tourist shops.

USES AND PRODUCTS

In terms of direct use by people, the most widespread use of large-leafed mangrove is for wood, which is used for purposes ranging from firewood to construction of homes and canoe parts. Other uses of the tree include food (mainly from the propagules), dyes, and medicines.

Staple food

Leaves and peeled propagules have reportedly been soaked, boiled, and eaten as a staple in Papua New Guinea, although most likely only in times of severe shortage of other foods. Although large-leafed mangrove is not widely used for food, reports of the use of propagules as a food source also exist for India, Bangladesh, and other parts of Southeast Asia.

Fruit

The fruit (propagule) is reportedly "eaten cooked, after scraping or grating, washing, and drying (to remove tannins) and sometimes mixed with coconut in Melanesia and Nauru; fruit is sold as a vegetable at the Honiara Market [Solomon Islands]." (Clarke and Thaman 1993)

Medicinal

The bark is used as an abortifacient and for treating burns in the Solomon Islands The bark is reportedly used for diarrhea and fever in Indonesia. The astringent (and mildly toxic) bark has also been used to treat malaria in Cambodia. The fruits have antiviral properties, and bark extracts of the closely related *B. sexangula* are reportedly active against at least two types of cancerous tumors (Sarcoma 180 and Lewis lung carcinoma).

Timber

The wood is widely used for structural components (e.g., poles, beams, and rafters) of traditional homes and other structures. It is also used for other purposes, ranging from traditional uses such as fishing stakes, spears, and copra-huskers to use as a source of chips for pulp production. The species has also been used for transmission and telephone poles in some regions (e.g., the Andaman Islands), and is likely durable in direct contact with the ground (i.e., rot resistant).

THE LEGEND OF THE ORIGIN OF POHNPEI

Long ago, there lived a man named Sapkini on the island of Eir. Under his guidance, a great canoe was built to sail into the unknown in search of a new land. Sapkini believed this new land existed where the sky touched the sea. Sapkini wisely selected his crew, each of whom was endowed with the skills or magical power needed for sailing or working the land. After many days at sea they met an octopus named Lidakika, who directed them to a distant shallow reef on which a small coral head was exposed. They named it Tierensapw ("bit of land"), because it was no larger than the distance between the canoe and its outrigger. From this bit of coral, the island of Pohnpei was built.

By magic, they called stones and boulders to Tierensapw from other places, but the earth and soil was continuously washed away by the waves of the sea. The people called on Katengenior ("stabilizer of the shore") for help. Katengenior surrounded the land and created a barrier reef for protection. Still the land was not stable, so they called on Katenanik, who caused the mangrove trees to take root to hold the shore in place. After the shore was secure, the people dug earth and piled it into a platform, which they named pei (stone altar). Pohnpei was built on top of (pohn) the altar, thus the island was named Pohnpei, or "upon a stone altar."

Source: Lambeth 2000

Fuelwood

The wood has a high calorific value and is used for fuelwood on some Pacific Islands (e.g., Kosrae). It is also made into charcoal in countries such as Malaysia and Indonesia.

Craft wood/tools

Sometimes used for tool handles or digging sticks.

Canoe/boat/raft making

The wood has been used to make canoe parts. In the Marshall Islands, it has been used for keel-pieces (maal), outrigger (kie), and outrigger struts (kein-eon erre). Canoe paddles are also made from large-leafed mangrove on some islands.

Body ornamentation/garlands

Flowers of the closely related *B. sexangula* are used in Hawai'i to produce a type of lei called the kukuna o ka la ("rays of the sun") (Allen 1998).

Tannin/dye

Used to produce dyes ranging from red-brown to black (the latter with repeated dying). The bark has a high tannin content, but tends to color leather excessively unless the bark is collected "at the end of each growing season."

Cosmetic/soap/perfume

The knee roots (or "breathing roots") reportedly have been used for making perfumes.

COMMERCIAL CULTIVATION

Although not as desirable as *Rhizophora* species, large-leafed mangrove is frequently sold by commercial firewood suppliers on some islands (e.g., Kosrae, Chuuk in FSM). *Bruguiera* timber is harvested commercially for charcoal production in SE Asia, although *Rhizophora* is preferred. The calorific value of the timber is enhanced significantly by converting it to charcoal. Mangrove forests are used for wood chips in Malaysia, New Guinea, and the Solomons using unsustainable harvesting of native forests. Large-leafed mangrove plantations have been established on Fiji for land reclamation and timber.

Spacing

Mangrove plantations in general are typically planted at spacings of about 1.0 to 1.5 m (3.3–5 ft). Spacings wider than about 2.5 m (8 ft) tend to result in a high proportion of multiple stemmed and/or shorter trees. Wider spacings may be desired for coastal protection projects but not for timber production.

In the absence of significant natural mortality, timber plantations should be thinned to densities of 2.5 to 3.5 m (8–11.5 ft) as the stand develops and becomes crowded.

Management objectives

In areas where the mangrove fern (*Acrostichum aureum*) is common, it may need to be controlled to promote early growth of large-leafed mangrove, although the high shade tolerance of this species may make this less important than for other mangrove tree species.

Some published guidelines for mangrove silviculture exist and are referenced in this profile, but guidelines on thinning, fertilizing, etc., that are specific to large-leafed mangrove are generally unavailable.

Growing in polycultures

Large-leafed mangrove naturally occurs in mixed-species stands, and each species has its own ecological and economic values. Mixed-species plantings are therefore recommended, including *R. apiculata* and other *Rhizophora* species.

Large-leafed mangrove may be slower growing than other mangrove species but is able to persist and may even eventually dominate in mixed-species plantations.

Estimated yields

No data available.

Markets

Markets on most Pacific Islands are local in nature, with little in the way of large-leafed mangrove products (other than indirect products like mangrove crabs and fruit bats) being exported from one island to another. In Southeast Asia, large quantities of large-leafed mangrove wood chips and charcoal may be moved greater distances and in greater volumes than wood products on smaller islands.

PUBLIC ASSISTANCE AND AGROFORESTRY EXTENSION

USDA Forest Service
Institute of Pacific Islands Forestry
1151 Punchbowl Street, Room 323
Honolulu, HI 96813, USA
Attn: Tropical Forested Wetlands Team

Marine Botany Group
Centre for Marine Studies
The University of Queensland
St. Lucia QLD 4072, Australia
Web: http://www.marine.uq.edu.au/marbot/index.htm

Extension offices for agroforestry and forestry in the Pacific: http://www.traditionaltree.org/extension.html

INTERNET

For a nice set of FAQ's about mangroves (from the Phil-

Mature forest showing stems and typical above ground roots with Erick Waguk (Kosraen State Forester) pictured for scale. Kosrae, Federated States of Micronesia. PHOTO: N.C. DUKE ippines: http://www.pemsea.org/young%20environ/ye101/mangrove_index.htm

For a brief summary of *B. gymnorrhiza* characteristics produced by the Purdue University Center for New Crops & Plant Products: http://newcrop.hort.purdue.edu/newcrop/duke_energy/Bruguiera_gymnorrhiza.html

For a useful publication called "One Hundred Pacific Island Agroforestry Species": http://www.unu.edu/unupress/unupbooks/80824e/80824Eop.htm

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Traditional Tree Initiative—Species Profiles for Pacific Island Agroforestry (www.traditionaltree.org)

Bruguiera gymnorrhiza (large-leafed mangrove)

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Acknowledgments: The authors and publisher thank Tom Cole, Farid Dahdouh-Guebas, Judith Drexler, Dale Evans, and Kathy Ewel for their input.

Recommended citation: Allen, J.A., and N.C. Duke. 2006. *Bruguiera gymnorrhiza* (large-leafed mangrove), ver. 2.1. In: Elevitch, C.R. (ed.). Species Profiles for Pacific Island Agroforestry. Permanent Agriculture Resources (PAR), Hōlualoa, Hawai'i. <http://www.traditionaltree.org>.

Sponsors: Publication was made possible by generous support of the United States Department of Agriculture Western Region Sustainable Agriculture Research and Education (USDA-WSARE) Program; SPC/GTZ Pacific-German Regional Forestry Project; USDA Natural Resources Conservation Service (USDA NRCS); State of Hawai'i Department of Land & Natural Resources Division of Forestry & Wildlife; and the USDA Forest Service Forest Lands Enhancement Program. This material is based upon work supported by the Cooperative State Research, Education, and Extension Service, U.S. Department of Agriculture, and Agricultural Experiment Station, Utah State University, under Cooperative Agreement 2002-47001-01327.

Series editor: Craig R. Elevitch

Publisher: Permanent Agriculture Resources (PAR), PO Box 428, Hōlualoa, Hawai'i 96725, USA; Tel: 808-324-4427; Fax: 808-324-4129; E-mail: par@agroforestry.net; Web: <http://www.agroforestry.net>. This institution is an equal opportunity provider.

February 2007
ver. 1

Banana and plantain—an overview with emphasis on Pacific island cultivars

Musaceae (banana family)

Randy C. Ploetz, Angela Kay Kepler, Jeff Daniells, and Scot C. Nelson

'Manini', a variegated Hawaiian banana.

INTRODUCTION

The plant family Musaceae, composed of bananas, plantains, and ornamental bananas, originally evolved in Southeast Asia and surrounding tropical and subtropical regions (including New Guinea). Africa is a secondary center of diversity.

The two genera *Ensete* and *Musa* in the family Musaceae are covered here.

Please note that this manuscript is not all-inclusive and that much of the complex species and cultivar taxonomy is in the process of revision and expansion. Readers are encouraged to consult with the many excellent online resources listed in the "Bibliography" for current information.

Part 1: Taxa in the Musaceae

Ensete

The genus Ensete ranges throughout Africa and southern Asia. Depending on the authority, the genus *Ensete* contains as many as nine species. They are monocarpic, unbranched herbs that sucker rarely and are used for food, fiber, and as ornamentals. They resemble banana plants, but their wide-spreading and immensely long, paddle-shaped leaves with usually crimson midribs, are unmistakable. Their fruits are similar in appearance to those of banana, but they are dry, seedy, and inedible. The entire plant dies after fruiting.

Ensete gilletii (De Wild.) Cheesman

Ensete glaucum (Roxb.) Cheesman. Common names: Wild banana, Seeded sweet banana, "Virgin" banana, or Virgin (Philippines)

Synonyms: *M. glauca* Roxb., *M. nepalensis* Wallich in Roxb., *M. troglodytarum* L. var. *dolioliformis* F. M. Blanco, *M. gigantea* Kuntze, *M. calosperma* von Mueller, *M. wilsonii* Tutcher, *E. calospermum* (von Mueller) Cheesman, *E. wilsonii* (Tutcher) Cheesman, *M. agharkarii* Chakravorti, *E. gigantea* (Kuntze) T. Nakai, *E. nepalensis* (Wallich) Cheesman, *err. cal.* Simmonds, *E. agharkarii* (Chakravorti) Hore, Sharma and Pandey

Description: This species has small, oval bananas in a very small, compact bunch, atop a huge bud with green turning to pale brown, persistent bracts producing a "messy" rachis similar to dwarf edible bananas (for example, 'Dwarf Cavendish', 'Prata Aña'). The seeds are about 10 mm diameter x 11 mm deep (0.4 in x 0.43 in). The seeds are strung into necklaces in PNG.

Ensete homblei (Bequaert) Cheesman

Ensete perrieri (Claverie) Cheesman

Ensete superbum (Roxb.) Cheesman

Ensete ventricosum (Welw.) Cheesman. Common names: Enset, Ensete, Abyssinian banana or Plantain, Ethiopian, Black, Bruce's or wild banana

Synonyms: *Musa ensete* Gmel., *M. ventricosa* Welw., *M. buchananii* Baker, *M. schweinfurthii* Schumann and Warburg ex Schumann, *M. arnoldiana* De Wild., *M. holstii* Schumann, *M. ulugurensis* Warburg and Moritz ex Warburg, *M. fecunda* Stapf, *M. laurentii* De Wild., *M. bagshawei* Rendle and Greves, *M. davyae* Stapf, *M. ruandensis* De Wild., *M. rubronervata* De Wild., *E. edule* Horan., *E. buchanani* (Baker) Cheesman, *E. schweinfurthii* (Schumann and Warburg) Cheesman, *E. arnoldianum* (De Wild.) Cheesman, *E. holstii* (Schumann) Cheesman, *E. ulugurense* (Warburg) Cheesman, *E. fecundum* (Stapf) Cheesman, *E. laurentii* (De Wild.) Cheesman, *E. bagshawei* (Rendle and Greves) Cheesman, *E. davyae* (Stapf) Cheesman, *E. ruandense* (De Wild.) Cheesman, *E. rubronervatum* (De Wild.) Cheesman, *M. africana* Hort.

Description: This is the most important species in the genus. Reaching 5–7 m (16–23 ft) tall, it ranges throughout much of the African continent, and produces a rhizome that is used as a staple food by approximately 8 million people in the Ethiopian highlands. The variety 'Maurelii', 'Red Abyssinian', or 'Black banana' (synonym *E. maurelii*) is the most colorful, with the brightest red midribs, above and below, with rich dark red leaf stalks (petioles) and blackish-red leaf blades. Its flower cluster, embraced in maroon bracts, may reach 3 m (10 ft) long. The seeds are large, about 18 mm diameter x 14 mm deep (0.7 in x 0.5 in). Introduced into Hawai'i, it is rare or no longer present there.

Ensete ventricosum. PHOTO: J. DANIELLS

Musa

The genus *Musa*'s center of origin is Asia (primarily southern and southeastern). A great number of important plants are found in the genus; those that bear edible fruit are the most significant. In addition to fruit, bananas and plantains provide many cultures with medicines, beverages, fibers, edible floral parts, dyes, fuel, steam for cooking, cordage, wrapping materials, etc. With few exceptions, the familiar eating bananas are naturally occuring hybrids among the various subspecies of *M. acuminata* and interspecific hybrids between *M. acuminata* and *M. balbisiana*.

Musa taxonomy is confused by several factors including the sterility, ancient domestication, and hybrid origins of the cultivated varieties (cultivars), and the unwillingness of many to adopt newer, correct names. For example, Linnaean binomials such as *M. paradisiaca* ('French' plantain) and *M. sapientum* ('Silk') are still used decades after the cultivars to which these names refer were recognized as *M. acuminata* × *M. balbisiana* hybrids (see Part 2). Constantine summarized the confusion (Constantine, 2004).

Historically, four sections have been recognized in *Musa*, AUSTRALIMUSA, CALLIMUSA, MUSA (formerly known as EUMUSA), and RHODOCHLAMYS. Recent molecular analyses indicate a reduction to two sections, but much further study is required before the above system is abandoned.

Section AUSTRALIMUSA (chromosome number: x = 10)

Seeds subglobose or compressed, smooth, striate, tuberculate or irregularly angled. Contains the Fe'i bananas, which are important in the Pacific. Their origins are complex and may involve as many as three species, *M. lolodensis, M. maclayi* and *M. peekelii*. Also included in the section is an important source of fiber, abacá (*M. textilis*).

Plants in the AUSTRALIMUSA section are generally tall, with seeded fruit, and distinctive green or greenish-yellow buds (if present). Their seed structure is important for classification purposes, viz. either subglobose or compressed, smooth, striate, tuberculate, or irregularly angled.

Section AUSTRALIMUSA ranges naturally from New Guinea and northern Queensland into the western Pacific. However, a principal component, the Fe'i bananas have become famous because of their association with French Polynesia, where they were transported long distances in canoes by Polynesian seafarers as far back as 250 BC (Marquesas Islands) and later in ~800 AD (Tahiti). In 2004, Micronesian Fe'i bananas enjoyed spotlighting in Pacific agricultural circles. 'Karat', 'Utin lap' and other bananas have been shown to contain the high levels of beta carotene (vitamin A precursor).

Fe'i are robust plants bearing erect bunches of brilliant orange-gold fruit, which are delicious and nutritious when baked or boiled, especially if the slices are swathed in fresh coconut cream. Additional characteristics (also in *M. jackeyi*) are a "bloody" purple-magenta sap and the production of reddish-amber to red urine by those who consume the fruit.

M. textilis (abacá or Manila hemp) is particularly important in Philippine culture, and to a certain extent in some traditional islands of Micronesia, as a source of fiber. The translucent, silky shirts (often embroidered) worn by Filipino men on important occasions are woven from paper-thin strips of abacá pseudostem. In the outer islands of Yap, islanders still use hand-looms to weave abacá fiber into women's wrap-around skirts or lavalavas (pareus). Abacá produces a shiny, apple-green bud.

M. bukensis Argent

M. jackeyi W. Hill. Common name: Johnstone River banana.

This has only a small range in North Queensland, Australia. It greatly resembles a Fe'i, with upright fruit stalk, Fe'i-like bananas, an enormous green bud pointing skyward, and "bloody" sap. May be synonymous with *M. maclayi* subsp. *ailuluai.*

M. lolodensis Cheesman

Possible precursor of the Fe'i bananas. Native to the West Sepik region of Papua New Guinea and parts of Indonesia.

M. maclayi von Muell. ex Mikl.-Maclay

Possible precursor of the Fe'i bananas. The fruits are rounded, appressed together in tight bunches, and in some varieties, partly joined together laterally.

- subspecies ***ailuluai*** Argent
- subspecies ***maclayi***
  - var. ***erecta*** (Simmonds) Argent
  - var. ***maclayi***
  - var. ***namatani*** Argent

M. peekelii Lauterb.

Possible precursor of the Fe'i bananas. A very tall plant (>10 m [33 ft]), with a bunch of fruits tipped with a narrow green bud which is pendent, rather than reaching skyward. Its geographical range includes Papua New Guinea, and it was found in the Philippines (Palawan) in 1960. Introduced into Hawai‘i, this banana can be seen at the Waimea Valley Audubon Center, O‘ahu.

subspecies ***angustigemma*** (Simmonds) Argent Synonym: *M. angustigemma* Simmonds

subspecies ***peekelii***

M. textilis Née. Common names: abacá, Manila hemp, amukid, maguindanao (Philippines)

Synonyms: *M. formosana* Hayata, *M. textilis* Née. var. *tashiroi* Hayata

Before the advent of synthetic textiles, *M. textilis*, was the source of one of the world's premier fibers—soft, silky, glistening, and fine-textured. Its fibers were also suitable for other manufactured products such as rayon, cellophane, and newsprint. It was even a constituent in some European paper money. Commercial production was greatest in the Philippines and Central America, but has now all but disappeared. Niche markets now cater to intricately woven floor mats, fancy place mats, and specialty paper.

Abacá is a beautiful, tall plant, typical of the AUSTRALIMUSA section. Introduced into Hawai‘i for commercial purposes in the late 1800s, it is now rare. It can be found at the Waimea Valley Audubon Center (O‘ahu) and National Tropical Botanical Garden (Kaua‘i).

Section CALLIMUSA (chromosome number: x = 10)

Bracts plain, firm, shiny on the outer surface, rarely glaucous and strongly imbricate when closed. These plants are most important as ornamentals. Most bear upright flower stalks, variously colored buds and flowers, and small seedy fruit.

M. alinsanaya Valmayor, sp nov. Common name: Alinsanay

Its shiny green bud hides purple inner linings, and its small fruit are "long bottle-nosed" and seedy.

M. beccarii Simmonds

This species bears a narrow, elliptical, bright scarlet bud, with green-tipped bracts. Fruits are green and skinny.

M. borneënsis Beccari

M. campestris Beccari

M. coccinea Andrews. Common Names: Red (flowering) Thai banana, scarlet banana, Thai red banana, coccinea, Okinawa torch, Okinawan banana flower, red ornamental banana

Synonyms: *Musa uranoscopos* Lour. non Rumph., *Musa uranoscopos* Lour. non Colla.

This species bears a rounder red flower cluster than *M. beccarii*, composed of erect spirals of red bracts, inside which are enclosed tubular yellow flowers. Its orange, seeded fruit are small (ca. 0.8 cm [2 in] long). Native to China and Indochina. Occasionally grown in Hawai‘i at commercial heliconia farms, especially on Maui and the island of Hawai‘i.

M. exotica R. Valmayor, sp. nov.

A species described in 2004, *M. exotica* was originally collected from the Cuc Phuong Forest Reservation, Ninh Binh Province, Vietnam. It has a clear orange, upright bud and male flowers, below which small yellow bananas develop.

M. flavida M. Hotta

M. gracilis Holttum

A beautiful plant (<2 m [6.6 ft] tall), with narrow, magenta and green striped fruits, and an upright pink-purple bud. Native to Malaysia and Thailand.

M. salaccensis Zoll. Common name: Javanese wild banana

M. suratii G. C. G. Argent

M. violascens Ridley

A fairly short ornamental plant, with mauve bud bracts. Occasionally found in Hawai‘i's botanical gardens. This species is often confused with *M. ornata*.

Section MUSA (former section) EUMUSA (chromosome number: x = 11)

Most cultivated varieties (cultivars) of edible banana originated from two species in this section, *M. acuminata* and *M. balbisiana*.

Musa acuminata Colla.

Synonyms: *M. chinensis* Sweet, *M. corniculata* Kurz, *M. rumphiana* Kurz, *M. simiarum* Kurz

A variable species with six to nine subspecies, depending on the authority (eight are described here). Recent genetic studies have identified which subspecies were probable parents of some important edible cultivars worldwide (see Part 2). Recent expeditions have focused on finding, analyzing, and attempting to protect the myriad forms of this species, in the hopes that banana breeders will be able to develop more—and better—strains of disease-resistant bananas. Because of the increasing incidence of debilitating pests and banana diseases, together with increasing world populations, breeders are expending great effort to develop desirable seedless bananas, suitable for growing under a wide range of environmental conditions and appropriate for many cultural food preferences. *M. acuminata*'s native habitat ranges throughout SE Asia (west to Myanmar) and Papua New Guinea.

subspecies *banksii* (F. Muell.) Simmonds. North Indonesian islands, Papua New Guinea, and northern Queensland, eastward to Samoa, where it is called 'Fa'i Taemanu' (rare today).

Synonym: *M. banksii* F. Mueller

This is a key subspecies for those interested in edible, hybrid bananas that arose within the Pacific, since it is considered to be both maternal and paternal parents of Plantain and 'Pōpō'ulu' subgroups, and the maternal parent of the 'Maia Maoli' subgroup. Maoli bananas, characterized in part by 15–20 cm (6–8 in), sausage-shaped fruit with rounded tips, are the primary clone represented in Oceania, ranging from the western Pacific >6400 km (>4000 mi) eastwards to the Marquesas Islands.

subspecies *burmannica* Simmonds. Burma, southern India and Sri Lanka.

subspecies *burmannicoides* DeLanghe. Southern India.

subspecies *errans* Argent. Common names: Fleur de banane des Philippines, saging maching, saging na ligao, saging chongo, agutay (Philippines)

Synonyms: *M. errans* Teodoro, *M. troglodytarum* L. var. *errans, M. errans* Teodoro var. *botoan*

Another banana that was significant in the past for its maternal contributions to many AA and AAA dessert bananas. It is a very pretty subspecies, with a blue-violet pendent bud and very pale green immature fruit.

subspecies *malaccensis* (Ridley) Simmonds. Peninsular Malaysia and Sumatra.

Synonym: *M. malaccensis* Ridley

Paternal parent of 'Silk' AAB, the "true apple" banana, common in the West Indies (not to be confused with "apple" bananas of Hawai'i). The clone 'Pisang Lilin' is a derivative of this subspecies.

subspecies *microcarpa* (Beccari) Simmonds. Borneo.

This subspecies has given rise to the clone 'Veinte Cohol'.

subspecies *siamea* Simmonds. Cambodia, Laos and Thailand.

subspecies *truncata.* Peninsular Malaysia (highlands)

subspecies *zebrina* (Van Houtte) R. E. Nasution. Java. Common Name: Blood banana

Synonyms: *M. acuminata* Colla subsp. *sumatrana* (Becc.) A.N. Other, *M. acuminata* Colla 'Sumatrana' Hort., *M. sumatrana, M. sumatrana* 'Rubra'

This subspecies was transported not only eastwards into the Pacific, but west to Africa, where it evidently became the paternal parent of the Mutika/Lujugira subgroup AAA (aka East African Highland Bananas).

This plant has striking dark green leaves splotched with variably sized maroon patches. Thriving under heavy shade, it is also characterized by very slender pseudostems and small, slender, prominently "beaked" fruits full of grape-like seeds.

In Hawai'i, it may be seen only occasionally, primarily in botanical gardens such as Waimea Valley Audubon Center, and Lyon Arboretum (O'ahu), and rarely in private gardens. It is of cultural significance in Hawai'i, because it is possibly the only seeded banana variety introduced as a medicinal plant by pre-Cook Polynesians. As such, it is called 'Mai'a 'Oa', although there has been much local confusion with other seeded bananas, particularly *M. balbisiana*.

M. balbisiana Colla. Common names: Balbisiana, Balbis banana, Starchy banana, Mealy banana, Seedy banana, Wild (starchy) banana, Devil banana and Seeded "apple" banana (Maui, Hawai'i), Pisang Klutuk Wulung, Botohan, and Pacol (Philippines).

Synonyms: *M. brachycarpa* Back., *M. liukiuensis* (Matsum.) Makino, *Musa* × *sapientum* var. *liukiuensis* Matsum., *M. sapientum* L. var. *liukiuensis* Matsum. *M. sapientum* L. var. *pruinosa*

This species is extremely robust, fast-growing, and drought-resistant. The wild, seedy forms are much less variable than *M. acuminata*, although five morphotypes have been described. It is found in Hawai'i (Maui, O'ahu), likely having been introduced from the Philippines into O'ahu in the late 1800s with the fiber plant, abacá (*M. textilis*). It eventually became a useful windbreak. *M. balbisiana* is one of the parents of many edible seedless bananas. It is native to Southeast Asia from Sri Lanka to the Philippines.

M. basjoo Sieb. Common names: Japanese (fiber) banana

Synonym: *M. japonica*

Used for fiber and as an ornamental. Native to Japan (including the Ryuku Islands), this is probably the world's most cold-hardy banana. It is a medium-sized plant (to 5 m [16 ft]) similar to abacá, with a beautiful, rounded, large green and yellow, shiny bud and inedible fruit. It is also used for fiber, elegant fabrics, and as an ornamental.

M. cheesmani Simmonds

M. flaviflora Simmonds

M. halabanensis Meijer. Common name: West Sumatra wild banana

M. itinerans Cheesman

M. nagensium Prain

M. ochracea Shepherd

M. schizocarpa Simmonds

M. sikkimensis Kurz
Synonym: *M. hookerii* King

Section RHODOCHLAMYS (chromosome number: x = 11)

Many highly ornamental species are found in this section.

M. aurantiaca Mann ex Baker

M. laterita Cheesman. Common name: Indian dwarf banana.

Native to Myanmar (Burma) and Thailand, this is an orange-red budded ornamental bearing yellow female flowers.

M. mannii H. Wendl. ex Baker. Common name: Mannii, dwarf banana

This little known species from Assam, rare in the wild, has recently been discovered by horticulturalists, propagated, and made available to tropical plant enthusiasts. A dwarf ornamental (ca. 1 m [3.3 ft] tall), its most notable features are bright pink-purple fruiting stems and bud bracts.

M. ornata Roxb. Common names: Ornamental banana, flowering banana, ornata

Synonym: *Musa rubra* Wall.

Originally hailing from Bangladesh, Burma and India, this species is probably the most widely planted ornamental banana in the tropics and subtropics. In Hawai'i, *M. ornata* is occasionally grown in botanical and private gardens, particularly along the wet, windward coasts.

M. rosacea Jacq.

M. rosea Baker

M. rubra Wall. ex Kurz

M. sanguinea Hook. f.

Synonym: *Musa* × *paradisiaca* L. ssp. *sapientum* (L.) Kuntze var. *sanguinea* Welw.)

Another striking ornamental from northern India, this one (like *M. mannii*) has a pink-purple bud and fruit stalk. The bud bracts are whitish inside, and immature fruits are pale green.

M. velutina H. Wendl. and Drude. Common names: Fuzzy (pink) banana, self-peeling banana, pink banana, hot pink banana, Velutina

Native to northern India, it is widespread in tropical botanical gardens, and is becomingly increasingly available for homegardens. Its upright "hot" pink bud, whose bracts are crowded with bright yellow flowers, produce small, fuzzy, fat, bright pink bananas. Their white inner flesh is packed with black seeds, which germinate readily, although rather slowly. This banana's species name, *velutina*, means "velvety", as indeed it is. When ripe, the banana's flesh bursts through its skin at the apex, then proceeds to "peel itself", true to its alternate common name, "self-peeling banana". In Hawai'i, this species thrives wherever it is planted, especially in wet, windward regions. It can grow at least as high as 1100 m (3600 ft) on Haleakalā, Maui.

Incertae sedis (taxa with uncertain taxonomic positions)

M. boman Argent (x = ?)

A tall plant from New Guinea with a glossy yellow bud, resembling abacá (*M. textilis*).

M. ingens Simmonds **(chromosome number: x = 7)**

This is the world's largest herb, and can reach 15 m (49 ft) in height and 2.5 m (8 ft) in circumference at the base. It is found on the island of New Guinea between 1000 and 2100 m (3300–6900 ft) in elevation.

Part 2: Cultivated varieties (cultivars) of edible bananas

Most edible bananas originated from two species in the section MUSA, *M. acuminata* and *M. balbisiana*. The cultivars are either hybrids among subspecies of *M. acuminata* (see Part 1) or between *M. acuminata* and *M. balbisiana*. These hybrids are diploid (two sets of chromosomes), triploid (three sets, the most common and important ploidy), or tetraploid (four sets). A perceptive observer can usually deduce a variety's genome (i.e., its ploidy and relative content from *M. acumniata* and *M. balbisiana*) by observing leaf thickness, size, and orientation, and by using a scoring system that considers 15 morphological characteristics. However, ploidy is best determined by chromosome counts or flow cytometry. These include pseudostem ("trunk") color, leaf stem (petiole) structure, fruit stalk (peduncle) hairiness, shape and size of the male bud, scars left from falling flowers on the lower fruit stalk (rachis), and details of the male flowers. When denoting each cultivar's genome, a lettering system is used. For example, *M. acuminata* and *M. balbisiana* are diploids, with genome AA and BB, respectively, and AA and AB clones are cultivated. Hybrid triploids are classified as AAA, AAB, or ABB. Tetraploid bananas (mostly products of breeding programs) may be AAAA, AAAB, AABB, or ABBB.

M. acuminata evolved primarily in tropical rainforests in Southeast Asia, whereas *M. balbisiana* originated in monsoon areas in northern Southeast Asia, and southern Asia. Thus, pure *M. acuminata* cultivars developed first in Southeast Asia and its hybrids with *M. balbisiana* arose where distributions of the two species overlapped. As newly discovered hybrids were carried by indigenous peoples by land and sea, more opportunities for hybridization arose, especially since not all were completely sterile. However, variation in the crop in its secondary centers resulted primarily from mutations in the cultivars.

Major secondary centers of diversity occur in West Africa (Plantain subgroup), Polynesia (Maoli-Pōpōʻulu and Iholena subgroups, aka Pacific Plantains), and East Africa (Mutika/Lujugira subgroup, aka East African Highland Bananas). With the exception of hybrids from the breeding programs, all cultivars discussed below are natural hybrids. Over thousands of years, they were selected by people and henceforth propagated vegetatively as clones. They can produce fruit without fertilization, which is called "parthenocarpy." Many cannot interbreed because they are sterile. Bananas produce basal suckers (called *keiki* in Hawaiʻi, the local word for "children"), which can be used to propagate an individual plant vegetatively. Only recently have the origins of the hybrids begun to be understood (see Part 1).

The edible bananas are highly diverse. Some of the most variable traits include: plant stature and architecture; sucker production; pigmentation; bunch size, orientation, and shape; fruit size, shape, color, and taste. Estimates of the numbers of cultivars that occur worldwide range from 300 to more than 1000. Common names that have been given to some of the cultivars are ambiguous. There are hundreds of duplicate names and close clonal relatives found in every region of every banana-growing country. There are so many names that even compiling lists for specific countries or regions is a daunting task. For example, 'Lady(')s) Finger' has been used to name at least four distinct AA, AB, and AAB clones.

In the following list, cultivars and groups of cultivars with an *acuminata/balbisiana* heritage are listed alphabetically within a given genome. Where it first appears, the most widely used common name of a cultivar is listed in boldface type. Other, less commonly used names are listed thereafter, and specific countries or regions in which the names are used are listed in parentheses. Bananas that are hybrids between *M. acuminata* and *M. textilis*, and *M. acuminata* and *M. schizocarpa* are unimportant and not included below. The Feʻi bananas, which arose from a different group of *Musa* spp. in the AUSTRALIMUSA section, are covered separately at the end of Part 2.

Seeded fruit of M. balbisiana. PHOTO: R. PLOETZ

AA GENOME

Cultivars with an AA genome are most abundant in Malaysia, Indonesia, India, and Papua

New Guinea (the only place where AA clones are common). They are cultivated due to their extraordinarily sweet, fine quality fruit. In general, they are less hardy than triploid cultivars.

Inarnibal subgroup

'Inarnibal' (Philippines) lit. "syrup"

Other common names: 'Pisang Lemak Manis' (Malaysia); 'Pisang Lampung' (Indonesia); Pisang Berlin (Indonesia)

Lakatan subgroup (There is an accession of this cultivar in Australia with an AAA genome.)

'Lakatan' (Philippines)

Other names: 'Pisang Berangan Merah/Kuning' (Malaysia), 'Pisang Barangan Merah/Kuning' (Indonesia), 'Kluai Hom Maew', 'Kluai Ngang Phaya' (Thailand); Mapang

A delicious, much-loved cultivar, commonly grown in the Philippines. Not to be confused with the tall Cavendish cultivar 'Lacatan' (AAA).

Pisang Lilin subgroup

'Pisang Lilin' (Malaysia, Indonesia)

Other names: 'Lidi', 'Pisang Lidi', 'Pisang Empat Puluh Hari', 'Pisang Lemak Manis Terenganu', 'Pisang Lemak Manis Kelantan', 'Pisang Mas Sagura', 'Pisang Ekor Kuda' (Malaysia); 'Mama-on' (Philippines); 'Pisang Lemak Manis', Pisang Muli' (Indonesia); 'Kluai Lep Mu Nang', 'Kluai Thong Ki Maew', 'Kluai Thong Kap Dam' (Thailand), 'Chuoi Tien' (Vietnam).

Sucrier subgroup

'Sucrier' (Fr. lit. "sugar bowl or basin")

Other common names: 'Lady's Finger' (Hawai'i); 'Amas', 'Caramelo', 'Kamoros' (Philippines); 'Pisang Mas' (Ma-

Left: 'Sucrier'. PHOTO: I. MAGUIRE **Right: 'Sucrier' fruit.** PHOTO: A. K. KEPLER laysia, Indonesia); 'Kluai Khai' (Thailand); 'Sagale Nget-Pyaw' (Burma/Myanmar); 'Surya Kadali' (India); 'Kudud' (Pohnpei, Federated States of Micronesia); 'Sucrier', 'Sucrier Fig', 'Fig', 'Datil', 'Honey', 'de Rosa', 'Fig Sucré' (West Indies); 'Orito' (Ecuador); 'Lady Finger', 'Nino' (Florida); 'Bocadillo' (Colombia); 'Banana Ouro' (Brazil), 'Peru', 'Fig', Tinito (French Polynesia); 'Rose', 'Golden Early', 'Date', 'Fig', 'Dedo de Dama', 'Niño', 'Manices', 'Guineo Blanco', 'Cambur Titiaro' (Latin America), 'Parika' (Guyana).

'Sucrier', originating in Malaysia, is the most widely cultivated AA cultivar and is one of the world's most popular local bananas. Its finger-sized fruit are deliciously sweet. The plant resists Panama disease (Fusarium wilt) and thrives when grown in partial shade. Its fruit length depends on soil and climate, reaching 1.6–2 in (4–5 in) under perfect growing conditions. It is rare in Hawai'i.

Other AA cultivars

'Chingan' (India)

Other common name: 'Manniyilla Chingan' (India)

'**Hapai**' (Hawai'i) lit. "pregnant"

Other names: **'Hapū**' (Tahiti) lit. "pregnant"

The AA genome has been assigned to this previously unclassified, rare Polynesian banana, based on morphological characters. Occasionally, the bananas of this clone develop within the pseudostem, causing a swelling that is reminiscent of pregnancy, thus the name.

'Tuu Ghia/Gia'

A variety introduced into several Pacific islands with a distinctive long bud and "messy" rachis is resistant to black Sigatoka disease and is used in breeding.

Miscellaneous AA cultivars

'Malaysian Blood', **'Pisang Jari Buaya'** (Indonesia, Malaysia), **'Rose'** (Indonesia), **'Senorita'** (Philippines), **'Tapo'**, and numerous PNG cooking cultivars.

AB GENOME

AB cultivars are uncommon. Among these, 'Ney Poovan' is grown most widely, due to its exceptional flavor.

Kamarangasenge subgroup

'Sukari Ndizi' (also, 'Sukali Ndizi') (Uganda)

Other common name: 'Kamarangasenge' (Rwanda)

AA cultivar 'Peleu' typical of PNG, growing in Pohnpei. PHOTO: J. DANIELLS

Ney Poovan subgroup

'Ney Poovan' (India)

Other common names: 'Safet Velchi' and 'Chini Champa' (India); 'Kisubi' (Uganda); 'Ranel' (Sri Lanka); 'Apple', 'Farine France', 'Lady's Finger' (West Indies)

'Ney Poovan' produces a sweet, subacid fruit with white flesh. Older reports that indicate that the cultivar resists Panama disease are in error.

Other AB cultivar

'Kunnan' (India)

AAA GENOME

Cavendish subgroup

This is a most significant subgroup of edible bananas. The Cavendish cultivars produce fruit that are used in international commerce; they are major export commodities in Central America, South America, the Caribbean, West Africa, and the Philippines. Local production of these clones is of even greater importance. In total, Cavendish cultivars are the most popular and valuable of the edible bananas; they comprise over 40% of these fruit that are produced worldwide. In equatorial lowlands where the ambient temperatures are high, fruits turn greenish-yellow when ripe, although where temperatures are a bit cooler or when artifically ripened, they turn bright yellow.

The subgroup is resistant to Panama disease in the western tropics, but is susceptible to the Sigatoka leaf spots; management of the latter disease is a major expense in commercial production, especially in areas with high rainfall.

The various clones are similar except for their height and characteristics of the bunch and fruit. In general, the trades have chosen productive cultivars of moderate stature (tall clones lodge in high wind and are difficult to harvest). All but 'Extra Dwarf Cavendish' are productive if they are provided with ample fertilizer and water. The list below is in descending order of the height to which they will grow in a given location (for a given cultivar, height varies greatly with elevation, temperature, and water supply).

'Pisang Masak Hijau' (Malaysia) (lit. "green ripe banana")

Other common names: 'Hamakua' (Hawai'i); 'Bungulan' (Philippines); 'Lacatan' (western tropics); 'Pisang Buai', 'Pisang Embun Lumut' (Malaysia); 'Pisang Ambon Loemoet' (Indonesia); 'Kluai Hom Kiau' (Thailand); 'Thihmwe' (Burma/Myanmar); 'Sapumal Anamalu' (Sri Lanka); 'Bout Rond' and 'Giant Fig', 'Congo' (West Indies); 'Mestiça' (Brazil); 'Monte risto' (Puerto Rico), 'Chuoi Tieu Cao #1' (Vietnam); 'Siaine' (Tonga, also general name for Cavendish Group); 'Amoa Kauare' (Cook Is.); 'Veimama' (Fiji)

This cultivar is usually too tall for commercial production. It is grown in Jamaica and Puerto Rico, and used for coffee shade in Colombia and Ecuador. In Hawai'i, it was recently wiped out on O'ahu by bunchy top disease; the authors have not yet found it elsewhere in the State.

'Giant Cavendish' cultivars

Other common names: 'Veimama' (Fiji); 'Giant Chinese' (general name); 'Mons Mari', 'Tall Mons Mari' (Queensland); 'Williams', 'Williams Hybrid' (Australia and most Pacific islands, including Hawai'i); 'Harichal' (India); 'Robusta', 'Nain Gánt', 'Giant Governor' (West Indies); 'Nanicó' (Brazil); 'Pisang Cina' (Malaysia); 'Robusta', 'Valery' (Central America, Jamaica, Hawaii); 'Taiwan' (Hawai'i), 'Porto Rique' (Dominica, West Indies); 'Poyo' (Guadeloupe); 'Congo' (Surinam—see also 'Pisang Masak Hijau'); 'Maghrabi', 'Williams' (Egypt); 'Tumok' (Philippines); 'Pisang Ambon Hijau' (Indonesia); 'Kluai Khlong Chang' (Thailand); 'Chuoi Tieu Nho' (Vietnam); 'Siaine' (Tonga, also name for general Cavendish Group); Fa'i Palagi (Samoa, also general name for Cavendish Group); 'Amoa Taunga' (Cook Is.); 'Vaimama Leka' (Fiji); 'Saina' (New Guinea); 'Congo' (Surinam); 'Bijiaw' (China); 'Amoa Taunga', 'Amoa Kauare' (Cook Islands); 'Siaine Ha'amoa' (Tonga); 'Hamoa' (French Polynesia); 'Utin Wai' (Pohnpei, Federated States of Micronesia).

There are several 'Giant Cavendish' cultivars that are so similar that they cannot be distinguished unless they are planted side by side. Even their male flowers are indistinguishable. Mid-way in stature between 'Pisang Masak Hijau' and 'Dwarf Cavendish', they may differ in height by about 40 cm (1 ft) and exhibit subtle differences in bunch, finger, trunk, and rachis morphology and color.

'Grande Naine' (also **'Grand Nain'**) (Fr. lit. "big dwarf")

Other common names: 'Umalog' ('Umalag' is another spelling) (Philippines); 'Pisang Ambon Jepang' (Indonesia); 'Chuoi Va Huong' (Vietnam)

'Grande Naine' is the most important commercial clone worldwide due to its resistance to wind throw and production of large bunches and fingers despite its relatively small stature. It should be understood that these height designations assume that the different clones are being compared side-by-side, i.e., growing simultaneously in the same location. It can be sensitive to drought and other adverse soil conditions. In Hawai'i, it is occasionally seen at high elevations.

'Dwarf Cavendish'

Synonyms: *M. cavendishii* Lamb., *M. cavendishii* Lamb. & Paxt., *M. cavendishii* Paxt., *M. nana auct. non* Lour., *M. sinensis* Sweet ex Sagot

Other common names: 'Cavendish', 'Chinese', 'Dwarf Chinese', 'Pake' (Hawai'i); 'Poot', 'Tampohin', Tampihan, 'Sulay Baguio' (Philippines); 'Jainaleka' (Fiji); 'Fa'i Palagi' (also refers to 'Giant Cavendish' in Samoa) (Samoa); 'Chuoi Duu' (IndoChina); 'Canary Banana', 'Dwarf Cavendish' (general); 'Pisang Serendah' (Malaysia); 'Pisang badak' (Indonesia); 'Kaina Vavina' (Papua New Guinea); 'Dwarf Cavendish' (Australia); 'Ai Keuk Heung Ngar Tsiu' (Hong Kong); 'Kluai Hom Khieo Khom', 'Kluai Hom Kom' (Thailand), 'Wet-ma-lut' (Burma/Myanmar); 'Banane Gabou' (Seychelles); 'Pacha Vazhai', 'Mauritius', 'Vamanakeli', Pachawara', 'Basrai', 'Kabulee', 'Bhusawal', 'Jahaji' (India); 'Binkehel', 'Nanukehel', 'Pandi' (Sri Lanka); 'Kinguruwe', 'Malindi' (Tanzania and Zanzibar), 'Nyoro' (Kenya); 'Giuba' (Somalia); 'Mouz siny', 'Moz Hindi', 'Hindi', 'Indian', 'Basrai' (Egypt); 'Bazrai' (Pakistan); 'Johnson' (Canary Islands); 'Camyenne' (Guinea); 'Guineo Enano', 'Petite Naine', 'Governor' (West Indies); 'Camburi Pigmeo', 'Enano' (lit. "dwarf") (Latin America); 'Ana', Ananica', 'Caturra' (Brazil); 'Mei'a', 'Meika Kina', 'Kira' (French Polynesia); 'Chuoi Tieu Lun' (Vietnam); 'Siaine Tonga' (Tonga); 'Amoa Taunga Potopoto' (Cook Is.); 'Park-yuk' (China)

This is the most widely distributed clone of edible banana worldwide; it is also the shortest used for commercial production. It bears good-quality fruit, with a long transport life if picked at the correct maturity (which is a general character of Cavendish subgroup), and is well suited for homegarden, commercial, and agroforestry cultivation. Short and compact, it is relatively cold-tolerant. However, it is highly susceptible to banana bunchy top virus, and chokethroat (impeded bunch emergence) where temperatures below 15°C (59°F) occur for extended periods. In Hawai'i, 'Dwarf Chinese' is grown everywhere from the lowlands to the coldest elevations which banana tolerates (approximately 1300 m [4260 ft]).

'Double'

Sometimes called 'Māhoe' or 'Mahoi' in error, because it is different from the true 'Māhoe' in the Maoli-Pōpō'ulu Group, is a 'Dwarf Chinese' mutant that produces 2–7 bunches per plant (these are surprisingly common in French Polynesia), but evidently occur wherever this clone is grown.

'Extra Dwarf Cavendish'

Other names: 'Dwarf Parfitt' (Australia); 'Dwarf Nathan' (Israel)

This clone, less than 1 m (3.3 ft) tall, does not produce acceptable fruit and is used as an ornamental plant.

Left: 'Williams', a 'Giant Cavendish' cultivar. Ulaino, windward Maui, Hawai'i. Right: Young 'Dwarf Cavendish' bunch. Haiku, Maui. PHOTOS: A. K. KEPLER

Gros Michel subgroup

Members of this subgroup are listed below in descending order of height. They can be confused with members of the Cavendish subgroup (note common names in Burma and Sri Lanka). Cultivars in the Gros Michel subgroup can be distinguished from those in the Cavendish subgroup by their green/pale pink vs bright red undersheath, bottle-necked fruit, ripening to full yellow color at ambient equatorial temperatures, short pedicels, and extreme susceptibility to Panama disease in the Americas and Africa. These clones produce a few seed when pollinated and have been used in the breeding programs.

'Gros Michel' (West Indies)

Other common names: 'Bluefields' (Hawai'i); 'Jainabalavau' (Fiji); 'Au Malie', 'Fa'i Fia Palagi' (Samoa), 'Pisang Embun', 'Pisang Ambon' (Malaysia); 'Pisang Ambon Putih' (Indonesia); 'Kluai Dok Mai', 'Kluai Hom Thong' (Thailand); 'Avabakor', 'Disu' (Papua New Guinea); 'Anamala' (Sri Lanka); 'Thihmwe' (Burma/Myanmar); 'Guineo Gigante', 'Guaran' (Puerto Rico); 'Raimbaud', 'Makanguia' (French Antilles); 'Banano', 'Habano', 'Guineo' (Colombia); 'Plantano Roatan' (Mexico); Jainabalavu (Fiji); 'Siaine Fisi' (Tonga); 'Ambon' (Philippines); 'Chuoi Tieu Cao #2' (Vietnam)

'Gros Michel' is a vigorous plant, but is tall (7 m [23 ft] or more) and very prone to wind damage. It produces excellent fruit that are more durable than those of the 'Cavendish' cultivars. It was the standard for export until the mid-1900s, but was eliminated from commercial production due to widespread and destructive epidemics of Panama disease. As a result, members of the Cavendish subgroup replaced this clone in most of the affected areas. Isolated pockets of 'Gros Michel' production remain, especially where disease suppressive soils exist. 'Bluefields', the cultivar's name in Hawai'i, is the port in Nicaragua from which the clone was sent to the island.

'Cocos' (Honduras), **'Highgate'** (Jamaica)

These smaller versions of 'Gros Michel' were used extensively in breeding programs, especially in Jamaica and Honduras. Several hybrid bananas developed in Honduras in the FHIA program have proven to be disease-resistant, highly productive, basically seedless, and of generally acceptable taste. They are currently being introduced to many Pacific islands (e.g., Micronesia, Samoa, Tonga, French Polynesia) to eventually supplement more established bananas that are being weakened and killed by introduced pests and diseases.

'Lowgate' (Honduras)

This smallest version of 'Gros Michel' is used in the FHIA breeding program.

'Gros Michel'. Puohokumoa Stream, Maui. PHOTO: A. K. KEPLER

Ibota subgroup

'Yangambi Km 5'

Mutika/Lujugira subgroup

Synonym: Musa brieyi De Wild.

These bananas, known generically as the East African Highland Bananas, are staple foods in the Rift Valley region of East Africa, especially in Burundi, Rwanda, and Uganda. They are found nowhere else in the world, and are an example of secondary diversity in the bananas developing outside Southeast Asia. They are cooked and brewed for beer, and are diverse. Over 200 cultivars are recognized in Uganda, five clone sets of which are recognized: 'Beer', 'Musakala', 'Nakabululu', 'Nakitembe', and 'Nfuuka'.

Red subgroup

'Red'

Other common names: 'Jainadamu' (Fiji); 'Fa'i Suka', 'Fa'i Niue' (Samoa); 'Morado' (Philippines); 'Pisang Raja Udang' (Malaysia); 'Rong Rong' (Papua New Guinea); 'Kluai Nak (Thailand); 'Shwe Nget-Pyaw' (Burma/Mynamar); 'Chenkadali', 'Lal Kera' (India); 'Rathambala' (Sri Lanka); 'Rouge' (Seychelles); 'Neuse', 'Nyekundu Ya Kisungu', 'Mzungu Mwekundu' (East Africa); 'Morado', 'Colorado', 'Figue Rouge', 'Red', 'Claret' (West Indies); 'Red Dacca' (Queensland); 'Tafetan' (Colombia); 'Banana Roxa' (Brazil); 'Kinaki Tangata' (Cook Islands); 'Akadahn Weitahta' (Pohnpei); 'Red', 'Cuban Red', 'Pink banana' (Hawai'i)

A beautifully pigmented plant with deep red trunk, petioles, and midribs. It produces moderately sized bunches of fruit that have a reddish-green to deep maroon skin (depending on age and exposure to direct sunlight), and light orange flesh. They are usually eaten raw before getting mushy and fall apart when cooked or too ripe, although they can be cooked in their jackets.

'Green Red'

Other common names: 'Pisang Mundam' (Malaysia); 'Warabia' (Papua New Guinea); 'Green Dacca', 'Red Raja' (Queensland); 'Venkadali' (India); 'Galanamalu (Sri Lanka); 'Banane Monsieur' (Seychelles); 'Nyeupe Ya Kisungu', 'Mzungu Mweupe' (East Africa); 'Morado Verde', 'Colorado Blanco', 'Figue Rose Blanche', 'Green Red' (West Indies); 'Tafetan Verde' (Colombia); 'Caru Verde' (Brazil); 'Moradong Puti' (Philippines); 'Pisang Telor' (Indonesia); 'Kluia Kung Khieo' (Thailand); 'Tara Puakanio' (Cook Islands); 'Green-Red', 'Colorado Blanco' (old name) (Hawai'i); 'Akadahn' (Pohnpei); 'Green Macaboo' (Florida)

The Red/Green Red cultivars are related, in that those in the red series often give rise to a green form (the reverse has not been recorded). They are usually tall plants, although dwarf versions exist. They are moderate producers that are grown primarily for their attractive and unusual fruit. The fruits are usually eaten raw. Plants of the red clones are highly pigmented and produce fruit that have a red to deep maroon skin, and light orange flesh. They are used as ornamental plants in Hawai'i and elsewhere in the Pacific.

Other AAA cultivar

'Lakatan' (Philippines) (Note that some clones by this name are supposed to be AA.)

Other common names: 'Pisang Berangan' (Malaysia); 'Pisang Barangan' (Indonesia);

AAB GENOME

The Iholena and Maoli-Pōpō'ulu subgroups together form the "Pacific plantains," the principal Polynesian basic types of bananas from which many similar varieties evolved on different Pacific archipelagos over thousands of years. Their

Top: 'Dwarf Red'. Waip'io Bay, Maui. PHOTO: A. K. KEPLER
Bottom: 'Dwarf Red' female flowers. PHOTO: C. ELEVITCH

history is closely linked to Polynesian migrations, transported as suckers over relatively short distances (island to island). Their dissemination across the Pacific occurred gradually. Once staple dietary items on high islands from New Guinea to the Marquesas, they have sadly become neglected, rare, and virtually unknown in many cultures. Early visitors to Hawai'i in the late 1700s and 1800s were amazed at the prodigious numbers of "native" bananas (primarily Maoli-type) which were grown by the Hawaiian people. However, dietary tastes have changed, and the sweeter "dessert" bananas have largely displaced the native bananas since the 1850s. Land clearing, copra plantations, pests and diseases (especially banana bunchy top), plus a market economy, have all contributed to the demise of Polynesian bananas and plantains across the Pacific.

Today, only approximately half of the varieties that are known across Polynesia exist in Hawai'i, and most are rare. Polynesian high islands such as the Samoas, Tonga, Cook Islands, and French Polynesia still have some of these bananas here and there. Further west, Maoli, Pōpō'ulu, and Iholena types may still be found abundantly in local markets, e.g., in Vanuatu.

Full descriptions and photographs of Hawaiian (with some Pacific) varieties are being documented (Kepler and Rust, unpublished).

Iholena subgroup

Iholena types are poorly represented in the Pacific these days, but still survive (barely) in Samoa, French Polynesia, Vanuatu, New Guinea, and perhaps elsewhere including Tonga. In Hawai'i, they are the most common traditional bananas to be found in upland forests and are eaten cooked or raw. Of approximately 50 "native" Hawaiian varieties known historically, at least seven were Iholenas. Most are rare or extinct; five are still found naturalized in reasonable numbers. Three varieties ("Red" and "White" Iholenas, both forms of Mai'a [Iholena] Lele) and a Dwarf were sent to the mainland USA more than 30 years ago.

Iholena types are graceful plants. Their most outstanding characteristics are: a) new, unfolding (cigar) leaves with striking mauve or coppery undersides; b) fruit pointed at both ends with salmon-colored flesh; c) fruit arranged loosely and at right angles on the bunch; and d) male flowers with long, lavender stamens. Iholenas are characterized by pale yellow-green immature fruits from earliest development.

'Fa'i Mamae' (Samoa)

Very rare, this clone is characterized by a distinct red petiole rim and bright waxy-purple leaf undersides. Also called 'Mama'e Ulu'.

'Iholena Iholena' (lit. "yellow core") and its possibly extinct dwarf form, **'Iholena Ha'a Ha'a'** (lit. "short-short")

Extremely rare in Hawai'i, this banana is a semi-dwarf, with a pale yellow-green pseudostem (blackish in 'Ha'a').

'Iholena Kāpua' (the name refers to the slender, arrow-shaped, beautiful flower bud). Other names: 'Puapuanui'

This is easily recognized by its extremely long, red, slender fruit stalk (peduncle), and short-tapered fruit tips.

'Iholena Lele' (lit. "to fly")

This short-fruited Iholena was used in religious ceremonies. It was planted at *heiau* (temples), not near houses, because it was said to cause the souls of the house occupants to "fly" away. It also bears a dark red peduncle (up to 1.2 m [4 ft] long) and long pointed fruits with lengthly pointed tips.

'Ōre'a' (Tahiti)

This is the French Polynesian equivalent of Iholena. They appear to have been lost from the Marquesas but two or three rare clones still survive on Tahiti and Raiatea, perhaps also on Huahine.

Other Iholena clones include '**Mamae Hehefanga**' (Tonga)**; 'Uzakan**', '**Morpa**', '**Yamunamba**', '**Numeijo', 'Luba**' (Papua New Guinea)

Maoli-Pōpō'ulu subgroup

Maoli subdivision

These distinctive bananas occur throughout Oceania, usually tended by islanders who recognize that they are part of their Polynesian heritage. Like all Polynesian bananas, they are particularly susceptible to pests and diseases, requiring replanting every few years. This subgroup is best recognized by its sausage-shaped fruit with blunt ends. The Maoli types are long, whereas Pōpō'ulu types are fat and squat, and bluntly square at their tips.

In Hawai'i, the two subdivisions are easily distinguished. However, in the western Pacific, bananas exist which possess characters of both subgroups: long like a Maoli, but plumper and square-ended like a Pōpō'ulu. In Tonga the term Hopa means bananas of both Maoli and Pōpō'ulu types. In Pohnpei (FSM) bananas of this intermediate type exist also such as 'Peleu' and 'Karat en Iap' (unrelated to the more common 'Karat' bananas, which are Fe'i) (Englberger and Lorens, 2004).

In ancient Hawai'i, records exist for at least eleven Maoli varieties, together with several subvarieties. Along with new discoveries, there are currently twelve extant cultivars. In the rest of the Pacific, Maoli varieties—the base clone

 

'Iholena Lele'. Maui Nui Botanical Garden, Kahului, Maui. LEFT PHOTO: C. ELEVITCH, RIGHT PHOTO: A. K. KEPLER

for the majority of Polynesian plantains—have survived a little better than Pōpō'ulu and Iholena bananas.

'Manini' (lit. "striped surgeon fish"), **'Koa'e'** (referring to the bold, striped plumage of tropicbirds in juvenile plumage)

Other common names: 'A'ea'e' (lit. "hair prematurely graying"), 'Hawaiian Variegated' (Hawai'i)

'Manini' is a Hawaiian cultivar with green and white variegation that covers the entire plant: leaves, leaf stalks (petioles), immature and ripe fruit, even the male and female flowers. The achlorophyllous tissues have a tendency to sunburn. Grows to height of 6–7 m (20–23 ft), prefers acid soil (<pH 6), will not tolerate neutral or basic soils, and thrives best in cloudy or lightly shaded areas. The fruit are best cooked, but are palatable raw when fully ripe.

'Ele'ele' (lit. "black-black")

Other common names: 'Black Hawaiian', 'Hawaiian Black Banana' (Florida)

An attractive Hawaiian banana, this is extremely uncommon, preferring streambeds and well-watered forested areas. It is immediately recognizable by its shiny, blackish-burgundy trunk, leaf stalks, and midribs (especially in wild, shaded locales). Its fruit is long, meaty, and delicious fried. Its variants, 'Poni' ("purple"), 'Hinupua'a' ("shiny like hog grease") and 'Puna' (region on the island of Hawai'i) are less black overall.

'Ere'ere' (lit. "black-black")

Other names: 'Iri mo'o' ("lizard skin"), 'Iri pa'o' ("black skin/bark")

This Tahitian variety appears to be virtually identical to Hawai'i's 'Ele'ele'.

Left: 'Manini' variegated leaves and fruit. PHOTO: A. K. KEPLER **Right: 'Manini' leaves of young plant.** PHOTO: C. ELEVITCH

'Fa'i Samoa' (lit. "Samoan native bananas")

This group of plantains is the Samoan equivalent of Maoli and Maoli-Pōpō'ulu types of cooking bananas. Several varieties are still grown in gardens, although they are not common: **'Fa'i Samoa'** (most often seen), **'Fa'i Samoa Pau Manifi'** ("thin-skinned" Samoan banana), **'Fa'i Samoa Au Malie'** ("shark-handle", with longer fruit than Fa'i Samoa and less even fruit bunches). '**Fa'i Samoa Puputa'**, **'Fa'i Samoa Lautele'**, and **'Fa'i Samoa Lap Lapa'** are all rare.

'Hai'/'Haikea' (waxy form of 'Hai', meaning "pale")

Very rare in Hawai'i, this clone has a reddish trunk and very pink flowers.

'**Hopa'** (Tonga)

As indicated above, the Tongan "Hopas" include Maoli, Maoli-Pōpō'ulu, and Pōpō'ulu types. Two varieties of these sausage-like Maolis still in existence are: **'Feta'u'** and '**Feta'u Hina'** (a whiter form). These can usually be seen on Tongan farms in Hawai'i.

'Māhoe'

Other common names: 'Palua', 'Mana-lua', 'Hualua' (Hawai'i)

Appears to be extinct.

'Mangaro' (Aitutaki, Cook Islands)

These are the Cook Island equivalents of Hawai'i's Maoli types. At least five varieties still exist, only very rarely. **'Mangaro Torotea'** has a very even, large bunch of fruit of plump fruits, which are perfectly sweet and delicious when still green. Rare (or nearly extinct) Mangaro varieties from the Cook Islands are 'Mangaro Manii', 'M. Aumarei', 'M. Taanga', and 'M. Akamou'.

'Māo'i' (Marquesas Is.) and **'Mā'ohi'** (Tahiti)

Māo'i are the French Polynesian equivalents of Maoli, a clone almost revered in some areas because of its ancient cultural associations. Most are rare, but are locally common in a few areas. Selected varieties still in existence (as of 2004) are: **'Māohi Huamene', 'Māo'i Koka'**, **'Māo'i**

Ku'uhua', '**Māo'i Pukiki'**, **'Mei'a Ma'ohi Hai'** (Marquesas, Tahiti), **'Mei'a Mao'i Maita'** (Fatu Hiva, Marquesas). Dozens of varieties have become extinct.

'Maoli' (lit. "native")

A very attractive plant with pink coloration especially when young, it has large bunches of even, sausage-shaped fruit. It can be seen in botanical gardens in Hawai'i. Throughout Polynesia there are equivalents to this clone.

Other rare, extant Hawaiian Maoli varieties are: **'Kaualau'** (with distinctive dark red male flowers), **'Mānai 'ula'** (with tough trunk fibers used for stringing leis), and **'Puhi'** (whose young fruits are complexly oriented like a bunch of young eels).

'Pacific Plantain'

This striking Maoli cultivar has an unknown origin in the western Pacific (Solomon Isands?). Beautiful and dark, it resembles the dark 'Ele'ele'/'Ere'ere' varieties (black trunk and leafstalks), with dark green, sausage-shaped bananas.

Other cultivars elsewhere include **'Mei'a Ma'ohi Hai'** and **'Mei'a Mao'i Maita'** (French Polynesia); **'Comino'**, **'Pompo'** (Colombia); **'Comino'**, **'Pompo'** and **'Maqueño'** (Ecuador); **'Pacific Plantain'** (Australia)

'Pōpō'ulu' subdivision (lit. "like the male fruiting structure of breadfruit")

Like Maoli, Pōpō'ulu is a Hawaiian word; however, this type of banana is found throughout the Pacific, although in ever-decreasing numbers. Historically, Hawai'i harbored at least eight cultivars, of which six are extant. The most famous because of its size is the 'Huamoa' (see below). Pōpō'ulu cooking bananas range in size from 5–22 cm (2–9 in long), with some 'Huamoa' in Hawai'i recently found measuring 30 cm (12 in) in circumference. The fruits tend to split when ripe, so they are usually harvested shortly before fully ripening on the stalk. They are delicious sauteed or boiled, especially with coconut cream added.

Left: 'Ele'ele' bunch. Ko'olau Forest Reserve, Maui. Right: 'Fa'i Samoa'. Apia, Samoa. PHOTOS: A. K. KEPLER

'Huamene' (Tahiti) On the verge of extinction, formerly widespread in French Polynesia.

'Huamoa' or **'Moa'** (lit. "chicken" or "goose egg")

Other names: 'Hawaiiano' (Florida, imported from Hawai'i)

This clone occasionally forms only a few, extraordinarily large fruit on the bunch; otherwise, the bunch is normal, but with fruit ranging from small eggs to 20 cm (8 in) in length by 6 cm (2.5 in) in diameter. The Samoan **'Fa'i Samoa Fua Moa'** is extremely similar and has a name with the same meaning.

'Ka'io' (lit. "like the round, bitter gourd")

The smallest of the Hawaiian Pōpō'ulu fruit, of which only one cluster of plants is known. Its taste varies from inferior to delicious.

'Lahi', **'Lahilahi'**, or **'Ili Lahilahi'** (lit. "thin-skinned") Hawai'i

A thin-skinned form of 'Pōpō'ulu Pōpō'ulu'.

'Mangaro Akamou' (Aitutaki, Cook Islands)

This Cook Islands' Pōpō'ulu has relatively few fruit.

'Pōpō'ulu Pōpō'ulu' (lit. "ball-shaped like a breadfruit")

Very rare, this clone's fruit is longer than most Pōpō'ulu fruit, more resembling the parental Maoli-type.

'Putalinga' (Tonga)

Probably the most red of all the Maoli-Pōpō'ulu Group, this beautiful "hopa" is associated with Tongans, either in their homeland, Hawai'i, or elsewhere. With a predominantly red trunk, red, purple, and yellow leaf stalks (petioles), and a broadly oval bunch of chubby fruit that project out perpendicularly to the axis. This is a notable Polynesian specialty with several greener variants than the popular 'Putalinga Kula'.

Mysore subgroup

Synonyms: *M.* × *paradisiaca* L. ssp. *sapientum* (L.) Kuntze var. champa, *M. sapientum* L. var. *champa* Baker.

Other common names: 'Liganimarama' (Fiji); 'Misiluki' (Samoa); 'Pisang Keling' (Malaysia); 'Kluai Kai Ferang' (Thailand); 'Nget-pyaw Chin' (Burma/Myanmar); 'Poovan', 'Mysore', 'Champa', 'Lal Velchi' (India); 'Embul', 'Honderawala' (Sri Lanka); 'Kikonde' (Zanzibar); 'Mysore', 'Thousand Grain', 'Fillbasket' (West Indies); 'Mysore' (Australia); 'Pang', 'Kahiki Hae', and 'Dwarf Waimea' (Hawai'i)

This widely spread dessert clone is vigorous and resists Panama disease and the Sigatoka leaf spots. Most accessions of it are infected with, and display symptoms caused by, *Banana streak virus* (BSV).

'Huamoa'. Waipi'o Bay, Māui. PHOTO: A. K. KEPLER

Pisang Raja subgroup

'Pisang Raja'

Synonym: *M. regia* Rumphias

Other common names: 'Pisang Raja' (Malaysia and Indonesia); 'Larip', 'Houdir', 'Kalamanawudu' (Papua New Guinea); 'Grindy' (Windward Islands); 'Biu Raja' (Java)

Plantain subgroup

Synonym: *M. discolor* Horan.

This diverse group of "true" plantains is not to be confused with Pacific plantains or with other cooking bananas with an ABB genome. Plantain fruit are often longer and far more pointed. They comprise 21% of annual *Musa* production worldwide, assuming their greatest dietary importance in West Africa and Latin America. In these regions they are a major source of dietary carbohydrates. Four subsets

'Putalinga Kula'. Tongan-owned farm, Waihe'e, Maui. PHOTO: A. K. KEPLER

of cultivars are recognized based on the size and shape of the bunch and fruit. Within the different sets are numerous cultivars.

Members of the plantain subgroup are characterized by long, curved, very starchy bananas. Some particularly large horn plantains are the size and shape of bull horns, and are named thus in different languages, e.g., 'Kerepiha/Kerepifa' or "beef's horn" (Marquesas) and 'Tara puatoro' or "bull's horn".

French plantains are generally differentiated from Horn plantains by their retention of bud bracts on the stalk (rachis) below the fruit, whereas Horn plantains develop a small or nonexistent bud (putting all their energy into the huge fruit). In other words, French plantains have a very "messy" rachis and big bud below the fruit, whereas the Horn plantains have a "clean" rachis, with little or no bud on the end. Intermediate inflorescence characteristics are found in the French Horn and False Horn subsets of cultivars. Below are listed some prominent members in each.

'French'

Synonym: *M. paradisiaca* L., *M. paradisiaca* L. var. *viridis* De Wild., *M. purpureo-tomentosa* De Wild., *M.* × *paradisiaca* auct. non L.

Many ill-defined forms of French plantain exist, some overlapping with the next two clonal clusters: 'Green French', 'Pink French', 'Wine', 'Black French', 'Tiger', and 'Giant'.

Some common cultivars: **'Obino l'Ewai'** (Nigeria); **'Njock Kon'**, **'Bobby Tannap'** (Cameroon); **'Nendran'** (India); **'Dominico'** (Colombia); **'Tarapuakanio'** (Cook Is.). French plantains are known only in India, Africa, Egypt, and the Americas.

'French Horn'

Some common cultivars: **'Mbang Okon'** (Nigeria); and **'3 Vert'** (Cameroon)

'False Horn'

Synonyms: *M. decrescens* de Briey

Some common cultivars: **'Agbagba'** and **'Orishele'** (Nigeria); **'Dominico-Hartón'** (Colombia); **'Cuerno'** (Central America); **'Barragante'** (Ecuador) **'Batard'**

'Horn'

Synonyms: *M. corniculata* Rumphias, *M. corniculata* Lour., *M. emasculata* de Briey ex De Wild., *M. protractorachis* De Wild.

Some common cultivars: **'Ishitim'** (Nigeria); **'Pisang Tandok'** (Malaysia)

Pome subgroup

The Pome subgroup, prominent in places such as Brazil, India, Hawai'i, Cameroon, and Australia, is characterized by fruit stalks that emerge at an angle until the fruit develop, whereafter the rachis falls vertically. Fruit are distinctly "beaked" or "bottle-nosed" and have a particularly subacid or "apple-like" taste. Because of this piquant flavor, various cultivars have been named "apple" thereby confusing these cultivars with 'Silk', the more widely recognized "apple" banana.

'Pome'

Other names or similar clones: 'Apple', 'Tall Apple', 'Brazilian', 'Brazilian Tall' (Hawai'i); 'Pisang Kelat Jambi' (Malaysia); 'Vannan', 'Virupakshi', 'Sirumalai' (India); 'Puwalu' (Sri Lanka); 'Kijakazi' (Zanzibar); 'Bakweri' (West Africa); 'Pome' (Canary Islands); 'Brazilian' (Florida); 'Lady's Finger' (Queensland) and a newer variety 'Improved Lady's Finger' (Australia, western Pacific islands, see 'Pacha Naadan', below); 'Rio' (Tahiti, Marquesas); 'Pime' (Nuku Hiva, Marquesas); 'Krishna Vazhai' (black-trunked sport, India); 'Pime pukiki' (red-stemmed sport, slightly smaller fruit), 'Brazilian Red', 'Rio 'Ute'ute', 'Rio Rouge', 'Rio Pukiki' (French Polynesia); 'Preisihl' (Pohnpei, Federated States of Micronesia).

These plants are sturdy, vigorous, highly productive and can be quite tall. In Hawai'i and French Polynesia, local Pome-type clones are favored above all others. They are the most common home-grown and island-grown commercial banana.

'Prata Aña'

Other names: 'Dwarf Apple', 'Dwarf Brazilian', 'Santa Catarina' (Hawai'i); 'Prata Santa Catarina' (Brazil)

In Hawai'i, this clone ranks second in cultivated area, yield, and production. Its delicious fruit command high prices due to their sweet-acid flavor and long shelf-life. The plants are sturdy, vigorous and relatively tolerant to pests and diseases.

'Pacovan' (Brazil), **'Pacha Naadan'**

Other names: 'Pachanadan' (India); 'Improved Lady Finger' (Queensland); 'Lady's Finger' (Western Pacific islands)

This dessert cultivar represents about 5% of Australian production. It is drought hardy and resists strong winds.

Silk subgroup

'Silk'

Synonyms: *M. sapientum* L., *M. paradisiaca* L. ssp. *sapientum* (L.) Kuntze var. *cubensis*, *M. berteri* Colla, *M. berteroi* Colla, *M. berteroniana* von Steudel

Other names: 'Amorosa', 'Manzano', 'Manzana', 'Lady Finger' (Hawai'i), 'Apple' (Florida); 'Letondal', 'Latundan', 'Tordan', 'Tundan', 'Turdan', Cantong', 'Amorosa', 'Katungal' (Philippines); 'Silk Fig', 'Manzana', 'Manzano', 'Figue Pomme', 'Apple' (West Indies); 'Rasthali', 'Sonkel', 'Mutheli', 'Morthoman', 'Sabari' (India); 'Kolikutt' (Sri Lanka); 'Pisang Rastali' (Malaysia); 'Worodong', 'Maramba'. 'Avundumong' (Papua New Guinea); 'Sugar' (Queensland, Australia); 'Pukusa' (Zanzibar); 'Kipukusu', 'Kipungusu' (East Africa); 'Manzano', 'Manzana' (Latin America); 'Maça' (Brazil); 'Hta-bat' (Burma/Myanmar); 'Kluai Nam' (Thailand); 'Chuoi Goong' (Vietnam) ; 'Miti Ruki', 'Tiki'

Left: 'Pome'. Papeete, Tahiti. Right: 'Silk'. Kīpahulu, Maui. PHOTOS: A. K. KEPLER

(Cook Islands); 'Utin Kuam', 'Utin Menihle', 'Uht Tikitik (Pohnpei, Federated States of Micronesia)

Only 'Dwarf Cavendish' is found more widely than this cultivar. It produces exceptionally flavorful fruit with a sub-acid, apple-like taste. The fruit peel splits and the flesh is white when ripe, and is astringent when not. It has declined in importance there and elsewhere due to its pronounced susceptibility to Panama disease. In Hawai'i, it is found almost exclusively within Filipino communities, who perhaps introduced it to Hawai'i, bringing with it their Philippine name, 'Amorosa'. Grown at elevations above 500 m (1640 ft) or in poor soils, especially those deficient in calcium and boron, a common occurrence in tropical and subtropical regions, the fruit's flesh becomes hard, tasteless, and dry.

Other AAB cultivars

'Pisang Seribu' (Malaysia)

Synonym: *Musa chiliocarpa* Backer.

Other common names: 'Kluai Roi Wi' (Thailand), 'Thousand Fingers' (Florida)

'Pisang Kelat' (Malaysia)

Other names: 'Taiwang' (Pohnpei)

This is an important clone in Pohnpei, where it has been found to have fairly high levels of beta carotene.

ABB GENOME

These cultivars produce relatively starchy fruit, primarily used for cooking. The plants are drought resistant and generally resist the Sigatoka leaf spot diseases.

Bluggoe subgroup

These are vigorous clones. They produce widely spaced, large, angular, straight fruit that have long peduncles; usually, only four to seven hands are produced on a bunch. The various cultivars are distinguished by stature, bunch size and the fruit skin (green, silver, or waxy). They are susceptible to race 2 of Panama disease and Moko disease.

'Bluggoe'

Other common names: 'Largo' (Hawai'i); 'Jamani' (Fiji); 'Fa'i Pata Samoa', 'Puataelo' (Samoa); 'Pisang Abu Keling' (Malaysia); 'Pisang Batu' (Java); 'Nalla Bontha' (India); 'Hpi Gyan' (Burma/Myanmar); 'Mondan' (Sri Lanka); 'Mkojosi', 'Bokoboko', 'Kproboi', 'Muskat', 'Punda', 'Kidhozi', 'Kivivu' (East Africa); 'Matavia' (Philippines); 'Kluai Som' (Thailand); 'Square Cooker', 'Mondolpin' (Australia); 'Burro', 'Chato', 'Cachaco', 'Cuatrofilos', 'Largo', 'Majoncho', 'Apple Plantain', 'Horse Banana', 'Hog Banana' (Americas); 'Burro', 'Orinoco' (Cuba); 'Horse Plantain' (Jamaica, Dominican Republic, Trinidad and Tobago) ; 'Poro'ini', 'Poro'ini Pa'afa'afa'a', 'Poro'ini Hima'a umu', 'Largo' (French Polynesia); 'Pata Tonga' (Tonga); 'Tarua Matie' (Cook Islands); 'Chuoi Ngop Lun' (Vietnam); 'Whitehouse Plantain', 'Chamaluco', 'Poteau', 'Cacambou', 'Moko', 'Bluggoe', 'Buccament', 'Mafoubay' (West Indies)

'Bluggoe' is grown in many countries due to its excellent taste, bountiful productivity, and resistance to drought.

'Dwarf Bluggoe'

Other common name: 'Chamaluco Enano', 'Cachaco Enano' (Puerto Rico)

'Silver Bluggoe'

Other common names: 'Katsila' (Philippines); 'Silver Bluggoe', 'Silver Moko' (West Indies); 'Kluai Hakmuk' (Thailand); 'Thella Bontha' (India); 'Pisang Nipal' (Malaysia); 'Poro'ini hinuhinu', 'Poro'ini Pa'amanina'; 'Poro'ini rehu' (Tahiti); 'Poro'ini pivai, 'Poro'ini blanc' (Marquesas Is.); 'Cenizo' (tropical America); 'Pata Sina' (Samoa); 'Tarua Teatea (Cook Is.); 'Inahsio Pehsehs' (Pohnpei, Federated States of Micronesia)

'Silver Bluggoe' is an attractive plant, commonly named in local languages for its silvery fruit coating.

Monthan subgroup

'Nalla Bontha Bathees' (India)

'Monthan' (India)

Other names: 'Monthan' (India); 'Maduranga' (Philippines); 'Pisang Abu Bujal' (Malaysia); 'Kluai Nom Mi' (Thailand); 'Chuoi Ngop Cau' (Vietnam)
Not considered prime quality, this Indian variety is nonetheless widespread in SE Asia. Its characteristic fruits bear large bulbous tips, resembling 'Bluggoe' but larger.

'Sambrani Monthan' (India)

'Pacha Monthan Bathees' (India)

Klue Teparod subgroup

'Kluai Tiparod'

Other common names: 'Pisang Abu Siam', 'Pisang Batu', 'Pisang Siam' (Malaysia); 'Tiparot', 'Balongkaue' (Philippines); 'Kluai Teparod', 'Kluai Sangkivo', 'Kluai Plihai' (Thailand); 'Pya-ye San' (Burma/Myanmar)

Formerly, this cultivar was thought to have an ABBB genome.

Ney Mannan subgroup

'Ney Mannan' (India)

Other names: 'Ice Cream' (Hawai'i, Florida); 'Blue Java', 'Java Blue', 'Vata', 'Pata' (Fiji,); 'Blue Java', 'Blue Lubin' (Australia); 'Alukehel', 'Ash Plantain' (Sri Lanka); 'Ney Mannan'(India); 'Pata Hina', 'Pata Lahelahe' (Tonga); 'Fa'i Pata Sina', 'Pata papalagi' (Samoa); 'Tarua Teatea' (Cook Is.); 'Dukuru' (Pohnpei, Federated States of Micronesia)

The fruit is named for its flavor and texture, sweet and smooth. When fully ripe, the flesh can be eaten with a spoon. Externally, the fruit is colored a beautiful silver-green, due to a heavy coating of wax.

Top: 'Bluggoe' female flowers. PHOTO: A. K. KEPLER **'Bluggoe'.** PHOTO: I. MAGUIRE

Pelipita subgroup

'Pelipia' (Central America)

Other common name: 'Pilipia' (Philippines)

This clone tolerates Moko disease, due to its persistent bracts. It was offered as a resistant replacement for 'Bluggoe' in the Americas where that clone was decimated by Moko disease.

Pisang Awak subgroup

'Pisang Awak' (Malaysia)

Other common names: 'Katali' (Philippines); 'Kluai Namwa' (Thailand); 'Pisang Klotok' (Indonesia); 'Choui Tay' (Vietnam); 'Karpuravalli' (India); 'Kayinja' (East Africa); 'Ducasse' (Australia); 'Yakhine (Burma/Myanmar); 'Pey Kunnan', 'Kostha Bontha', 'Monohar', 'Sail Kola' (India); 'Nyeupe' (Kenya); 'Balaliki', 'Paradaika' (Egypt)

This is the most widely disseminated ABB cultivar; 70% of all bananas that are grown in Thailand are of this clone. It is vigorous and tolerates adverse conditions, especially drought, but is susceptible to race 1 of Panama disease. A dwarf version, 'Kluai Namwa Khom', comes from Thailand and is now being widely distributed in the Pacific islands including Samoa and the Cook Islands.

Saba subgroup

'Benedetta'

'Inabaniko', 'Uht Kapakap' (Pohnpei); 'Praying Hands' (Florida); 'Ripping' (Philippines)

'Cardaba'

A Philippine cooking banana. With 'Saba', it was classified erroneously as having a BBB genome.

'Saba' (Philippines)

Other common names: 'Pisang Kepok' (Indonesia); 'Pisang Abu Nipah' (Malaysia); 'Kluai Hin' (Thailand)

The male bud of this clone is a popular vegetable in the Philippines.

AAAA, AAAB, AABB AND ABBB GENOMES

There are no natural AAAA and very few natural AAAB, AABB, and ABBB bananas, none of which are important. Tetraploids that are most common in cultivation are products of the breeding programs. In general, they have resulted from crosses between triploid female and diploid male parents. A few promising varieties are found in cultivation (including some Pacific islands) in those areas where banana diseases are rampant. Most notable among the bred tetraploids are those from the FHIA program in Honduras: dessert AAAA, 'FHIA-02' (aka 'Mona Lisa'), 'FHIA-17' and 'FHIA-23'; dessert AAAB, 'FHIA-01' (aka 'Goldfinger') and cooking and dessert 'FHIA-18'; plantain-like AAAB, 'FHIA-20' and 'FHIA-21'; and cooking or dessert AABB, 'FHIA-03'.

BB GENOME

Parthenocarpy did not evolve in *M. balbisiana* as it did in *M. acuminata*. Thus, edible diploid cultivars of the species do not exist. BB clones that are cultivated, such as 'Tani' (Thailand), are grown for their leaves and for animal feed.

BBB GENOME

Philippine ABB clones such as 'Cardaba' and 'Saba' were classified previously as BBB. Whether an uncommon clone in Thailand, 'Kluai Lep Chang Kut', is BBB is unclear.

FE'I BANANAS

The Fe'i cultivars range naturally from the Moluccas to French Polynesia. Particularly associated with the Marquesas and Society Islands (French Polynesia), Fe'i were staple and ceremonial foods since the Marquesas were first settled from the Samoa-Tonga region (~250 BC)

Left: 'Benedetta'. PHOTO: I. MAGUIRE **Right: Saba type 'Utin Ruk' in Pohnpei.** PHOTO: J. DANIELLS

Left: 'FHIA-03', an experimental AABB cooking or dessert banana. Right: 'FHIA-01' (aka 'Goldfinger'), an experimental AAAB dessert banana. Both photos: Nu'u Agricultural Station, 'Upolu, Samoa. PHOTOS: A. K. KEPLER

and Tahiti around 700–800 AD. Unfortunately their prevalence has declined drastically in recent decades. In addition to their erect bunches, they also can be recognized by their bright magenta to dark purple sap, heavily ridged, squarish red/coppery fruit, and near-iridescent orange or yellow fruit flesh. The fruit of some clones is exceptionally high in beta carotene (see e.g., Englberger and Lorens 2004). Although they can be quite sensitive during the establishment phase and some are susceptible to Panama disease, they are generally vigorous, tolerate most diseases and pests, and require little care once established.

These bananas are unique and distinct from the *acuminata/balbisiana* cultivars in the section MUSA. Although they are clearly in the section AUSTRALIMUSA, their precise origins are poorly understood. *M. maclayi* (based on morphology) and *M. lolodensis* (based on DNA studies) were suggested as probable parents of the extant clones. Recent genetic work indicated that they are closest genetically to these plus an additional species, *M. peekelii*. Thus, the Fe'i bananas may be interspecific hybrids. Genetic diversity among the Fe'i cultivars is as great as that that is found in the entire section AUSTRALIMUSA (see Part 1). Sharrock (2001) provided a recent summary of the history of and taxonomic work on this group.

Relationships and common names for the various clones in different areas are unclear. Prominent clones on different islands are listed below as distinct although some may be synonymous.

'Pisang Tongkat Langit' (eastern Indonesia) and **'Pisang Tongkat Langit Papua'** (Irian Jaya)

Synonym: *M. troglodytarum* L.

'Daak' (New Caledonia)

Synonym: *M. fehi* Bert. ex Vieill.

Top left: ‘Fe‘i ‘A‘ata’. Papeari, Tahiti. Top right: ‘Fe‘i ‘Auiri’. Papeari, Tahiti. Bottom left: ‘Fe‘i Tati‘a’. Papeari, Tahiti. Bottom right: All Fe‘i have bright magenta sap, some clones brighter than others. PHOTOS: A. K. KEPLER

'Soaqa' (Fiji)

Synonym: *M. seemanii* F. v. Muell.

'Fe'i' (Society Islands)

Synonym: *M. aiori* Sagot

The most common cultivars in home gardens today are **'Fe'i Aiuri'** and **'Fe'i Tatia'**.

Some common cultivars and synonyms elsewhere include **'Borabora'**, **'Polapola'**, **'Mai'a Ha'i'** (Hawai'i); **'Menei'**, **'Rimina'**, **'Utafan', 'Sar',** and **'Wain'** (Papua New Guinea); **'Chongk'** (New Hebrides); **'Fe'i'** and **'Soanga'** (Tonga); **'Soa'a'** (Samoa); **'Utu'** (Cook Islands); **'Huetu'** (Marquesas); **'Utin Iap'** and **'Karat'** (Pohnpei, Federated States of Micronesia); and **'Kulasr'** and **'Kolontol'** (Kosrae, Federated States of Micronesia)

PUBLIC ASSISTANCE AND AGROFORESTRY EXTENSION

Extension offices for agroforestry and forestry in the Pacific: <http://www.traditionaltree.org/extension.html>.

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Banana and plantain—an overview with emphasis on Pacific island cultivars

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Acknowledgments: Photo contributions from Ian Maguire are gratefully acknowledged. The authors are deeply thankful for the generous support they have received from academic colleagues and farmers throughout the Pacific.

Recommended citation: Ploetz, R.C., A.K. Kepler, J. Daniells, and S.C. Nelson. 2007. Banana and plantain—an overview with emphasis on Pacific island cultivars, ver. 1. In: Elevitch, C.R. (ed.). Species Profiles for Pacific Island Agroforestry. Permanent Agriculture Resources (PAR), Hōlualoa, Hawai'i. <http://www.traditionaltree.org>.

Sponsors: Publication was made possible by generous support of the United States Department of Agriculture Western Region Sustainable Agriculture Research and Education (USDA-WSARE) Program; SPC/GTZ Pacific-German Regional Forestry Project; USDA Natural Resources Conservation Service (USDA NRCS); Kaulunani, an Urban Forestry Program of the DLNR Division of Forestry and Wildlife and the USDA Forest Service; State of Hawai'i Department of Land & Natural Resources Division of Forestry & Wildlife; USDA Forest Service Forest Lands Enhancement Program; and Muriel and Kent Lighter. This material is based upon work supported by the Cooperative State Research, Education, and Extension Service, U.S. Department of Agriculture, and Agricultural Experiment Station, Utah State University, under Cooperative Agreement 2002-47001-01327.

Series editor: Craig R. Elevitch

Publisher: Permanent Agriculture Resources (PAR), PO Box 428, Hōlualoa, Hawai'i 96725, USA; Tel: 808-324-4427; Fax: 808-324-4129; E-mail: par@agroforestry.net; Web: <http://www.agroforestry.net>. This institution is an equal opportunity provider.

April 2006
ver. 2.1

Barringtonia procera (cutnut)

Lecythidaceae (Brazil nut family)

cutnut (English); *katnat* (Solomon Islands: pidgin); *navele* (Vanuatu); *pao* (Papua New Guinea)

Richard L. Pauku

IN BRIEF

Distribution Indigenous to the Solomon Islands, Vanuatu, and Papua New Guinea.

Size Grows to a typical height of 20 m (66 ft) with crown diameter of about 5 m (16 ft).

Habitat Lowland humid tropical rainforest, at elevations of 0–600 m (0–1970 ft) and uniformly distributed annual rainfall of 1500–4300 mm (60–170 in).

Vegetation Common in old gardens, mature coconut plantations, and coastal villages, and in remnants of secondary lowland rainforests.

Soils Wide range of light to heavy soils with free drainage.

Growth rate Moderate, mean height growth of <1 m/yr (3.3 ft/yr) for the first 10 years.

Agroforestry uses Windbreak, soil stabilization, "living ladder" (climbing tree), and homegardens.

Main products Nut.

Yields Estimated at 10–50 kg (22–110 lb) of fruits/tree/year. At 20 years of age, an annual yield estimate is 2–3 mt (2.2–3.3 t) fresh fruits annually per hectare, or 0.33–0.5 mt (0.37–0.55 t) kernel-in-testa/ha/yr.

Intercropping With proper spacing, it can be interplanted with a variety of shade-tolerant crops.

Invasive potential Does not appear to have potential to become a pest outside its native range.

PHOTO: R. PAUKU

Branching and canopy structure of cutnut. Poporo, Kolombangara, the Solomon Islands.

INTRODUCTION

Cutnut (*Barringtonia procera*) is a medium size, evergreen, tropical tree found in secondary forests of the Solomon Islands, Vanuatu, and Papua New Guinea It is grown in homegardens and coconut plantations and is common within the surroundings of both inland and coastal rural villages. The tree has been associated with human settlements since ancient times and is unlikely to occur in a truly wild form. Throughout Melanesian countries, cutnut is well known as a nut tree, and the people have both planted and protected it on their land.

Cutnut prefers light shade, which makes it a good companion to overstory tree species such as vi (*Spondias cyathera*), canarium nut (*Canarium* spp.), and breadfruit (*Artocarpus altilis*). Its open canopy structure allows sufficient light penetration to the ground level for other crops to be interplanted under it. For instance, farmers in Temotu province of the Solomon Islands have used cutnut as a companion and interline tree crop in an improved traditional agroforestry system. On Kolombangara Island, Solomon Islands, it has been used as a trellis tree for the cash crop betel leaf (*Piper betle*), as well as for marking land boundaries and creating windbreaks.

In a homegarden situation, cutnut provides good shade and shelter to root and cereal crops and other understory crops such as sugarcane (*Saccharum officinarum*) and a nutritious native leafy tree spinach called bele or edible hibiscus (*Abelmoschus manihot*). The species has a well formed lateral root system yet does not appear to cause major impediments during soil preparation for understory crops, e.g., making mounds for the root crops, nor does it seem to compete heavily with understory crops. In tree farming, cutnut may be planted as a shade tree for crops such as cacao (*Theobroma cacao*), joint fir (*Gnetum gnemon*), and betel nut (*Areca catechu*). There is no record of cutnut becoming invasive, and *in situ* observation on the distribution of wildings appears to rule out any potential invasiveness. Since 2002, a program to domesticate this species has been receiving much support from the local community in Kolombangara Island in the Solomon Islands.

DISTRIBUTION

Native range

Cutnut is indigenous to the Solomon Islands, Vanuatu, and Papua New Guinea. It is widespread and common at lower altitudes and is found mainly in villages and food gardens. These areas are characterized as wet tropical lowland rainforest.

Current distribution

Beyond its native range the species has not been widely distributed as an exotic species. However, it has been introduced to Howard Newport in Australia. It is reported to have been introduced into Fiji, although these may be *B. edulis*; without a thorough taxonomic classification, the presence of *B. procera* in Fiji remains uncertain.

BOTANICAL DESCRIPTION

Preferred scientific name

Barringtonia procera (Miers) Knuth

Family

Lecythidaceae (Brazil nut family), or Barringtoniaceae according to some authors

Non-preferred scientific names

B. guppyana Knuth
B. magnifica Laut.
B. schuchartiana K. Schum.

Common names

cutnut (English)
katnat (Solomon Islands: pidgin)
navele (Vanuatu)
pao (Papua New Guinea)

The standard common name in the Pacific is cutnut. In the Solomon Islands, it is a well known tree and has names in many local dialects, including *fala/aikenu* in Kwara'ae (Malaita Is.), *kenu* in To'oabaita (Malaita Is.), *vele* in Varisi (Choiseul Is.), *fara* in Santa Ana (Santa Ana Is.), *kino* in Nduke (Kolombangara Is.), *tinghe* in Roviana (New Georgia Is.), *oneve* in Marovo (New Georgia Is.), *fala* in Maringe (Isabel Is.), *nofe* in Zabana (Isabel Is.)

Size and form

Cutnut is a medium-size tree which can reach a height of 24 m (80 ft). The typical tree height is thought to be in the range of 8–12 m (26–40 ft), with a crown diameter of 0.8–6 m (2.6–20 ft). The diameter of the trunk at breast height of mature fruiting trees ranges from 2 to 45 cm (0.8–114 in) (mean = 18 cm [7 in]). The smaller height and trunk diameter measurements refer to a so-called dwarf form. A reasonably clear bole up to one fifth of the tree height is typical, although this varies among individual trees and cultivars. Irregular scars are occasionally found on the trunk as remnants of healed-over branch attachments. Cutnut produces a vigorous framework of branches resulting from whorls of main branches that fork regularly following the formation of the terminal inflorescences.

Flowers

Cutnut has a racemose inflorescence with a 30–110 cm (12–43 in) long pendulous spike containing up to 150 densely packed flower buds, arranged in spirally alternate pattern, and varying in colors, typically from green to white or red. Flowering is terminal on the shoots. Flower buds are semi-sessile to sessile and are protected by a calyx closed in the bud, which ruptures into two to four pseudolobes. The calyx apical pore varies in diameter, depending on the stage of development of the flower. It is completely closed at very early stage but later opens, making way for fully developed flower buds. Cutnut flowers are bisexual, with male and female reproductive parts occurring on the same flower.

At lower elevations in the Solomon Islands and Papua New Guinea, flowering occurs irregularly two to three times per year. On Kolombangara Island, Solomon Islands, two peak seasons occur in May–June and October–November each year, although low off-season fruiting does occur.

Leaves

The large, simple, lanceolate leaves are arranged in a whorl at each node. Leaf size varies, typically measuring 21.5–66 cm (8.5–26 in) long and 5–20 cm (2–8 in) wide. The upper surface of the leaf is dark green and glossy; the lower surface is slightly paler. Typically, the leaf has a truncated base and an acuminated apex, with undulated margins. Leaf veins are reticulated and vary in number according to leaf size, but there can be up to 34 on each side. The short thick petiole is up to 6 mm (0.25 in) in length with a mean width of 10 mm (0.4) at the basal end.

Fruit

Fruits are multiple, sessile, and borne on a pendulous rachis. At maturity they are indehiscent, but the skin can be easily peeled off when ripe. The elongated, oblong to obovoid fruits taper toward the apex and base. The shape of the fruit at the apex is emarginate-rounded and truncate-rounded at the base. Typical length of a mature fruit is 25–95 mm (1–4 in). Width at apex, mid-section, and base is, respectively, 14–45 mm (0.6–1.8 in), 22–59 mm (1–2.3 in), and 15–50 mm (0.6–2 in). Fruits in Vanuatu are longer and more cylindrical than those in the Solomon Islands. Fruit color

Flowers in white, yellow, and red. Tiny bees can be seen foraging on the flowers. Hunda, Kolombangara, Solomon Islands.
PHOTOS: R. PAUKU

Left and top right: Fruits and kernels. PHOTOS: R. PAUKU **Bottom right: Cutnut variation, green fruit with purplish color of testa and shell. This type is called Kobakilo in Varisi dialect, Choiseul Province, the Solomon Islands.** PHOTO: R. LEAKEY **All three photos were taken at Hunda, Kolombangara, the Solomon Islands.**

is variable, from grayish green to purplish red. In Vanuatu, fruiting occurs once a year in the wet season (September to March).

Seeds

The seed or kernel is contained in a fibrous, white to purplish, cylindrical, eight-sided endocarp shell (prominent when exocarp and mesocarp are removed). The fleshy mesocarp is food for animals such as cockatoos and flying foxes, and they disperse the seeds. The testa of green fruits in certain varieties can have a reddish/purplish color.

Bark description

The bark is smooth at early the stages of growth but becomes fissured as the trees grow older. Large lenticels up to 5 mm (0.2 in) across are present.

Rooting habit

The tree has a relatively shallow taproot and a well formed network of lateral roots, concentrated in the topsoil layer.

Similar or look-a-like species

The three edible species of *Barringtonia* (all called cutnut) are *B. procera*, *B. edulis*, and *B. novae-hiberniae*. The latter species is clearly distinguishable by its simple, near-entire leaves, and it is largely found in the wild form. The distinction between *B. procera* and *B. edulis* is not easy to identify because of the great variation within each of the species, which means that morphological characteristics can be overlapping, leading to confusion. Typically, however, *B. procera* is recognized as having glossy leaves, very short to sub-sessile petioles, and short to no pedicel.

Comparative morphological characteristics of edible *Barringtonia* species. Source: Payens 1967 and Evans 1999

Species	Leaf length (mm)		Leaf width (mm)		Petiole length (mm)	Pendicel length (mm)	Fruit shape	Calyx in bud
	min	max	min	max				
Barringtonia procera	45–60	48–60	15–24	17–24	Sub-sessile	Sessile	8-gonous	Closed/open
Barringtonia edulis	38–45	55–48	15–16	17–23	Short	Pedicelled	Ovoid	Closed
Barringtonia novae-hiberniae	20–25	23–35	7–10	8–15	Long	Pedicelled	Broad-ovoid	Large apical pore

The leaf and fruit morphology of *B. novae-hiberniae* is different from *B. procera* and *B. edulis*. *B. novae-hiberniae* and *B. procera* occupy overlapping geographic areas (sympatric). *Barringtonia edulis* and *B. procera* often have overlapping ranges, but *B. edulis* is absent in New Britain of Papua New Guinea and is present in Fiji. *B. novae-hiberniae* is largely undomesticated and thus is commonly found in secondary forests, fallow forests, and under coconut plantations but is less abundant around and within village surroundings. In terms of products and agroforestry services, they have similar domestication and market opportunities, but no formal investigations have been conducted on the vegetative propagation of *B. edulis* and *B. novae-hiberniae*. A molecular study is currently in progress to determine the integrity of these three species and whether any hybridization has occurred between them.

GENETICS

Variability of species

As is typical for out-breeding species, there is extensive variation in many morphological characteristics in cutnut, such as flower and fruit colors, etc. For example, fruits can be 20–140 g (0.7–5 oz) (mean = 64 g) in fresh weight; 25–95 mm (1–4 in) (mean = 67 mm) in length; and 14–45 mm (0.6–1.8 in) (mean = 28 mm) (apex), 22–59 mm (0.9–2.3 in) (mean = 39 mm) (mid), and 15–50 mm (0.6–2 in) (mean = 31 mm) (base) in diameter. For kernel-in-testa the fresh weight range is 5–25 g (0.2–1 oz) (mean = 11 g), the range of length is 10–50 mm (0.4–2 in) (mean = 33 mm), and the widths range as follows: 5–33 mm (0.2–1.3 in) (mean = 16.9 mm) (apex), 7–45 mm (0.3–1.8 in) (mean = 21.7 mm) (mid), and 6–37 mm (0.25–1.5 in) (mean = 18.2 mm) (base). The shell weighs 10–70 g (0.35–2.5 oz).

While most tree species such as *Pometia pinnata*, *Inocarpus fagifer*, *Artocarpus altilis*, and *Dacryodes edulis* are known for their outbreeding characteristics, it was observed in Kolombangara, Solomon Islands, that at very low levels cutnut might be self-pollinated as well. This observation, however, needs to be validated with further research on the reproductive biology of the species.

Known varieties

Traditionally, people have undertaken intensive selection over many years and have produced identifiable varieties that vary in several characteristics, particularly fruit color, shape, and size. In the Solomon Islands, four varieties of cutnut have been recorded, varying in fruit color, leaf size, and tree height. One of the varieties has a purplish testa and inner shell.

Culturally important related species in the genus

Species of cultural importance include *B. asiatica* and *B. racemosa*. In the Solomon Islands, *B. asiatica* is used for fish poisoning and treating toothache, while *B. racemosa* is

Left to right: Leaves and fruits of *Barringtonia procera* (dwarf tree), *B. edulis*, *B. procera*, and *B. novae-hiberniae*. PHOTO: B. EVANS, REPRODUCED WITH PERMISSION FROM EVANS 1999 a good live fence and is used for the treatment of venereal diseases, such as gonorrhea.

Genetic resources where collections exist

There has been little formal research on germplasm conservation or improvement of this tree. A provenance trial was set up in 1989 at Avuavu on the south coast of Guadalcanal in the Solomon Islands, and a small clone collection has been developed at Ringgi Cove on Kolombangara Island.

ASSOCIATED PLANT SPECIES

While cutnut is reasonably widely distributed in its native range, it is commonly found in old gardens, mature coconut plantations, and coastal villages. These habitats are remnants of secondary lowland rainforests.

Associated species commonly found in native habitats

Within the natural range of cutnut are other species including canarium nut (*Canarium* spp.), breadfruit (*Artocarpus altilis*), coconut (*Cocos nucifera*), Tahitian chestnut (*Inocarpus fagifer*), poumuli (*Flueggea flexuosa*), sago palm (*Metroxylon salomonense*), Malay apple (*Syzygium malaccense*), *Mangifera minor*, *Ficus* spp., *Macaranga* spp., *Terminalia* spp., and tava (*Pometia pinnata*).

Species commonly associated as aboriginal introductions in Pacific islands

Species commonly associated as aboriginal introductions in Pacific islands include other cutnut species *B. edulis* and *B. novae-hiberniae*, canarium nut, Malay apple, Tahitian chestnut, and *Terminalia* spp.

Left: Seedling root system. PHOTO: R. PAUKU **Right: The author examines flowers *B. novae-hiberniae* at Vovohe, Kolombangara Island.** PHOTO: R. LEAKEY

BARRINGTONIA ASIATICA

Barringtonia asiatica is a widespread tree, present in coastal India, Africa and southeast Asia to Melanesia, Micronesia, and Polynesia. It can grow up to 25 m (82 ft) in height. *B. asiatica* is morphologically distinct from the edible *Barringtonia* species. Its fruits are inedible and poisonous. Its leaves are large and simple, undulated, and held in rosettes at the ends of branches. The large stamens of the flowers are white with a pinkish color toward the apex. The fruits are four-sided with a conspicuous ridge on the angles, green when immature and yellowish brown when ripe. The fruit floats and the tree is commonly found in coastal locations—sandy and rocky shores. *B. asiatica* is commonly associated with *Intsia bijuga*, *Hibiscus tiliaceus*, and *Calophyllum inophyllum* close to the beach. Because the fruits float and can remain viable for many months, *B. asiatica* may have been introduced to the Pacific islands from southeast Asia. Although the seed is poisonous to humans, other parts of *B. asiatica* have medicinal value and are culturally important. The heated leaves are used to treat stomachache and rheumatism in the Philippines, while an extract of the boiled bark is used for treating toothache in the Solomon Islands. In many countries the leaves, seeds, or bark are used to stun fresh and saltwater fish and prawns. The species serves well in protection of coastal areas.

Flowers and fruits of *B. asiatica*. PHOTOS: C. ELEVITCH

Species commonly associated in modern times or as recent introduction

Species commonly associated with more recent introductions include banana (*Musa* spp.), cacao (*Theobroma cacao*), citrus (*Citrus* spp.), and papaya (*Carica papaya*).

ENVIRONMENTAL PREFERENCES AND TOLERANCES

Climate

Cutnut is commonly found in lowlands of the humid tropics, in areas with warm to hot temperatures throughout the year. The species tolerates the tropical cyclones that usually occur during the wet season from November to March in the Solomon Islands, Papua New Guinea, and Vanuatu. In its natural range, cutnut does not experience a dry season of more than a few months. Its tolerance of a longer dry season is not known. It is adapted to high rainfall up to 4300 mm (170 in) per annum. In Kolombangara, the Solomon Islands, high rainfall appears to reduce fruit set and thereby lowers fruit production.

Elevation range

0–600 m (0–1970 ft)

Mean annual rainfall

1500–4300 mm (60–170 in)

Rainfall pattern

The tree grows in climates with a uniform rainfall pattern.

Dry season duration (consecutive months with <40 mm [1.6 in] rainfall)

3–5 months. Monthly rainfall rarely falls below 40 mm in consecutive months in its range.

Mean annual temperature

26.4–27.7°C (80–82°F)

Mean maximum temperature of hottest month

29.4–34.5°C (85–94°F)

Mean minimum temperature of coldest month

20–23°C (68–73°F)

Minimum temperature tolerated

Unknown. Prolonged temperatures below 20°C (68°F) may negatively affect tree growth.

Soils

Cutnut generally grows in coastal coral soils with light to heavy textures. It occurs in soils with medium to high fertility, and it tolerates rocky soils. The tree grows well in coastal soils high in pH (up to 8.5), but it does not tolerate waterlogged soils.

Soil texture

It grows in light to heavy soils (sands, sandy loams, loams, sandy clay loams, sandy clays, clay loams, and clays).

Soil drainage

It prefers soils that have free drainage.

Soil acidity

The tree grows in mildly acid to neutral or mildly alkaline soils (pH 5.1–8.5).

Special soil tolerances

The tree tolerates shallow, saline, and infertile soils.

Tolerances

Drought

The tree is likely to be intolerant of prolonged drought.

Full sun

Cutnut grows well in full sunlight but is usually found as a sub-canopy species in low-density, mixed-species environments.

Shade

Cutnut tolerates 20–70% shade. Mature trees are more tolerant than young seedlings. In Kolombangara, Solomon Islands, 5-month-old seedlings grown under 30% shade and in full sunlight grew equally well (stem heights were about 34 cm for both) (author's unpublished research).

Fire

It is likely to be intolerant of fire.

Frost

This tropical species does not experience frost and is likely to be sensitive to temperatures below 15–20°C (59–68°F).

Waterlogging

Cutnut does not tolerate waterlogging.

Salt spray

The species is commonly found in coastal villages and sometimes grows a short distance from the sea, indicating some tolerance of salt spray.

Wind

Cutnut has medium to high tolerance of steady and strong winds including cyclones. Branches and twigs do not easily snap, but they may be broken off by strong winds. The trees rarely suffer from windthrow due to their height, open canopy structure, and good lateral rooting system.

ABILITIES

Self-prune

The tree is naturally self-pruning of lower branches up to about one-fifth of the height of the tree.

Coppice

Trees coppice well and young leafy shoots regrow rapidly following cutting. Stumps as short as 10 cm (4 in) in height coppice well.

Pollard

Pollarded trees resprout well. In Kolombangara, Solomon Islands, one to six shoots per pollarded branch sprouted after 2–3 weeks.

GROWTH AND DEVELOPMENT

Growth rate

Generally, cutnut grows moderately fast, but this varies significantly depending upon trees and growth conditions. Mean annual increment (MAI) for height of trees up to 5 years is 62 cm (24 in); thereafter the MAI increased about 1 m (3.3 ft) annually for the next 5 years. Thirty-year-old trees had an average MAI of about 1.4 m (4.6 ft). Diameter at breast height appears to be relatively uniform with age. Trees aged 5, 10, 15, and 20 years old have all attained an MAI for diameter at breast height on the order of 1.4–1.6 cm (0.55–0.63 in).

Flowering and fruiting

Trees begin flowering as early as 1.5 years (dwarf variety), although the average is probably 3 years. Flowering occurs two or three times a year in PNG and the Solomon Islands but once a year in Vanuatu. Some trees flower throughout the year in Kolombangara, Solomon Islands.

Reaction to competition

Cutnut does not withstand invasive vines such as *Mikania* and *Merremia* at the seedling stage, but mature trees grow well together with other tree species from their native range in mixed-species plantings. Seedlings generally compete well with grasses and eventually grow out of suppression.

PROPAGATION

The most common method of propagating cutnut is by direct planting of fruits into the field or raising the seedlings in the nursery before transplanting into the field. Vegetative propagation through air-layering and stem cuttings has proved highly successful in the Solomon Islands. Juvenile cuttings set in a non-mist propagator (Leakey et al., 1990) gave 100% rooting in 3 weeks, while 100% of air-layers rooted in 4 weeks.

Propagation by seed

Seed collection

Collect well formed fruits, which fall to the ground when they are ripe. Fruits take about 3 months to reach full size and a further 3–4 weeks to ripen to maturity. Collecting fresh fruits from the tree will result in low germination success if they are immature. Generally, a distinctive die-back of the persistent stigma at the base of the fruit is a good indicator of fruit maturity.

Seed processing

The seeds (nut-in-shell) are extracted from the mature fruits. Cutnut is commonly propagated by sowing the whole fruit. When ripe, the skin splits open along longitudinal grooves, exposing the outer fleshy mesocarp. The mesocarp will rot away within 7–14 days depending on the degree of maturity. The mesocarp of mature fruits can be easily peeled off using a kitchen knife or by hammering the fruit with a stone on a flat base. There are 10–30 (mean = 15) fruits in a kg (2.2 lb). Sow fruits in polyethylene nursery bags or on germination beds composed of river sand, forest soil, or coir.

Seed storage

Seeds are recalcitrant, do not withstand drying, and remain viable only for short period in dry storage. To maximize storage, it is best to retain the mesocarp on the nut and store the seeds in a shady, cool (19–25°C [66–77°F]), and low-humidity (ca 50%) environment and out of reach of pests such as crabs and rodents.

Pre-planting treatments

There appears to be no special pre-planting treatment for cutnut. Viability of the seeds can be tested by placing them in water. Fruits that float are likely to be non-viable.

Growing area

Seeds may be sown directly into the field or raised in the nursery in polyethylene bags or root trainers (one seed per cell). It is important to avoid direct exposure of seeds to full sunlight. Shade of 30–50% provides adequate protection from direct solar heat for the germinated seeds. Sown seeds must be watered regularly until the first foliage leaves have emerged. Excess watering encourages rotting.

Germination

The seed should be sown 3–5 cm (1.2–2 in) deep in a vertical position with the basal end down—the roots emerge from this end and the shoots emerge from the apex. Seeds from ripe fruits will start to germinate after 7 days. Seeds on their side will take longer to become established. Nearly 100% of viable seeds can be expected to germinate, as there is no seed dormancy. It takes 2–3 months to germinate a ripe fruit. The kernel (embryo) in the shell does not degenerate rapidly but can remain attached to the young developing seedlings up to 5–12 months.

Media

Well drained potting mix, which is light, permeable, and has good water-retention capacity, can be made from topsoil and coir. Coir is derived from decomposed and shredded coconut husk. The coir should be sterilized prior to use by heating it to about 100°C (212°F) for 30–45 minutes.

Time to outplanting

Seedlings are ready for field planting about 2–3 months after germination. Prior to field planting, seedlings should be hardened off by exposing them to increased light intensity (80–90%) for at least 4 weeks. Field planting should be encouraged during wet periods to minimize adverse field effects on the young seedlings.

Approximate size

Ideally, seedlings should be 20–30 cm (8–12 in) tall when they are outplanted. Seedlings 2–3 months old should have already attained such a stem height, actively producing 8–21 true leaves and a crown diameter of 15–33 cm (6–13 in).

Other comments on seedlings

Wildings (volunteer seedlings) can be easily transplanted, and can be stored in a shaded and cool location for up to 2–3 weeks if the seed (nut-in-shell) is left attached.

Germinating seed.
PHOTO: R. PAUKU

Guidelines for outplanting

In a small-scale plantation, seedlings may be planted at 5 x 5 m (16 x 16 ft) spacing, or 400 trees/ha (162 trees/ac). In its native range, mature trees were found at low density and extremely uneven spacing (ca. 10–15 trees/ha [4–6 trees/ac]). Seedlings may be planted on cleared land or as line-plantings in secondary forests, in which selective thinning of the forest allows more light to reach the seedlings. Planting cleared land may be more successful and rewarding if other multipurpose trees and crops such as *Canarium* spp., *Gliricidia sepium*, *Pterocarpus indicus*, *Flueggea flexuosa*, and *Musa* spp. are established a year in advance to give some shade and create an agroforest. Planning is required to achieve optimal spacing and configurations, such as those developed by farmers in Temotu islands.

Before planting, seedlings should be sprayed with water to reduce stress through transpiration, especially during transportation. It may also be necessary to trim the leaves to reduce transpiration losses. Coconut fronds or forest branches can also be used to shade seedlings before and after planting to reduce physiological stress.

A planting hole should be dug with a slant-cut digging stick or a digging spade. The hole should be filled with a good mixture of topsoil and organic materials to maximize survival and growth of seedlings. Watering may be necessary if prolonged dry weather is experienced after planting.

Propagation by leafy stem cutting

A relatively inexpensive, watertight enclosure called a poly-propagator is well suited for rooting stem cuttings. In the poly-propagator system, water is supplied through a pipe and retained within layers of sand, stones, pebbles, and growth media. The water keeps the temperature and relative humidity fairly constant inside the propagator; these conditions are maintained by opening the lid only when absolutely necessary. Whenever the enclosure is opened, the cuttings should be sprayed with water before closing the lid. The water level should be checked regularly through an observation pipe inserted in the medium, and refilled if low.

Collecting cuttings

Cuttings may be collected from stumps or coppiced trees, seedlings, wildings, or managed stockplants or hedges. To propagate cultivars, a multiplication garden of stockplants originating from selected superior parent trees can be established under the shade of mature forest trees. The multiplication garden should be established close to the nursery for easy access.

The first cuttings should be ready for harvest within 6–12 months from initial planting. At this age in good growing conditions, stock plants should have attained 0.8–1.5 m (2.5–5 ft) in height and will produce cuttings of four to six internodes with stem diameters of 10–15 mm (0.4–0.6 in) and internode lengths of 2–15 cm (0.8–6 in). Cuttings with longer internode lengths root best.

After the first harvest of cuttings it will take about 3–4 months for shoots from recently pruned stockplants to be ready for the next harvest of cuttings. Typically two to six shoots will be produced from individual stumps. To achieve good rooting success, shoots should be harvested when they are about 40–50 cm (16–20 in) in height, with two or three fully elongated internodes.

Harvesting cuttings

Single-node cuttings should be collected in the morning or late afternoon when it is cool. Collect only shoots that are healthy and pest-free. Sever shoots with a clean cut using a sharp knife or hand pruner. Typically, there are two leaves per node. One should be cut off and the other reduced in surface area to about 30 cm^2 (4.7 in^2). If cuttings are being harvested at a distance from the nursery, it may be necessary to store them in a cooler, a sealed polyethylene bag containing wet paper or cloth, or in a bucket of water. In this case, the whole shoot should be kept intact until arrival at the nursery. Cuttings should not be allowed to come into contact with ice when using a cool box. It is important to keep the shoots from each plant or clone separate and to record their identity on labels inside and outside the bag.

Storage of cuttings

For best results, the cuttings should be immediately set in the poly-propagator. Leafy cuttings cannot be stored for more than a few hours. Storage overnight can be done but may result in reduced success.

Left: Stockplants of selected trees in multiplication garden. Right: Poly-propagator system. All photos taken at Ringgi nursery, Kolombangara, Solomon Islands. PHOTOS: R. PAUKU

Treatments

It is not necessary to treat cuttings with fungicide prior to setting. Rooting hormone (indole butyric acid, IBA) has been shown to significantly increase the rate of rooting and number of roots formed, although there is no significant effect on the take rate as compared to using no hormone. A rooting powder with 0.8% IBA has been found to be best. Apply the hormone by dipping the base of the cutting in the rooting powder and then tapping gently to remove excess powder before placing the cutting inside the poly-propagator. Optimal leaf area is 30 cm^2 (4.7 in^2). The stem should be 10–15 mm (0.4–0.6 in) in diameter and 30–55 mm (1.2–2.2 in) in length.

Growing area

A non-mist, airtight, watertight poly-propagator is ideal for propagation from cuttings. It is made of clear plastic sheeting over a wooden frame. The base is filled with stones, which are then saturated with water. A layer of rooting media (10–15 cm [4–6 in] deep), such as sterilized coir, is placed on top of these stones. The poly-propagator should be placed under shade and protected from wind.

Time for rooting

Rooting starts within 14 days from the time cuttings are set. Preferably the cuttings are left in the propagator for 3–4 weeks, when most cuttings will have produced roots that are strong and well developed. Dead leaves and cuttings should be removed on a daily basis from the propagator, as they are a likely source of fungal infection. Strike rates of 70–100% were obtained in Kolombangara, Solomon Islands.

Media

When cuttings have rooted, they are transplanted into poly-bags (1–2 liters [1–2 quarts]), or other similar containers, filled with a potting medium that is well drained, has good water-retention capacity, and is light (for transportation). Coir has proven excellent, although freely drained garden soil (clay loam or sandy loam), preferably sterilized, is also good. Coir must be heated at 100°C (212°F) for 30–45 minutes to prevent potential occurrences of fungal infection, and then left overnight to cool before use. This may be simply done using a 200 liter (50 gal) barrel, cut in half longitudinally, placed over a wood fire. During heating, the coir should be turned over thoroughly four or five times. Well drained garden soil, which may be sterilized as a precaution against soil-borne diseases, also makes a good rooting medium. During routine use, the propagation unit should be treated with fungicide every 1–2 months.

Hardening

Potted cuttings should be weaned progressively from shade to full sun over a period of 2–3 months. Shade of 30–50% is best at first. Plants should be exposed to full sunlight for at least a month before field planting

Approximate size at outplanting

When about 5–6 months old, cuttings should have attained 30–50 cm (12–20 in) in height and are fit for field planting. They will have stem diameters of about 5–10 mm (0.2–0.4 in) and more than five well formed leaves.

Other comments on vegetative reproduction

Propagules can also be obtained from air-layering (air-layering). Air-layering can be done on primary, secondary, or tertiary branches, but this technique is especially suited for propagating mature shoots from pollarded trees that are difficult to root as stem cuttings. In Kolombangara, air-layers made on branches with stem diameter of 10–37 mm (0.4–1.5 in) attained 100% take rate within 30 days. Coir or soil can be used as growth medium in the air-layering process. Use freely drained soils suited to the tree. Wetting the medium before application is vital to the success of the air-layer.

Guidelines for outplanting

There is little if any research or experience on growing cutnut in planted stands, although there is the time-tested experience of farmers growing trees within homegardens and villages. There are no clonal field plantings known.

DISADVANTAGES

Seeds are recalcitrant and can easily lose viability during international transport. This limits germplasm exchange between countries and reduces opportunities for comparing provenances.

Lack of appropriate postharvest extraction, drying, and storage of kernels at village level may be a production constraint. Centralized extraction units may be impractical due to unreliable transportation and consequent deterioration of kernels.

Six-month-old clone at Ringgi nursery (KFPL), Kolombangara, Solomon Islands. PHOTO: R. PAUKU

The lack of awareness of the potential economic benefits of the species may be limiting the cultivation of cutnut.

Potential for invasiveness

The tree is unlikely to be a major invasive species outside its natural range, and it does not appear to have potential to become a pest.

Diseases and pests

Leaf miners can be a problem at the seedling stage in the nursery. At maturity, foliage damage appears to be minimal, but developing flowers and fruits are quite susceptible to pest and pathogen infection. Overall, cutnut is generally free of major pests and diseases.

Host to crop pests/pathogens

There are no cases reported. However, cockatoo and flying

Top: Air-layer on branch in tree. Bottom: Four-week-old air-layer removed from tree. Hunda, Kolombangara, Solomon Islands. PHOTOS: R. PAUKU

foxes feed on the fruits, and parrots feed on the flowers. Potentially, these animal pests could be drawn to cutnut and thereby introduced to other tree and field crops within the same area.

AGROFORESTRY/ENVIRONMENTAL PRACTICES

Mulch/organic matter

Fallen leaves, flowers, and dead branches enrich the surrounding soil.

Soil stabilization

The tree is rated high (more than 60% of farmers interviewed in Kolombangara, Solomon Islands) for soil stabilization due to a good network of lateral roots.

Crop shade/overstory

With appropriate spacing, the tree can provide medium shade that may be suitable for understory crops such as cocoa (*Theobroma cacao*), joint fir (*Gnetum gnemon*), and betel nut (*Areca catechu*).

Homegardens

A good candidate species for inclusion in the homegarden mix because it is compatible with common field crops such as cabbage, sweetpotato, banana, *Xanthosoma* spp., and cassava.

Living fences

The tree can act as a support for fencing in areas suitable for its growth.

Fence posts

The wood is unsuitable for posts because it is not durable.

Boundary markers

Traditionally, cutnut indicates human settlements and provides proof of land ownership, and therefore can serve as a good boundary marker.

Windbreaks

The tree is a good medium-height windbreak because it tolerates strong winds.

Silvopasture

A low planting density (10–15 trees/ha [4–6 trees/ac]) is recommended to avoid shading of the pasture grass.

Woodlot

The timber is of low quality, and therefore the tree is not grown for this purpose.

Native animal/bird food

Birds (cockatoos, parrots) and flying foxes feed on the fleshy mesocarp of fruits and on the flower nectar.

Wildlife habitat

The tree provides a good wildlife habitat for some nesting bird species.

Host plant trellising

It is a good trellis tree for betel nut vine (*Piper betle*).

Bee forage

Bees forage on its flowers and act as pollinators during the flowering season.

Fish/marine food chain

The fallen kernels and mesocarps are food to some freshwater fish and prawns.

Coastal protection

Being adapted to coastal areas, it provides some coastal protection but is unlikely to tolerate increased saltwater contact.

Ornamental

It is an attractive evergreen tree with bright flowers that beautifies rural villages. It is also planted for shade.

Typical homegarden with cutnut in the background, and banana, cassava, etc. in the foreground. Poroporo, Choiseul, Solomon Islands. PHOTO: R. PAUKU

USES AND PRODUCTS

Cutnut is part of the traditional agroforestry practiced by native people in the Melanesian countries of the Solomon Islands, Vanuatu, and Papua New Guinea. The species has been planted or protected along boundaries, in secondary forests, and within the surroundings of human settlements. Like canarium nut (*Canarium* spp.), it traditionally indicated occupation and ownership of tribal lands. Almost every part of the plant has been traditionally useful. Leaves and bark are largely used for medicinal purposes, while fallen branches are used for firewood. Despite its poor quality, the wood is used by some for crafts and temporary light construction. Fruits are harvested either at maturity or collected as they fall to the ground when ripe. The kernel inside the fruit is edible, tasty, and highly nutritious and is eaten as a snack or prepared into dishes for a main meal. Kernels are sold in both domestic and export markets to generate income. Furthermore, the species is interplanted with other tree species and agriculture crops to maximize farm output. In this respect, cutnut provides good environmental services such as soil amelioration, shade, and shelter. It is a good middle-story companion tree species that provides easy access to the top of clear-bole species such canarium nut, breadfruit (*Artocarpus altilis*), and sago palm (*Metroxylon salomonense*).

Staple food

The kernel is a highly nutritious seasonal food in the Melanesian countries of origin.

Fruit

The outer flesh (mesocarp) is inedible for humans, but the ripe fruits are attractive and aromatic.

Nut/seed

The nutritious kernels have protein and carbohydrate content of about 10% and 25%, respectively, in their raw form. They are largely eaten fresh as snacks, but in the western Solomon Islands kernels are roasted and baked into puddings together with edible hibiscus (*Abelmoschus manihot*) and coconut cream.

Honey

The tree is a good bee forage.

Medicinal

The leaves were used to treat inflammation of the ear and headaches. Sap from the bark has been used for treating ciguatera poisoning, coughs, and urinary infections, and the red-leafed form is used as a contraceptive and for abortion.

Animal fodder

The kernel and mesocarp are a good feed for free-range chickens.

Flavoring/spice

The mesocarp of a ripe fruit is aromatic and may have potential for flavoring.

Beautiful/fragrant flowers

The racemes of the showy flowers are beautiful and can be used decoratively.

Timber

The wood is of poor quality, is non-durable and is, consequently, unsuitable for manufacturing or construction purposes.

Fuelwood

The fallen branches and felled trees make good firewood.

Craft wood/tools

The wood is sometimes used for making paddles in the Reef Islands, Temotu Province, Solomon Islands.

Wrapping/parcelization

The leaves are traditionally used for wrapping and parceling nuts.

Body ornamentation/garlands

The flower buds are potentially attractive for body garlands, but they were not used traditionally.

Cosmetic/soap/perfume

The kernel oil is not widely used in cosmetics or perfumes, although is has potential for cooking and body care products.

URBAN AND COMMUNITY FORESTRY

Cutnut has been found in homegardens throughout its native range. In Temotu province of the Solomon Islands, it was one of the species used in the improved traditional agroforestry systems as a companion and interline tree crop. Being a medium-size tree and providing good shade, it would be suitable as a park or street tree. Its pendulous flowers and fruits are attractive in an urban landscape. Its relative, *B. asiatica*, is planted as a street tree in Cairns, Australia.

Size in an urban environment

It is a medium-size tree with an open canopy structure and is suitable for interplanting with other understory crops.

Rate of growth in a landscape

No data is available, but it is likely to be moderately fast growing.

Root system

Roots of mature trees are not very likely to be invasive but do form a lateral network spreading over a radius of about 5–6 m (16–20 ft). In villages, roots are seen at the soil surface as soil is eroded away.

Products commonly used in a Pacific island household

The kernels are a common snack in households, and in the Solomon Islands and Vanuatu kernels are baked or roasted and incorporated in dishes with edible hibiscus leaves and coconut cream. Leaves, sap, and inner bark have been used for various medicinal purposes. The dry wood is used for firewood and when green for making paddles in the Reef Islands, Solomon Islands.

Light requirements

It is shade tolerant, although more than 70% shade may reduce yields.

Water/soil requirements

Freely draining soil is required. Mature trees can withstand a prolonged dry spell of up to several months.

Life span

The life span is 80–90 years.

Varieties favored for use in a homegardens

Lack of formal recognition of varieties makes it difficult to make recommendations. Dwarf cultivars and others with high fruit production should be preferred.

Hazards

Under normal conditions there are no special treatments for leaf, branch, or fruit drop. Trees that are too tall may be pollarded to reduce height and ensure safety around villages.

Common pest problems

Mature trees appear to have no major pest threats. Occasional attack by borers on flower buds and developing fruits may be reduced through regular pruning and burning of infected branches.

COMMERCIAL PRODUCTS

The edible kernel is the primary commercial product. In the domestic market, kernels are sold in fresh, dried, boiled, roasted, or in masimasi or lap-lap, a traditional pudding with edible hibiscus leaves. In the Solomon Islands a parcel of fresh kernels (extracted from 10–12 fruits) is worth about US$0.15. In terms of international trade, Vanuatu is the only country in the Pacific that exports kernels. The kernels are dried and packed in sealed jars.

Cutnut has potential to become an export commodity, but currently the supply is inadequate and market chains are undeveloped. This suggests that farmers need to be encouraged to increase their cultivation of cutnut, which also requires a domestication program in support of serving commercial markets.

Spacing

Suggested planting spacing is 5–6 x 5–6 m (16–20 x 16–20 ft), which gives 278–400 trees/ha (113–162 trees/ac). Potentially, a 1 hectare (2.5 acre) block will produce 1–1.5 mt (2.2–3.3 t) of fresh fruits per peak season. With two peak seasons per year, production could be up to 2–3 mt (2.2–3.3 t) annually. This amount may be manageable for a household of five or six members, with help sought from extended family members or various community social groups in the peak seasons. A plantation area of 100 ha (247 ac) from one or several farmers could yield 200–300 mt (220–330 t) of fresh fruits per year. Average kernel to fruit ratio is 0.17 or 17%. Thus, the average fruit-to-kernel ratio is 6. Based on this fruit-to-kernel ratio, such yields would provide 33–50 mt (36–55 t) of fresh kernels per year, which is likely to support an export market.

In agroforestry systems mixed with other species, 40 trees/ha (16 trees/ac) is suggested. This is estimated to give about 300 kg (660 lb) fresh fruit or 50 kg (110 lb) fresh kernels per ha.

Management objectives

Pollarding reinvigorates vegetative growth of trees, but fruit set in reproductively mature trees will decline in the year following pruning due to the loss of woody branches. In Kolombangara, some farmers have pollarded tall (> 10 m [33 ft]), mature trees to a height of about 3 m (10 ft) and claim to have induced early flowering. No thinning is necessary if using the suggested spacing unless trees require replacement due to infertility. Weeding is crucial for the first 2–3 years of growth in the field. As the trees mature, weeding operations may be scaled down to cleaning once a year (largely by removing vines from the trees). The fertilizer requirements are unknown, but application of slow-release fertilizers at the nursery stage should provide nutrients for the seedlings to compete well in their new environment in the first 6 months.

Advantages and disadvantages of growing in polycultures

Cutnut is typically grown under other species such as *Cocos nucifera*, *Canarium* spp., *Artocarpus altilis*, *Pterocarpus indicus*, *Metroxylon salomonense*, and *Flueggea flexuosa* developing as an agroforest. It may also provide easy access for climbers to harvest difficult-to-climb species such as *Metroxylon salomonense*. However, cutnut does not tolerate heavy shading, and so a poorly designed polyculture plot may reduce yield.

Yields

Cutnut has been estimated to yield 10–50 kg (22–110 lb) of fruits per tree per year. Yields begin as early as 2–3 years in dwarf cultivars, but fruiting generally occurs on the fifth year from planting. Thus, yield estimate for 5-year-old trees at a spacing of 278–400 trees/ha (113–162 trees/ac) with two crops per year is 0.5–0.7 mt/ha (0.2–0.3 t/ac) fresh fruits. As trees mature, the yield increases, and with the suggested spacing, 2.7–3.8 mt/ha/yr (1.2–1.7 t/ac/yr) should be achievable for 20 year old trees.

Processing required

The common method for extracting kernels is to cut through the fruit with a sharp knife. This, however, results in split kernels and increases the risk of bacterial contamination in commercial processing. The use of mechanical methods is possible but not practical unless uniformity in fruit size is achieved, and this will only occur through the development of cultivars with desirable fruit and/or kernel qualities. In a commercial sense, farmers would be better off extracting kernels at the farm in order to fetch higher market prices, but this requires appropriate storage facilities located in rural villages.

On-farm processing methods

In addition to kernel extraction, fruits can be dried or smoked to allow storage for several months. Again, the limited shelf life of the product would require the establishment of central processing and storage units within rural communities. This requires personnel training and enforcement of quality standards to meet export market conditions.

Market

Ideally, plantings should be connected by feeder roads and accessible to reliable transportation links to major market outlets within the region.

More market research is required in order to further develop the already existing international niche markets. Attention needs to be drawn to consistency and continuity of supply, quality product standards, attractive and appropriate packaging, and expansion of market outlets. Organic certification would allow farmers to reach new markets.

INTERPLANTING/FARM APPLICATIONS

Example system 1

Location

Kolombangara Island, Solomon Islands

Description

Following initiatives to domesticate the species in 2002, many farmers in Kolombangara, Solomon Islands, have been seeking to integrate cutnut with exotic timber species such as teak (*Tectona grandis*), Mindanao gum (*Eucalyptus deglupta*, and *Gmelina arborea*. Agricultural crops were also to be planted on the same plot in the early stage of tree growth. When the tree canopies are closed, the growing of annual crops would cease. In this practice, block planting is advocated for the tree species, and the choice of which field crop to plant is crucial. It is too early to evaluate these species combinations. However, farmers are expected to benefit from nut and timber production as well as from the annual crops.

Crop/tree interactions

Given the correct spacing and proper farm design, this practice may result in a positive crop-to-crop interaction. The level of inter- and intraspecies competition for water, light, and soil nutrients is unlikely to be significant as differences in rooting system, tree height, and canopy structure among species prevail. In a block-planting scenario, overstory tree species provide the upper layer structure. In the next adjacent block, understory species (e.g., cutnut) provide the middle layer structure, followed by a block of species tolerant of medium to heavy shade such as *Gnetum gnemon*, *Areca catechu*, and *Theobroma cacao*. Besides its ecological benefits, block planting enables easy access during harvesting. Unlike fruit trees, the timber trees would be felled at maturity, and planting in separate single-species blocks would ensure minimal damage to the neighboring crops during harvesting.

Spacing

The suggested spacing in a block planting for cutnut is 5–6 x 5–6 m (16–20 x 16–20 ft) or 278–400 trees/ha (113–162 trees/ac). Timber species may be planted at 10 x 10 m (33 x 33 ft) if thinning is not practiced or 5 x 2.5 m (16 x 8 ft) if progressive thinning is to be practiced. The former spacing will give 100 trees/ha (40 trees/ac) and the latter will account for 800 trees/ha (320 trees/ac).

Example system 2

Location

Temotu Province, Solomon Islands.

Description

The Improved Temotu Traditional Agriculture (ITTA) was developed in the eighties. The system uses 23 crop species allocated within a 0.5 ha (1.2 ac) block at appropriate spacing. The choice of which crop species to use at different positions within the planting block is crucial to the inevitable competition among species for water, light, and nutrients. Indeed, this polycultural, mixed-species system has been a success. Comparative yields of tree crops such as *Barringtonia* spp. and *Gnetum gnemon* are 7 kg (15 lb) and 10 kg (22 lb) fresh fruit per tree respectively at age 5–10 years. Yield also varies across different root crop species interplanted with *Barringtonia* spp. Yam production, for example, is 37 mt/ha (16.5 t/ac), compared to 12.3 mt/ha (5.5 t/ac) for giant taro.

Crop/tree interactions

Inevitable crop-to-crop interaction exists among the species in terms of the provision of shade, shelter, and the improvement of soil structure. However, the level of interactive benefits derived from each species in this system is very much dependent upon the appropriateness of planting spacing and the correct choice of crop species planted at different positions within a given area.

Spacing

In-row spacing of 10 m (33 ft) between trees and 5 m (16 ft) between rows has been suggested for *Barringtonia* spp. In a hectare block, this planting spacing gives 200 trees (80 trees/ac). Companion trees should be planted 1 m (3.3 ft) from the established cutnut trees. Spacing for root crops varies with species. Yams were planted at a spacing of 448 mounds per hectare (181 mounds/ac) compared to 392 suckers of giant taro per hectare (159 suckers/ac).

PUBLIC ASSISTANCE AND AGROFORESTRY EXTENSION

Extension offices for agroforestry and forestry in the Pacific: http://www.traditionaltree.org/extension.html

INTERNET

Edible Indigenous Nuts in Papua New Guinea: Their Potential for Commercial Development: <http://www.newcrops.uq.edu.au/newslett/ncnl5-3.htm>

One hundred Pacific Island agroforestry trees: <http://www.unu.edu/unupress/unupbooks/80824e/80824Eop.htm>

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Traditional Tree Initiative—Species Profiles for Pacific Island Agroforestry (www.traditionaltree.org)

Barringtonia procera (cutnut)

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Acknowledgments: The author and publisher thank Barry Evans, Dale Evans, Roger Leakey, Diane Ragone, and Art Whistler for their input. Photo contributions by Barry Evans and Roger Leakey are greatly appreciated. The author thanks farmers in Kolombangara Island for allowing their tree resources to be studied. The author also gratefully recognizes the sponsors of his *Barringtonia* research: Australian Centre for International Agriculture Research (ACIAR), Rainforest Cooperative Research Centre (CRC), James Cook University (JCU), and Kolombangara Forest Products Limited (KFPL).

Recommended citation: Pauku, R.L. 2006. *Barringtonia procera* (cutnut), ver. 2.1. In: Elevitch, C.R. (ed.). Species Profiles for Pacific Island Agroforestry. Permanent Agriculture Resources (PAR), Hōlualoa, Hawai'i. <http://www.traditionaltree.org>.

Sponsors: Publication was made possible by generous support of the United States Department of Agriculture Western Region Sustainable Agriculture Research and Education (USDA-WSARE) Program; SPC/GTZ Pacific-German Regional Forestry Project; USDA Natural Resources Conservation Service (USDA NRCS); State of Hawai'i Department of Land & Natural Resources Division of Forestry & Wildlife; and the USDA Forest Service Forest Lands Enhancement Program. This material is based upon work supported by the Cooperative State Research, Education, and Extension Service, U.S. Department of Agriculture, and Agricultural Experiment Station, Utah State University, under Cooperative Agreement 2002-47001-01327.

Series editor: Craig R. Elevitch

Publisher: Permanent Agriculture Resources (PAR), PO Box 428, Hōlualoa, Hawai'i 96725, USA; Tel: 808-324-4427; Fax: 808-324-4129; E-mail: par@agroforestry.net; Web: <http://www.agroforestry.net>. This institution is an equal opportunity provider.

Broussonetia papyrifera (paper mulberry)

Moraceae (fig family)

***ai masi* (Fiji); *aute* (Societies, Cooks, Australs, New Zealand); *hiapo* (Tonga, Niue); *hiapo, tutu* (‘Uvea); *lafi* (Futuna); paper mulberry (English); *u‘a* (Samoa); *ute* (Marquesas); *wauke* (Hawai‘i)**

W. Arthur Whistler and Craig R. Elevitch

IN BRIEF

Distribution Native to Japan and Taiwan; an ancient introduction to many Pacific islands as far east as Hawai‘i.

Size Small tree up to 12 m (40 ft).

Habitat Humid tropical, subhumid tropical, and temperate climates; 0–1500 m (5000 ft).

Vegetation Associated with numerous plants in cultivation.

Soils In the Pacific, moist volcanic soils are preferred.

Growth rate Growth rate is fast, usually 12–18 months to reach harvest size of 3–4 m (10–13 ft).

Main agroforestry uses Soil stabilization, homegarden.

Main products Bark for cloth and traditional medicine.

Yields No information for Pacific islands.

Intercropping Commonly planted with a wide variety of other species in fields and homegardens.

Invasive potential In the Pacific islands, only male clones were introduced. Because both male and female plants are required for viable seeds to be produced, paper mulberry is not invasive in the Pacific. In many places where both the male and female plants are present, such as the eastern U.S., the species is considered an invasive pest.

PHOTO: C. ELEVITCH

Paper mulberry cultivated in a mixed agricultural system in Tonga.

INTRODUCTION

Paper mulberry is native to Japan and Taiwan and is an ancient introduction across the Pacific as far east as Hawai'i. Although the tree is fertile in its native range, the plants carried into the Pacific were all male clones, transported and planted as rootstock or stems. Thus, the female plants with flowers and consequently fruit are absent.

The tree reaches a height of 12 m (40 ft) or more if allowed to grow, but in practice it is usually harvested at a much shorter height when the stems are about 2.5 cm (1 in) in diameter and 3–4 m (10–13 ft) tall. The tree was very important in traditional Polynesian culture, as its bark supplied one of the most important materials in ancient Polynesia—tapa cloth.

To make tapa, the bark is peeled from the cut stems to obtain a single long strip. The inner bark or bast is then separated from the outer bark, and after being scraped and washed, the strips are pounded to flatten them. The resulting sheets were felted together to form tapa, which could then be bleached in the sun and printed with native dyes to produce the finished traditional tapa cloth.

Today, the tree has disappeared from most of its traditional range and is cultivated to any extent only in Tonga, Fiji, and Samoa. It is important in these places because it is a major source of handicraft income in the form of finished tapa cloth. Although it is no longer used in Polynesia for clothing, in Tonga and Samoa tapa cloth is still worn during ceremonial occasions such as festivals or dances. It does not last very long when worn as everyday clothing.

The tree is grown in plantations and homegardens on islands where tapa cloth is still made. It can tolerate a wide range of environmental extremes, and even does well in temperate climates (its native habitat). Since only the male clones are present in Polynesia, the tree has no potential for becoming invasive.

DISTRIBUTION

Native range

The tree is native to Japan and Taiwan, where it is now mostly restricted to cultivation.

Current distribution

Paper mulberry was an ancient introduction eastward across the Pacific to Hawai'i. It was commonly grown throughout the high islands of Polynesia and Melanesia. In Micronesia it was recorded only from Pohnpei and Yap (modern introductions), but is virtually unknown there now. It is also virtually unknown and usually not recognized on islands and archipelagoes where its bark is no longer fashioned into tapa cloth (i.e., in most of Polynesia except Tonga, Samoa, and Fiji). It is now recognized as a culturally significant plant in Hawai'i, however, which has led to a renewed interest in its cultivation. On the U.S. mainland, where both fertile male and female trees have been introduced, it is found from Illinois to Massachusetts, south to Florida and west to Texas. The tree is reportedly naturalized in Burma and Thailand.

The traditional art of tapa making is being rediscovered in Hawai'i, as at this cultural demonstration at Pu'uhonua o Hōnaunau, Kona, Hawai'i. PHOTO: C. ELEVITCH

BOTANICAL DESCRIPTION

Preferred scientific name

Broussonetia papyrifera (L.) Vent.

Family

Moraceae (fig family)

Non-preferred scientific names

Morus papyrifera L.

Common names

paper mulberry (English)
ai masi (Fiji)
aute (Societies, Cooks, Australs, New Zealand)
hiapo (Tonga, Niue)
hiapo, *tutu* ('Uvea)
lafi (Futuna)
mûrier à papier (French)
u'a (Samoa)
ute (Marquesas)
wauke (Hawai'i)

Size

Small tree up to 12 m (40 ft) in height, but it is often not allowed to get that tall in cultivation.

Flowers

Flowers occur in elongate, male spikes up to 8 cm (3.2 in) long and female axillary globose heads up to 2.5 cm (1 in) long, on separate male and female trees (although all trees in the tropical Pacific islands are apparently male). Female flowers have a two- to four-lobed perianth and a superior ovary with a filiform style. Male flowers have four valvate tepals and four free stamens with filaments inflexed in the bud. Flowering is unknown or infrequent over most of the tree's distribution in the Pacific.

Leaves

Leaves are simple, alternate, blade ovate to three- to five-lobed, 8–20 cm (3.2–8 in) long; lower surface densely tomentose, upper surface scabrous; margins serrate; petiole nearly as long as the blade.

Fruit

The fruit is a globose to club-shaped syncarp 1–2.5 cm (0.4–1 in) in diameter comprised of numerous red to yellow drupes (but not reported from the tropical Pacific islands).

Paper mulberry leaves. PHOTO: C. ELEVITCH

Seeds

Not known to set seed in the Pacific islands, where the traditional population present belongs to a sterile clone.

Similar species

Since the tree rarely flowers, it may be hard to distinguish from other trees in a sterile state. However, the fuzzy, alternate, ovate, and often three-lobed leaves and the milky sap are the most characteristic indicators. Its habit of producing root suckers is one distinguishing feature. Also, the plant is always found in cultivation or in formerly cultivated sites. Some leaf forms can be confused with common mulberry; however, paper mulberry leaves have a rough, sand paper-like upper surface, whereas mulberry leaves are smooth.

GENETICS

Variability of species

The leaves are the most variable part, from slightly to deeply lobed, but this variation is not recognized taxonomically.

Known varieties

No varieties are reported. However, the ancient Polynesian plants are all male clones of the species, and it has been noted that Hawaiians used at least three terms to describe cultivars or forms of the plant (Meilleur et al. 1997).

Culturally important related species in the genus

One other species of the genus, *Broussonetia luzonica*, is native to the Philippines; its wood is used for timber. It was reportedly introduced to Polynesia, but if so, it has not become established.

Genetic resources where collections exist

The trees used traditionally in the Pacific islands are sterile, while those grown on the U.S. mainland were introduced from where the tree is fertile (i.e., from its native range). The best genetic resources for the traditional clone are probably found in Tonga and Fiji, where the tree is still commonly grown.

ASSOCIATED PLANT SPECIES

The flora of its native habitat is secondary temperate forest. In the Pacific islands, the flora most often associated with the tree is comprised of introduced plants, both weeds and cultigens, which vary from island to island. The tree has virtually disappeared from much of its Pacific island range, but where it does occur, it is either cultivated or persists in moist valleys where it has survived after cultivation has ceased. The tree is found mostly in lowland plantations and homegardens, where it is associated with other cultivated plants, such as dryland taro, breadfruit, etc.

Species commonly associated as aboriginal introduction in Pacific islands

The tree is cultivated in plantations in Tonga and Fiji, and to a lesser extent Samoa, although elsewhere in the Pacific the tree has all but disappeared. It has traditionally been associated with trees like coconut and breadfruit, which are also grown in plantations and homegardens. Today, the same species are often associated with it as were in the past, with the addition of modern introductions, such as papaya, mango, and weeds of more recent introduction.

ENVIRONMENTAL PREFERENCES AND TOLERANCES

Climate

The tree has a wide ecological tolerance and can be grown in humid tropical, subhumid tropical, and temperate climates (since it is originally native to Japan and Taiwan). It is grown on the U.S. mainland as far north as Illinois, but farther northward it cannot survive the colder winters. It was originally cultivated in northern New Zealand, presumably limited southward by the colder winters there. Sufficiently moist, warm to cool climates are suitable for its cultivation. It is not found on Pacific atolls, presumably because of the soil and maritime conditions.

Elevation range

Lower Near sea level.

Upper Up to 1500 m (5000 ft), but usually limited to the lower elevations by human factors (plantations rarely go high into the montane forest in the Pacific islands).

Mean annual rainfall

No data available, but it prefers wet climates.

Rainfall pattern

Grows under any rainfall pattern that keeps the soil moist most of the year. The tree also frequently grows along streams.

Dry season duration (consecutive months with <40 mm [1.6 in] rainfall)

It can survive a 3–4 month dry period.

Mean annual temperature

Lower Below freezing, but the tree will not tolerate bitterly cold winters.

Upper This is not a limiting factor.

Soils

In the Pacific, moist volcanic soils are preferred. The tree is not cultivated on atolls, presumably because of the coral substrate.

Soil texture

Prefers light and medium texture soils (sands, sandy loams, loams, and sandy clay loams).

Soil drainage

Grows in soils with free drainage as well as seasonally and continually waterlogged soils.

Soil acidity

No data available.

Special soil tolerances

It can grow along streams.

Tolerances

Drought

It is able to tolerate long dry spells if properly situated. For example, it has been growing for years at Manukā State

Park in Kaʻu, Hawaiʻi, where it has survived many years with 6–8 months of drought.

Full sun

The tree does best in sunny places.

Shade

It does not grow well in heavy shade.

Fire

The tree probably would survive fire, as it sprouts from its root base when the stems are harvested.

Frost

The tree is tolerant of frost but not bitterly cold winters.

Waterlogging

It is somewhat tolerant of waterlogged soils, as populations in Hawaiʻi that have persisted long after being actively cultivated are often found along streams.

Salt spray

The tree is probably intolerant of salt spray.

Wind

It does not tolerate wind well.

ABILITIES

Regenerate rapidly

It can regenerate rapidly, as it readily forms new stems from the rootstocks after the stems have been harvested.

Self-prune

The buds that form lateral branches are usually removed so that they do not form side branches that leave holes in the inner bark, which would appear in the tapa cloth.

Coppice

The tree coppices well, and in fact, it is the main means of production of new stem shoots from the root system.

GROWTH AND DEVELOPMENT

The tree does not produce seed in the Pacific islands (since the trees are all male clones), thus there are no seedlings. The means of propagation is vegetative, either from root or stem cuttings. The tree grows rapidly, and when the stems are harvested, the rootstock rapidly forms new, fast-growing stems.

HAWAIIAN LORE

A Hawaiian legend tells of Hina and her tapa-making. Formerly, the sun always hurried across the sky. It went so rapidly that Hina's tapas did not have time to dry. So her son, Maui, went to the place of sunrise, caught the sun's first ray, and broke it off. Ever since, the sun has traveled more slowly (Neal 1965).

Growth rate

Under ideal conditions, harvest time can be reached in as little as 6 months. However, the time to reach harvest size of 3–4 m (10–13 ft) is usually 12–18 months. The side branches are usually removed from the stems to assure a clean, straight stalk free of side branches and, consequently, tapa cloth without major holes. Normally side branch buds are removed weekly, although during ideal growing conditions of sunlight, nutrients, and moisture, bud removal must be done twice weekly.

Yields

In Indonesia 2-year-old trees 2–3 m (6.6–10 ft) tall with stem diameter of 2 cm (0.8 in) yielded about 300 g (0.7 lb) of fresh bark per tree, equivalent to 90 g (0.2 lb) dry bark (Berg 2003).

Rooting habit

Paper mulberry generally grows with matted surface roots and a taproot. The surface roots frequently produce suckers. Mulch is beneficial to growth.

Reaction to competition

The tree can tolerate some competition, because the rootstock rapidly forms dense thickets of stems. It does not do well in the shade, however, which may be why in Hawaiʻi relictual stands are often found along streams, which are sunnier than deep forest.

Cultivation

Forster (1778) noted that the Tahitians "lop off the leaves and branches that are sprouting out, which operation increases the main shoot, and invigorates its straight growth." When the plants are 3–4 m (10–13 ft) high (less than 2 years old) and usually less than 4 cm (1.6 in) in diameter, the stems are harvested leaving the rootstock, which is allowed to regenerate new stems. The methods of cultivation and production of tapa were very similar all across Polynesia. In Tahiti, Forster noted the plants are cultivated in fenced plots and that the Tahitians "plant the young shoots of the

Left: Side branches should be removed when they are very small, as woody branches such as these will cause holes in the main stem bark. Right: Thinned stand of paper mulberry with side branches removed. PHOTOS: C. ELEVITCH

aouta [*aute*], in regular rows, at the distance of about 18 inches, or two feet…" In Fiji, Seemann (1865) noted the tree is "propagated by cuttings, and grown 60–90 cm (2–3 ft) apart, in plantations resembling nurseries. For the purposes of making cloth it is not allowed to become higher than about 4 m [13 ft] and about 4 cm [1.6 in] in diameter." In Hawai'i, plantations of paper mulberry were often surrounded by enclosures of dry banana leaves to protect the plants while they were young, and plantings of it were often surrounded by stone walls in the Marquesas.

PROPAGATION

Root shoots (suckers), cut matted roots, stem cuttings, or sections of "second growth" stems are used for propagation.

Propagation by root shoots

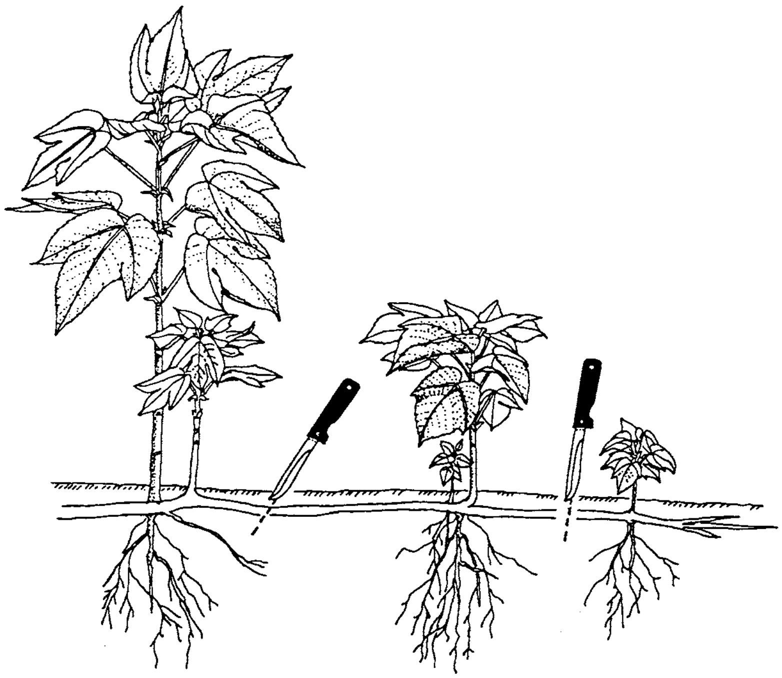
Transplanting root shoots is reportedly the easiest method. These are best harvested when 30–45 cm (12–18 in) in height. They are best cut from the mother plant by means of a sharp knife, and are then left to "harden" in place for a month before they are transplanted into a pot or directly into the field. When the shoots are gathered, care should be taken not to break the taproot. If this happens, the plant will dry up. The prepared shoots are placed in holes 80 cm (2.7 ft) apart in rows 1.2–1.8 m (4–6 ft) apart. In old Hawai'i, the land where the shoots were to be planted was cleared and mulched (Krauss 1974).

Shoot collection

Shoots about 2 m (6.6 ft) in length were used in Hawai'i (Krauss 1974). Shoots were cut from plants that had already started resprouting.

Shoot processing

All the leaves are removed from the shoots except for the terminal bud. As the plants grow, the lateral branches are plucked off to produce a clean, straight surface suitable for use in making tapa cloth.



Propagating paper mulberry from root shoots. ILLUSTRATION: JOAN YOSHIOKA, COURTESY HAWAIʻI STATE OFFICE OF ENVIRONMENTAL QUALITY CONTROL

Shoot storage

There is usually no need for storage of the slips, because these can be harvested from live plants at nearly any time.

Planting

Special treatments, such as growth hormones or fungicides, are usually not needed.

Growing area

The plants are taken from the source plant and planted directly where they are to be grown, with no need of potting and replanting. They are usually planted in sunny places.

Starting vegetative material

The plants are put into the ground the day after they are cut from the source plant. In Hawaiʻi, cuttings kept overnight before being planted the next day were wrapped in ti or banana leaves to keep them moist. The cuttings are planted directly in the ground and covered with loose soil to promote drainage, then mulched.

Propagation by stem cutting

The stem cuttings are typically planted directly into the ground rather than needing to be first put in a nursery for later transplanting. Nagata (1992), however, recommends that the cuttings be put into a light potting medium such as perlite and covered with a clear plastic bag supported by a wire frame. The medium should be kept moist by adding water once or twice a week. All leaves (but not the terminal bud) are removed from the cutting. Once the plants have rooted and are sprouting, they are planted in a weed-free area, then heavily mulched.

DISADVANTAGES

The plant was formerly important as a source of clothing. This use quickly disappeared throughout most of Polynesia after Western contact. The only modern use is as ceremonial dress and as handicraft. The methods of tapa making are largely forgotten on most of the islands where the plant was formerly cultivated. The process is very labor intensive.

Potential for invasiveness

The tree is not invasive in the Pacific islands, as all of the trees traditionally grown are male clones (hence, no seeds). Consequently, it can only spread slowly by root sucker and is easy to control. However, in temperate areas where fertile trees have been introduced, paper mulberry may become a pest since it fruits and produces seeds. As long as the male clone is used (which is the usual and useful type in the Pacific islands), there is no threat of invasiveness. Therefore, female plants should not be introduced in the Pacific.

Susceptibility to pests/pathogens

No information is available regarding pests and diseases of paper mulberry in the Pacific islands. In Japan the bacterial blight *Pseudomonas syringe* pv. *broussonetiae* affects paper mulberry. The fungi *Phytophthora boehmeriae* and *Dendryphiella broussonetiae* are known to attack the plant (Berg 2003).

Host to crop pests/pathogens

In China the plant is known to host crown gall (*Agrobacterium tumefaciens*), which causes tumor-like growths on the plant.

AGROFORESTRY/ENVIRONMENTAL PRACTICES

Soil stabilization

Due to the dense root mat and ability to grow on stream banks, it appears that some soil stabilization is provided by the growing plants.

Tapa making remains a very important part of Tongan culture. Pieces of tapa are much valued as gifts to be given by Tongans on special occasions. Nuku'alofa, Tonga. PHOTO: C. ELEVITCH

Homegardens

The plants are grown in homegardens and plantations in Tonga, Fiji, and Samoa. They are also sometimes grown in homegardens in Hawai'i, especially with the increased interest in this important traditional plant.

USES AND PRODUCTS

The most significant part of the paper mulberry is its strong, fibrous bark used in making native bark cloth commonly known as tapa cloth or tapa. The plant has other less important uses including medicinal ones.

Fruit

The sweetish fruits are edible, although where only male clones are present, such as in the Pacific Basin, no fruit is formed.

Leaf vegetable

In Indonesia, the steamed young leaves are eaten.

Medicinal

In Hawai'i, the slimy sap was used as a laxative and the ash of burnt tapa was used for treating thrush. In Samoa, an infusion of the crushed leaves is sometimes taken as a potion for treating stomach pains and ill-defined abdominal pains. The leaf, bark, and fruit are used medicinally in Indochina.

Animal fodder

The leaves are fed to pigs in Indochina and to silkworms in China.

Fuelwood

After removing bark for tapa, the stems can be used for kindling.

Fiber/clothing

The inner bark has been used for centuries in Southeast Asia for paper and textiles. The bark is traditionally used in Polynesia to make bark cloth known as tapa. The bark is stripped from the cut stems by making a lengthwise incision across the stem and pulling it off intact to obtain a single long strip. The inner bark, or bast, is then separated from the outer bark, and any green matter remaining on the bast is removed using scrapers; the bast is then washed to remove the slimy sap. The strips are pounded on a wooden anvil by using a square, billyclub-like beater made of a hard wood. Two or three of the strips are then felted together by the pounding, helped by the stickiness of the bark. Several of the resulting sheets are often pounded together in layers to increase the thickness or to cover over thin spots or holes in the individual sheets. A bit of paste in the sprinkling water is usually used at this point. These white tapas are then painted, or as in Hawai'i, printed with decorative designs. The finest and most delicate tapa in Polynesia was made in Hawai'i. Nowadays, however, tapa making in the Pacific is limited to Tonga and Fiji, and to a lesser extent, Samoa, and the tree and the art are nearly forgotten everywhere else.

Rope/cordage/string

The bark fiber can be used to make rough cordage, as can the roots.

Ceremonial/religious importance

The bark cloth is used ceremonially in Tonga, Fiji, and Samoa. In Hawai'i, tapa was important in burial wrapping and other funerary customs (Meilleur et al. 1997).

URBAN AND COMMUNITY FORESTRY

Paper mulberry is primarily of cultural rather than ornamental value. The tree can be grown in homegardens, but its tendency to produce root suckers requires constant maintenance. This maintenance is a normal part of cultivating the plant for tapa but may present an overwhelming burden to a homeowner or public works department. The tree can also be allowed to grow out to its full size as a shade tree, although a large tree still produces root suckers.

Size in an urban environment

The tree can grow to 12 m (40 ft), but in cultivation the stems are usually cut off at the base when they reach 4 m (13 ft). New stems quickly sprout back.

Rate of growth in a landscape

In a landscape, especially where weeds are controlled and irrigation used when necessary, the new growth is expected to reach 4 m (13 ft) annually.

Root system

Paper mulberry forms a dense surface root mat. Since these readily produce suckers every few feet, the tree can interfere with lawns and other landscaping features if not given plenty of space for growth.

Products commonly used in a Pacific island household

The most common use is for making tapa cloth. The cultural value of tapa artwork is enjoying a revival in some areas, such as in Hawai'i.

Light requirements

The plant requires full sun for vigorous growth. However, light shade from surrounding plants will not substantially reduce growth rates.

Water/soil requirements

It prefers light and medium soils, although it tolerates pe-

This planting has survived for decades at Manukā State Park, Ka'u, Hawai'i, with little care and long droughts. PHOTO: C. ELEVITCH

Paper mulberry stems are sold at the central market in Nuku'alofa, Tonga.
PHOTO: C. ELEVITCH

riodic waterlogging. The plant grows best with continuous soil moisture.

Life span

By all indications, the plant will grow for many decades, even when stems are cut off every 12–18 months.

Varieties favored for use in a homegardens

There are no known varieties in the Pacific, although the Hawaiians recognized three forms of paper mulberry. It is best to propagate a plant that is known to grow well in the area.

Seasonality of leaf flush, flowering, fruiting

Paper mulberry grows continuously as long as there is sufficient soil moisture. During drought, active growth ceases. The traditional paper mulberry plants of the Pacific islands do not usually flower and never set fruit (since all of the individuals are male).

Exceptional ornamental values

The light to dark green foliage is attractive. However, the plant is usually grown for its cultural values rather than as an ornamental.

Use as living fence, hedge or visual/noise barrier

A dense thicket of paper mulberry consisting of numerous plants or suckers spaced on a grid of about 0.75–1.5 m (2–4 ft) could serve as a visual barrier. Visual protection would require preserving the lower branches, which excludes use of the stems for making tapa.

Bird/bee/wildlife

In cultivation, the plant has little wildlife value, and due to the absence of flowers and fruit, it is of little importance to bees or birds.

Maintenance requirements

The tree can grow well without fertilizer, although in poor soils light applications of balanced fertilizer would be beneficial. Mulching is highly beneficial to the plant. Pruning side branches is necessary for tapa production, as is continual harvesting of the stems at a height of about 4 m (13 ft) and stem diameter of no more than 2.5–4 cm (1–1.5 in).

Nuisance issues

The plant tends to spread outward from the main plant by means of root suckering, which can easily become a nuisance, especially in small garden areas. The root suckers will come up in neighboring areas, and when cut off at the base, new sprouts often quickly arise. Since the root suckers are connected to the main plant, herbicide cannot be used to control suckers. The only means of control is continual cutting at the base.

Common pest problems

The plant is relatively free of pests. An occasional white fly infestation has been reported (Dego 2004).

Other comments about this species in homegardens

The tree is most suitable for those wanting to produce tapa cloth, which is still commonly made in Tonga and Fiji, and is having a revival in other places, such as Hawai‘i and Samoa.

COMMERCIAL PRODUCTS

The only commercial product of the paper mulberry is tapa cloth. Originally this was used for mostly ceremonial clothing. Nowadays it is used ceremonially in Tonga, Samoa, and Fiji, and is an important handicraft as well. Much time is spent by women in Tongan villages making tapa cloth. This is sold for export or local use. The dried strips of bark and the white, unpainted tapa cloth are also sold locally (e.g., in the Nuku‘alofa marketplace in Tonga) to women who want to make the finished product.

Spacing for commercial production

A spacing of 45–60 cm (18–24 in) has been noted by various sources.

Polycultures

Paper mulberry grows well with many other crops as long as it is not heavily shaded.

Estimated yield

No information is available for the Pacific islands. In Thailand, plants grown with a spacing of 1 x 1 m (3.3 x 3.3 ft) harvested 6–12 months after planting yielded 2400–2800 kg/ha (440–520 lb/ac) of bark.

Markets

Strips of the inner bark, raw (uncolored) tapa cloth, and finished tapa cloth are sold in local markets in Tonga. Elsewhere, the finished tapa cloth is the most common product, and this is imported as a handicraft in many curio shops in tourist areas in the Pacific. Otherwise nearly all of these products are used by the people who grow the plants (i.e., the handicraft makers grow their own trees).

INTERPLANTING/FARM APPLICATIONS

Paper mulberry is very flexible in its growth requirements, and was, consequently, grown in a variety of systems. It was described in Hawai‘i in 1793 growing with other traditional crops such as breadfruit and sweetpotato. The plantings were typically surrounded by fences made from dry banana leaves to shield them from the wind, according to Krauss (1993)

Example system (Johansen 2004)

Location

Manukā State Park, island of Hawai‘i

Description

Planted 20 years ago at base of a slope of established plumeria and pothos vine (*Scindapsus pictus*). The area has received minimal care for past 15 years.

Crop/tree interactions

Paper mulberry groves persist growing in and among plumeria trees and pothos plantings, despite little care and periodic extended droughts.

Spacing

The plant survives in sparse populations over a much wider area than the original planting.

PUBLIC ASSISTANCE AND AGROFORESTRY EXTENSION

Extension offices for agroforestry and forestry in the Pacific: <http://www.traditionaltree.org/extension.html>.

INTERNET

Canoe Plants of Ancient Hawai‘i: <http://www.canoeplants.com/wauke.html>.

Kapi‘olani Community College: <http://apdl.kcc.hawaii.edu/~ahupuaa/botany/fiber/wauke.htm>.

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Traditional Tree Initiative—Species Profiles for Pacific Island Agroforestry (www.traditionaltree.org)

Broussonetia papyrifera (paper mulberry)

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Acknowledgments: The authors and publisher thank Dale Evans, Heidi Johansen, Manuel Rego, and Peter van Dyke for their input.

Recommended citation: Whistler, W.A., and C.R. Elevitch. 2006. *Broussonetia papyrifera* (paper mulberry), ver. 2.1. In: Elevitch, C.R. (ed.). Species Profiles for Pacific Island Agroforestry. Permanent Agriculture Resources (PAR), Hōlualoa, Hawai'i. <http://www.traditionaltree.org>.

Sponsors: Publication was made possible by generous support of the United States Department of Agriculture Western Region Sustainable Agriculture Research and Education (USDA-WSARE) Program; SPC/GTZ Pacific-German Regional Forestry Project; USDA Natural Resources Conservation Service (USDA NRCS); Kaulunani, an Urban Forestry Program of the DLNR Division of Forestry and Wildlife and the USDA Forest Service; State of Hawai'i Department of Land & Natural Resources Division of Forestry & Wildlife; USDA Forest Service Forest Lands Enhancement Program; and Muriel and Kent Lighter. This material is based upon work supported by the Cooperative State Research, Education, and Extension Service, U.S. Department of Agriculture, and Agricultural Experiment Station, Utah State University, under Cooperative Agreement 2002-47001-01327.

Series editor: Craig R. Elevitch

Publisher: Permanent Agriculture Resources (PAR), P.O. Box 428, Hōlualoa, Hawai'i 96725, USA; Tel: 808-324-4427; Fax: 808-324-4129; E-mail: par@agroforestry.net; Web: <http://www.agroforestry.net>. This institution is an equal opportunity provider.

Calophyllum inophyllum (kamani)

Clusiaceae (syn. Guttiferae) (mangosteen family)

Alexandrian laurel, beach mahogany, beauty leaf, poon, oil nut tree (English); beach calophyllum (Papua New Guinea), *biyuch* (Yap); *btaches* (Palau); *daog*, *daok* (Guam, N. Marianas); *dilo* (Fiji); *eet* (Kosrae); *feta'u* (Tonga); *fetau* (Samoa); *isou* (Pohnpei); *kamani*, *kamanu* (Hawai'i); *lueg* (Marshalls); *rakich* (Chuuk); *tamanu* (Cook Islands, Society Islands, Marquesas); *te itai* (Kiribati)

J. B. Friday and Dana Okano

PHOTO: J. B. FRIDAY

Kamani trees are most commonly seen along the shoreline (Hilo, Hawai'i).

IN BRIEF

Distribution Widely dispersed throughout the tropics, including the Hawaiian and other Pacific islands.

Size Typically 8–20 m (25–65 ft) tall at maturity.

Habitat Strand or low-elevation riverine, 0–200 m (660 ft) in Hawai'i, up to 800 m (2000 ft) at the equator; mean annual temperatures 18–33°C (64–91°F); annual rainfall 1000–5000 mm (40–200 in).

Vegetation Occurs on beach and in coastal forests.

Soils Grows best in sandy, well drained soils.

Growth rate May initially grow up to 1 m (3.3 ft) in height per year on good sites, although usually much more slowly.

Main agroforestry uses Mixed-species woodlot, windbreak, homegarden.

Main products Timber, seed oil.

Yields No timber yield data available; 100 kg (220 lb) nuts/tree/yr yielding 5 kg (11 lb) oil.

Intercropping Casts a heavy shade, so not suitable as an overstory tree; has been grown successfully in mixed-species timber stands.

Invasive potential Low potential to become invasive.

INTRODUCTION

Kamani is a medium-sized to large evergreen tree that averages 8–20 m (25–65 ft) in height with a broad spreading crown of irregular branches. The tree supports a dense canopy of glossy, elliptical leaves, fragrant white flowers, and large round nuts. It grows along coastal areas and adjacent lowland forests, although it occasionally occurs inland at higher elevations. It is native to east Africa, India, Southeast Asia, Australia, and the South Pacific. It has been widely planted throughout the tropics and is naturalized in the main Hawaiian islands.

The tree is today chiefly valued for its hardiness and beauty as an ornamental tree that provides shade and shelter from the wind on streets, in parks, and in coastal areas. The wood is a prized timber for carving, cabinetmaking, and boat building. In Hawai'i it is traditionally used for food vessels and in Palau for storyboards. Oil from the nuts traditionally has been used for medicine and cosmetics and is today being produced commercially in the South Pacific. It is also used in varnishes and as lamp oil. The fragrant flowers have been prized as an adornment and as a perfume. The tree has been regarded as sacred in some Pacific islands, where it has been planted around altars and mentioned in old chants. Since the tree is tolerant of wind and salt spray, it has been used in coastal stabilization. The dense shade cast by the thick crowns provides shelter but does not favor understory plantings.

Kamani is a useful tree for coastal shelterbelts, windbreaks, and strand reforestation because it grows well despite the wind, salt spray, drought, and occasional flooding common to beach environments. It even withstands typhoons.

It has a shallow root system, prefers sandy or porous soils, and tolerates occasional inundation. The tree grows best in direct sunlight, but it grows slowly. Although wildings occur, it can be moderately difficult to propagate. Its slow growth and large seeds make it unlikely that the tree will become an invasive weed if introduced into new areas.

DISTRIBUTION

Native range

The tree is native from East Africa, through India and Southeast Asia to the Philippines, Taiwan, and the Marianas. Southward its range extends through Melanesia to Australia and through southern and eastern Polynesia. The habitat is primarily coastal and adjacent to lowland forests.

Current distribution

The tree is widely dispersed throughout the tropics, including the Hawaiian and other Pacific islands and the Caribbean. In Hawai'i it is naturalized in coastal zones on Hawai'i, Maui, Moloka'i, O'ahu, and Kaua'i.

BOTANICAL DESCRIPTION

Preferred scientific name *Calophyllum inophyllum* L.
Family Clusiaceae (syn. Guttiferae) (mangosteen family)

Non-preferred scientific names

Balsamaria inophyllum (L.) Lour.

Common names

Alexandrian laurel, beach mahogany, beauty leaf, poon, oil nut tree (English)
beach calophyllum (Papua New Guinea)
biyuch (Yap)
btaches (Palau)
daog, *daok* (Guam, N. Marianas)
dilo (Fiji)
eet (Kosrae)
feta'u (Tonga)
fetau (Samoa)
isou (Pohnpei)
kamani, *kamanu* (Hawai'i)
lueg (Marshalls)
rakich (Chuuk)
tamanu (Cook Islands, Society Islands, Marquesas)
te itai (Kiribati)

Some common names, e.g., tamanu and beach calophyllum, are used for more than one species of *Calophyllum*, especially when referring to lumber. "Bintangor" is a trade name for timber from other species of *Calophyllum* in Asia, usually not *Calophyllum inophyllum*.

***Calophyllum*, meaning "beauty leaf," is a remarkably apt name.**
PHOTO: C. ELEVITCH


Flowers and nearly ripe fruits. PHOTOS: C. ELEVITCH

Size

Kamani is a medium-sized to large evergreen tree 8–20 m (25–65 ft) in height, sometimes reaching up to 35 m (115 ft). Canopy width is often greater than the tree's height when the tree is grown in open locations.

Typical form

It has a broad, spreading crown, often with large, gnarled, horizontal branches. The light gray bark shows deep fissures alternating with flat ridges. Sap is milky white.

Flowers

It bears clusters of 4–15 fragrant white flowers about 2.5 cm (1 in) across and 8–14 mm (0.3–0.6 in) long on long, sturdy stalks in leaf axils. There are 4–8 oblong petals. Trees may flower all year, but flowering is heaviest in late spring/early summer and late fall in the northern hemisphere.

Leaves

The opposite leaves are dark green, shiny, and hairless with broadly elliptical blades 10–20 cm (4–8 in) long and 6–9 cm (2.4–3.6 in) wide. Both the tip and base of the leaves are rounded. Leaf veins run parallel to each other and perpendicular to the midrib. The scientific name *Calophyllum* comes from the Greek words for "beautiful leaf."

Fruit

The ball-shaped, light green fruits grow in clusters. Fruits are 2–5 cm (0.8–2 in) in diameter. The skin, which turns yellow and then brown and wrinkled when the fruit is ripe, covers the thin pulp, the shell, a corky inner layer, and a single seed kernel. Fruits are usually borne twice a year. In Hawai'i fruits fall from April–June and October–December.

Seeds

One large brown seed 2–4 cm (0.8–1.6 in) in diameter is found in each fruit. Seeds are prepared by cleaning off the skin and husk from the shell of the seed; there are 100–200 seeds/kg (45–90 seeds/lb), with shells intact but husks removed.

Similar species

Tropical almond (*Terminalia catappa,* sea or Indian almond) is sometimes called false kamani in Hawai'i, although it bears little resemblance to the true kamani. There are many other species in the genus *Calophyllum* in the Pacific, including *C. collinum*, *C. euryphyllum*, *C. laticostatum*, *C. papuanum*, *C. pauciflorum*, and *C. suberosum* in Papua New Guinea; *C. peekelii* and *C. vexans* in Papua New Guinea and the Solomons; *C. neo-ebudicum* (syn. *C. vitiense*) in Papua New Guinea, the Solomons, Vanuatu, Fiji, and Tonga; and *C. soulattri* and *C. pelewense* in Palau; *Calophyllum brasiliense* (Santa Maria) is an important timber tree in the Caribbean. Madagascar olive (*Noronhia emarginata*) is another coastal species of the Indian Ocean that is planted in the Pacific and may be confused with kamani.

How to distinguish from similar species

Tropical almond (*Terminalia catappa*) has egg-shaped leaves with the leaf stems attached at the narrow end. The leaves have branched veins and turn red as they age. Tropical almond fruits are almond-shaped, as the common name suggests. Kamani is generally a larger tree than *Terminalia*, with oval leaves with parallel veins and nearly spherical fruits. *Calophyllum brasiliense* is a straight-stemmed tree in contrast to the usually crooked, leaning kamani tree. *Calophyllum vitiense* is a tall, straight forest tree of the South Pacific. Its leaves are pointed on both ends, unlike the blunt oval leaves of kamani.

Malabar olive (*Noronhia emarginata*) is a smaller tree than kamani with only a few indistinct veins in the leaves, as opposed to the dense, parallel veins in the latter.

Kamani bark and view from underneath the canopy. PHOTO: J. B. FRIDAY

GENETICS

Calophyllum is a genus of about 190 species, mostly in Asia and the Pacific. *Calophyllum inophyllum* is common to locally abundant in the Pacific islands. Most other species only occur on the mainland of Asia or in Indonesia, the Philippines, and Papua New Guinea. Kamani has been identified as a priority species for further genetic research by the South Pacific Regional Initiative on Forest Genetic Resources (SPRIG). Named varieties include *C. inophyllum* var. *inophyllum*, var. *takamaka*, and var. *wakamatsui*.

ASSOCIATED PLANT SPECIES

The tree naturally occurs on beach and coastal forests of tropical Asia, Melanesia, Polynesia, and Australia. It may also occur on riverbanks further inland and is often replaced in lowland forest by other species of the same genus (e.g., *Calophyllum neo-ebudicum* in western Polynesia and eastern Melanesia) (Mueller-Dombois and Fosberg 1998).

In native habitat

In its native range kamani grows along with fish-poison tree (*Barringtonia asiatica*), ironwood (*Casuarina equisetifolia*, beach she-oak), kou (*Cordia subcordata*), beach hibiscus (*Hibiscus tiliaceus*), screwpine (*Pandanus tectorius*), tropical almond (*Terminalia catappa*, sea almond), and milo (*Thespesia populnea*). Associated shrubs often include naupaka (*Scaevola sericea*) and tree heliotrope (*Tournefortia argentea*). Native herbaceous plants commonly include *Canavalia* spp., beach morning glory (*Ipomoea pes-caprae*), and beach pea (*Vigna marina*) (Mueller-Dombois and Fosberg 1998).

As aboriginal introduction to Pacific Islands

Pacific islanders introduced coconut (*Cocos nucifera*), kou, beach hibiscus, screwpine, and milo along with kamani in areas where the trees were not native.

Recent introduction

In Hawai'i the tree is often found growing with the modern introductions ironwood, tropical almond, and tree heliotrope.

ENVIRONMENTAL PREFERENCES AND TOLERANCES

Climate

Kamani grows in warm temperatures in wet or moderate conditions. It is not suited to high elevations, cool areas, or very dry conditions.

Elevation range

0–200 m (660 ft) in Hawai'i; up to 800 m (2000 ft) at the equator


Although not its favored environment, kamani grows even at higher elevations, here planted on a farm at 440 m (1450 ft) in Kona, Hawai'i, among breadfruit, papaya, and candlenut. PHOTO: C. ELEVITCH

Mean annual rainfall

1000–5000 mm (40–200 in)

Rainfall pattern

Kamani prefers climates with summer, winter, or uniform rainfall patterns.

Dry season duration (consecutive months with <40 mm [1.6 in] rainfall)

4–5 months

Mean annual temperature

18–33°C (64–91°F)

Mean maximum temperature of hottest month

22–37°C (72–99°F)

Mean minimum temperature of coldest month

12–17°C (54–63°F)

Minimum temperature tolerated

8°C (46°F)

Soils

Kamani tolerates a wide range of soils. It grows best in sandy well drained soils in coastal areas but will tolerate clays, calcareous soils, and rocky soils.

Soil texture

It tolerates light to medium soils (sands, sandy loams, loams, and sandy clay loams).

Soil drainage

Freely draining as well as soils with impeded drainage or seasonal waterlogging are acceptable.

Soil acidity

Neutral to acid soils (pH 7.4–4.0)

Special soil tolerances

It tolerates shallow and saline soils.

Tolerances

Kamani is a hardy tree of tropical coastal areas that tolerates wind, salt spray, drought, and brief periods of waterlogged soil. It does not tolerate much shade nor cold weather.

Drought

Kamani can tolerate 4–5 months of drought in its natural littoral and riparian environments.

Full sun

Kamani prefers full sun, and only light shade is tolerated.

Fire

Kamani is moderately tolerant of wildfire, once the bark thickens.

Frost

Kamani grows only in warm climates and does not tolerate frost.

Waterlogging

Kamani tolerates occasional waterlogging in coastal areas.

Salt spray and wind

Kamani grows in areas subject to sea breezes and salt spray.

Abilities

Regenerate rapidly

The trees drop large amounts of fruit, and wildlings may often be found under mother trees, although growth is slow relative to many weed species.

Coppice

It regrows dependably but slowly after pruning.

Pollard

The branches can be pruned back every 2–3 years and they will regrow.

GROWTH AND DEVELOPMENT

The seedlings start out growing erect and with few branches. Growth slows after the first few years and the trees branch out, often developing multiple stems. Old trees in coastal environments are often bent and twisted by the wind and support many large horizontal branches and multiple stems.

Growth rate

Young trees in Hawai'i may grow up to 1 m (3.3 ft) in height per year for the first few years, but after that the growth rate slows. In Malaysia one stand of trees attained a diameter of 50 cm (20 in) at breast height in 70 years (Soerlanegara and Lemmens 1994).

Flowering and fruiting

The tree flowers twice a year in the northern hemisphere, in the late spring/early summer and late fall. In northern Australia, it flowers in January and June. Young trees begin flowering after 7 or 8 years.

Rooting habit

The tree has a non-aggressive root system.

Reaction to competition

The tree is only slightly shade tolerant and will not grow under dense forest canopies. It grows slowly in height and may be overwhelmed by weeds in young plantations.

PROPAGATION

Kamani is moderately easy to propagate by seed, and local seed sources are easily found in the Pacific Islands. Germination and initial growth is slow, however, and seedlings should be started 6 months before they are required. Once outplanted, seedlings are hardy but slow growing. They prefer full sun and tolerate wind, salt spray, and drought.

Seed collection

Ripe fruits are most easily collected from the ground under trees. Fruits fall twice a year in most locations.

Seed storage

Seed storage is intermediate. In other words, fresh seeds may keep for a few months stored cool and dry, usually with the husk removed.

Pre-planting treatments

Seed germination is slow if the entire fruit is planted. Ripe

Ripe fruit (left), cracked shell showing seed kernel inside (middle), and dry seed (right). PHOTO: J. B. FRIDAY fruits (skin is yellow or brown and wrinkled) may be soaked overnight to remove skin. Just prior to planting it is best to crack shells or shell seeds entirely using a mallet, pliers, or hammer. No additional treatments are required.

Growing area

Plants may be started in containers at least 6 cm (2.4 in) in diameter, of sufficient size to accommodate the fairly large seeds. Partial shade is useful during the first few weeks in hot areas. Seedlings should be grown in full sun after 1–2 months.

Germination

Seeds germinate gradually, and shelled seeds germinate faster than seeds in their shells. One study found average germination times of 22 days for seeds fully shelled, 38 days for seeds in cracked shells, and 57 days for seeds still in their shells (Parras undated). Germination rates for fresh seeds are greater than 90%.

Media

The tree grows in any well drained medium.

Time to outplanting

The seedlings are ready for outplanting 20–24 weeks after germination. Seedlings should be hardened-off in full sun before outplanting.

Approximate size at time of outplanting

Seedlings should have a well developed root plug and be 20–30 cm (8–12 in) tall at the time of outplanting.

Guidelines for outplanting

Survival is typically high, although the seedlings grow slowly at first and need to be protected from weeds during the first several years of growth.

Other comments on propagation

Because of its large seed, the tree may also be grown by direct-seeding. Seeds should be sown about 2.5 cm (1 in) deep. Wildlings may also be transplanted from under mother trees.

Nursery seedlings in various stages of development, grown in containers measuring 6 x 6 x 13.3 cm (2.4 x 2.4 x 5.25 in). PHOTO: C. ELEVITCH

DISADVANTAGES

Drawbacks of kamani include

- Kamani is a slow-growing tree. Plantings must be kept free of weeds for the first few years. Small seedlings are vulnerable to drought and mechanical damage.
- The wood shrinks appreciably upon drying and is difficult to work.
- The tree fruits prolifically and the round, hard, golf ball-sized nuts may be poisonous if eaten.
- The oil extracted from the nuts, while useful when applied externally, is mildly poisonous and should not be ingested.

Potential for invasiveness

Because of its slow growth and large, water-distributed seeds, the tree is not likely to become an invasive pest. Since the fruits are not carried by the wind or birds, they are not likely to be carried into inland forests. Kamani naturalizes along coasts and beaches, but its slow growth means that it is not likely to outcompete native vegetation. While it was introduced to Hawai‘i hundreds of years ago, it remains uncommon outside of cultivation.

Diseases and pests

Leaves and young shoots are susceptible to attack by various insects, and fungus rot may occur in adult trees. Young leaves are susceptible to attack from thrips, but trees usually outgrow infestations. Deer have damaged young trees on Guam by rubbing with their antlers.

Host to crop pests/pathogens

The tree is a host to the fruit fly *Bactrocera facialis* in Tonga. In Micronesia, it is host to a weevil (*Trigonops inusitata*), a psyllid (*Leptynoptera sulfurea*), a planthopper (*Lamenia caliginea*), and a palm scale (*Hemiberlesia palmae*). None are serious pests and trees usually recover quickly from attacks.

Other disadvantages or design considerations

While the tree is a valuable timber, lack of growth and yield data discourage people from planting it as an investment.

Kamani is a popular street tree and ornamental throughout the tropics (Dili, East Timor). PHOTO: J. B. FRIDAY

AGROFORESTRY/ ENVIRONMENTAL PRACTICES

Mulch/organic matter

Kamani's thick, waxy leaves decay slowly and form a thick layer of litter under kamani stands.

Soil stabilization

Kamani is a good tree for soil stabilization in coastal areas.

Fire control

Kamani is being planted for firebreaks on Guam, as it shades out fire-prone grasses, is moderately tolerant of fire itself, and is resistant to typhoons.

Crop shade/overstory

The tree casts a dense shade and usually does not transmit enough light to allow understory crops to thrive in a multistory system.

Homegardens

It is grown as part of the mixed garden agroforestry systems in many Pacific islands. In the Solomons, kamani has been traditionally retained or planted along with other trees such as breadfruit, sago palm, *Terminalia, Burckella, Pometia*, and *Canarium* in fallow yam and sweetpotato fields (Yen 1976).

Boundary markers

Kamani may be used to mark the location of temples, altars, and sacred sites in Pacific islands.

Windbreaks

Kamani is tolerant of wind and salt spray and makes a very good coastal windbreak tree.

Woodlot

Kamani's beautiful and highly prized wood could make it a valuable addition to a woodlot.

Coastal protection

The tree grows in coastal areas right down to the high tide mark and is highly tolerant of salt spray. It protects coastlines and stabilizes dunes, and the dense foliage shelters more sensitive plants from salt spray.

Ornamental

Kamani is a favorite ornamental tree in the Pacific. Its tolerance of poor soil conditions, salt spray, and poor air quality make it hardy in urban conditions. The large size makes it an impressive plant along wide avenues, but it is not suited to confined spaces.

USES AND PRODUCTS

Fruit

The mature fruit is burned for mosquito repellent.

Nut/seed

Oil derived from the seeds was used as an alternative to candlenut oil in lamps by some Polynesians. It may also be used for massage or hair oil, particularly when scented. The oil is also used to finish wooden bowls.

Medicinal

Oil from the seed is used for cosmetic and topical applications for healing of burns and skin diseases. The latex or a decoction of the bark is also sometimes used medicinally. A decoction of the leaves was used to treat eye ailments over much of Polynesia and westward into Malaysia.

Beautiful/fragrant flowers

Flowers are used in leis (garlands), to scent hair, and to scent bark cloth.

Timber

The beautiful wood has a fine, lustrous texture that shows a distinctive interlocked grain. It is white and red when fresh cut and ages to a reddish brown. Because of this interlocked grain, sawn surfaces tend to be woolly. The wood is moderately dense, specific gravity 0.6–0.8, and is somewhat difficult to work due to the interlocked grain. In Hawai'i the tree provides one of the most valuable woods on the market, although timber is often unavailable. It has been used for paneling and furniture. Elsewhere the wood is used for general cabinetry, construction, and boat building. It has, however, been variously described as vulnerable or resistant to termite attack (Grace and Tome 1995, Little and Skolmen 1989).

Craft wood/tools

The wood is particularly useful for food platters and calabashes, as it imparts no taste to the food. It is also prized for handicrafts because of its beauty. In Palau it is a favorite wood for carving traditional storyboards.

Canoe/boat/raft making

The tree has traditionally been used in boat building.

Thatch/roofing/mats

The bark is used as shingles for house walls in Yap.

Resin/gum/glue/latex

Latex from the cut bark has been made into a poison to kill rodents and stun fish.

Top: Kamani platter and bowl. Middle: Story board from Palau. PHOTOS: J. B. FRIDAY **Bottom: Typical wood grain, actual size.** PHOTO: C. ELEVITCH

Body ornamentation/garlands

The nuts are hollowed out and the shells are used in making leis. In ancient times whistles were made from the hollowed-out shells.

Dye

In ancient Hawai‘i, a brownish-mauve dye for tapa or bark cloth (*kapa*) was made from the fruit husks. The bark contains tannins that have been used to toughen fish nets.

Cosmetic/soap/perfume

The flowers and the sap were used to scent bark cloth (*kapa*) in old Hawai‘i.

Oil/lubricant

The seed oil is used as a wood finish.

Illumination/torches

The seed oil can be used as lamp oil.

Ceremonial/religious importance

The tree is a sacred tree in some Pacific island traditions and has been planted alongside temples. The tree is mentioned in old Hawaiian chants, and they were planted around altars in ancient times.

Ornamental

The tree is a favorite ornamental in the Pacific. The tree's tolerance of poor soil conditions, salt spray, and poor air quality make it hardy in urban conditions. The tree's large size is impressive along wide avenues, but it is not well suited to confined spaces.

Kamani growing as beach ornamental on ‘Upolu, Samoa. PHOTO: C. ELEVITCH

URBAN AND COMMUNITY FORESTRY

Kamani is an excellent urban forestry tree for large spaces in coastal areas. The tree's large, spreading crown and horizontal branches make it a good shade tree and focal point for parks and other open areas. Its distinctive glossy leaves have earned it the English name "beauty leaf" in some countries. Kamani thrives in coastal environments where other trees suffer from wind, flooding, and salt spray. Since the tree is adapted to the shallow, often flooded soils found in coastal areas, it is hardy in urban settings where similar environmental conditions occur.

The kamani tree is important to native cultures throughout the Pacific. Planting the tree helps celebrate and sustain island cultures.

Size

Kamani can become a huge tree and is best suited for growing in open spaces. The tree can reach 20 m (65 ft) in height, although planted specimens are usually 12–15 m (40–50 ft). In open areas the canopy is oval or umbrella-shaped and as wide as the tree is tall. Trunks of very old trees can be over 1 m (3.3 ft) in diameter. Given enough room, kamani trees are only a little smaller than rain tree (*Samanea saman*), although kamani grows much more slowly. Kamani may be pollarded or repeatedly pruned back to control its size.

Left: Kamani's shallow roots may damage pavement if the tree is planted too close to sidewalks, streets, or parking lots. PHOTO: J. B. FRIDAY **Right: Pollarded tree after 2 years of regrowth.** PHOTO: C. ELEVITCH

Rate of growth in a landscape

Newly planted kamani trees, if well cared for and planted in full sun, can grow 1 m (3.3 ft) in height and 60 cm (2 ft) in canopy spread per year for the first 5 years. Growth is slower thereafter.

Roots

Because it is adapted to shallow and occasionally flooded soils along coasts, kamani has a shallow, spreading root system. Its large woody roots spread at least as far as the canopy. If kamani trees are planted so that the canopy will eventually overhang buildings, streets, or parking lots, the roots may damage the pavement or walls. The roots also rise up above the surface of the soil, making it difficult to mow grass under the trees.

Products commonly used in a Pacific island household

Kamani furnishes a beautiful timber that is much in demand for carving, furniture making, boat building, and other uses. A medicinal oil is extracted from the nuts. The sweet-scented flowers have been used to impart fragrance to bark cloth and for personal adornment.

Light requirements

Kamani trees grow best in full sunlight. The trees cast a dense shade, so little grows underneath their canopies. Young kamani trees need to be kept weeded until they grow well above the surrounding weeds.

Water/soil requirements

Kamani prefers well drained, sandy soils but can grow in clay, rocky, or calcareous soils as well. The tree tolerates poor soil drainage and can grow right down to the water line. Kamani tolerates poor, compacted soils of urban areas and can grow in acid to neutral soils. Once established, it tolerates dry seasons of up to 4 months.

Expected life span in a homegarden

Although there is no data available, it is a long-lived tree that can be expected to live many decades in an urban environment.

Varieties favored for use in an urban environment

There are many species of *Calophyllum*, most of which are forest trees. Kamani is the only commonly grown coastal species in the genus.

Seasonality of leaf flush, flowering, fruiting

Kamani flowers twice a year in most locations. Flowers, green fruits, and ripe fruits may sometimes be seen on trees simultaneously.

Exceptional ornamental values

The flowers have a sweet scent, but their fragrance does not permeate the air the way scents from some other flowering trees do. The flowers are modestly showy. The chief attraction of the tree is its glossy green leaves.

Use as living fence, hedge, or visual/noise barrier

Kamani's dense crown makes a good visual barrier for buildings or other structures. Trees must be planted far enough away so that they do not damage buildings as they grow. The tree's large size makes it impractical as a living fence, although young trees have been pruned to make view screens in Florida.

Maintenance requirements

Relatively large container-grown trees may be outplanted in urban or park settings. Trees 3 m (10 ft) tall with a 10 cm (4 in) stem diameter can be successfully established. The planting hole should be dug twice as wide as the tree's root ball but no deeper. Roots that have begun to spiral in the container should be cut or separated so that they do not eventually strangle the rest of the root system.

Fertilizer can boost kamani's initial growth. While there are no specific fertilizer recommendations for kamani, seedlings have grown well with 50–170 g (2–6 oz) of a complete fertilizer such as 15-15-15 applied per seedling at planting and again after 6 months. Young, actively growing trees benefit from application of fertilizers containing 1–3 kg N per 100 m^2 of canopy or planting bed area (2–6 lb N per 1000 ft^2) per year. Fertilizers containing N and K are best applied in several small applications over the course of the year rather than all at once and best placed in holes dug around the drip line of the canopy of the trees. Alternately, or in addition to chemical fertilizers, well composted manures or other organic fertilizers can be added to the planting hole and spread around the base of the tree occasionally. A more effective fertilizer strategy can be developed by first testing the soil of the planting site. Trees benefit from mulching, but deep mulch should be kept out of direct contact with the trunk.

As with all ornamental trees, proper pruning is important to achieve good tree form. Dead branches should be removed promptly. Multiple main stems should be removed so that only one remains, especially if the timber will eventually be harvested. Although the canopy tends to spread laterally, side branches may be removed to encourage more upright growth. Kamani's large horizontal branches are unusually strong and do not need to be removed unless tree form or space is an issue.

The size of kamani trees may be controlled by a specialized pruning process known as pollarding. Pollarding a tree properly starts when a tree is young. A framework for the tree's growth is established. Young branches are cut back to this framework periodically, usually every growing season. Eventually, woody pollard heads develop at the branch ends. Pollarding is not the same as "topping" or "hat racking" in which large branches are cut and most of the tree's canopy is destroyed. When this is done, the tree is starved and becomes vulnerable to infections and dieback. Young branches that sprout after a tree is topped will be weaker than the original branches. If neglected and allowed to grow out, pollarded trees may become unsightly and develop weak branches. In general, it is better to plant kamani trees where they will have room to grow to their full size and select smaller trees for confined spaces.

Drawbacks

Kamani's chief drawback as an ornamental tree is its large size (although it can be kept smaller with regular pruning as noted above). Few yards or streets have room for such a large tree, which may eventually interfere with overhead wires. The spreading roots may damage pavement and structures.

Nuisance issues

In Hawai'i, kamani trees growing in public parks and private lands with public road frontage have been cut down by thieves who steal the wood.

Hazards

The fruits are mildly poisonous if many are eaten. The medicinal oil extracted from the seed is used externally for skin diseases and injuries and is toxic if taken internally. Kamani is a prolific seeder, and the hard, golf ball-size fruits must be frequently cleaned up if they fall on sidewalks, streets, lawns or other areas where slipping on a seed can be very hazardous.

Common pest problems

Kamani does not have many pest problems. Thrips may attack new leaves, but the trees usually outgrow the infestation and no treatment is needed.

COMMERCIAL PRODUCTS

Timber

The primary product harvested from the tree is the timber. Many species of the genus *Calophyllum* are traded, and a given batch of lumber may contain wood from several species of trees. A trade name for *Calophyllum* lumber in general in Southeast Asia is "bintagor." Commercial quantities are produced in Melanesia and the South Pacific. In Hawai'i the wood is much rarer, and retail sawn lumber prices for kamani range from $6.00 to $15.00/bf with logs fetching $3/bf. Wholesale lumber prices elsewhere in the Pacific may be $6.00 to $8.00 per board foot.

Spacing for commercial production

Most kamani timber is harvested from wild stands. Since kamani is a large tree, a relatively wide spacing (3–3.5 m, 10–12 ft) is a good distance between trees for planted stands. Kamani has done well when intercropped with the nitrogen-fixing tree *Acacia mangium* on Guam. The intercropping seems to have reduced damage from deer.

Management objectives

While clear lumber is valued, kamani trees tend to be branchy. Frequent pruning of young trees is recommended.

Design considerations

Planting trees in dense stands would promote straight growth and maximum timber production. Planted as shelterbelts or windbreaks in rows along shorelines or as border plantings to farms or agroforests, the tree form is often irregular and branchy, which is more effective for windbreaks but yields less clear timber.

Yield

No data are available for timber yields.

Processing required

Large trees may have large, horizontal branches that contain much useful wood. Care must be taken in harvesting these trees to avoid splitting the branches or stems when the trees are felled. Cut lumber longer than 3 m (10 ft) tends to warp.

Market

Hawai'i is currently importing the wood for high-quality flooring, moldings, and cabinetry. Elsewhere in the Pacific, the tree may be mixed with other, lower-value species of *Calophyllum* as an industrial or general-purpose timber.

Oil

The oil extracted from the nuts, called tamanu or dilo oil, is offered on the Internet at prices as high as US$360/l (US$1440/gal). This oil is produced in Vanuatu, Tahiti, and other South Pacific islands. Kamani nut oil is offered for sale in Hawai'i for $11.00 for a 250 ml (4 oz) bottle.

Spacing for commercial production

Widely spaced trees would yield the most nuts. Nuts today are mostly harvested from wild stands.

Design considerations

Nuts may be harvested from trees planted for other purposes, such as shelterbelts or ornamentals.

Yield

Five kg (11 lb) of oil may be extracted from 100 kg (220 lb) nuts. 100 kg of nuts is the approximate annual yield of a mature tree.

Processing required

The nuts are cracked and the kernels are extracted. The seeds need to be sun-dried on racks 1–2 months in order for the oil to form. Kernels will turn from creamy white to brown during this process. Any moldy nuts should be discarded. The oil is then extracted by cold-pressing and filtration.

Market

Tamanu oil is offered through various herbal and botanical companies on the Internet. Prices are as high as US$360/l (US$340/qt). Commercial production occurs in Tahiti and Vanuatu.

INTERPLANTING/FARM APPLICATIONS

Example 1

Location

'Ōpae'ula, O'ahu, Hawai'i

Description

A plantation was established May 16, 1997 on a deep, acid soil (Humoxic Tropohumult in the USDA classification) at 380 m (1250 ft) elevation, 2000 mm (80 in) rainfall. Trees were fertilized and weeded as needed.

Yields

Initial growth was rapid, with seedlings reaching 75 cm (30 in) height at 1 year and 190 cm (75 in) height and 1.5 cm (0.6 in) diameter at breast height in 2.5 years. Survival in the first 2 years was almost 100%.

Growth data

	9/16/97	5/12/98	12/9/98	5/24/99	11/23/99
Height	32 cm	76 cm	123 cm	154 cm	192 cm
DBH	-	-	-	-	1.5 cm

Crop/tree interactions

Adjacent stands were planted with kou (*Cordia subcordata*) and milo (*Thespesia populnea*).

Spacing

Trees were planted in solid blocks at 3 x 3 m (10 x 10 ft) spacing; no interplanting was done.

Example 2

Location

Moloka'i, Hawai'i

Description

An alley cropping demonstration was planted by the University of Hawai'i on former agricultural land on the island of Moloka'i in 1995 with kamani, kou (*Cordia subcordata*), milo (*Thespesia populnea*), and candlenut (*Aleurites moluccana*). The site is dry and windy, with only 460–530 mm (18–21 in) of rainfall annually, and is 150 m (500 ft) above sea level. The soil is classed as a Typic Torrox in the USDA classification. Soil pH is 6.5. Alfalfa for forage was grown between the trees until the canopies closed; after that a number of shade-tolerant crops were planted, including ornamental ginger, edible mushrooms, kava, and cacao.

Yields

Tree growth was satisfactory; kamani trees averaged 7.1 m (23 ft) in height with the tallest growing 9 m (30 ft) in 7 years. The constant high winds have caused the trees to lean over, however, and the effect of the stress on wood quality is unknown. Crop production is less than would be expected in full sun but nonetheless appreciable.

Crop/tree interactions

Crop yield, even for the shade-tolerant crops (except for the edible mushrooms), is reduced because of shading. Kava grew tall and spindly under the dense canopy of the kamani. However, the trees also serve as windbreaks, without which fragile crops such as kava would not grow at all. The crops receive supplemental irrigation, which also benefits the trees.

Spacing

The trees were planted in wide rows 5 m (15 ft) apart with 3 m (10 ft) spacing within the rows.

Example 3

Location

Kīpū, Kaua'i, Hawai'i

Description

A new plantation was established in 1998 on a deep, acid, clay soil (Typic Umbriorthox, USDA classification); elevation 125 m (415 ft); windy; average annual rainfall 1100 mm (43 in); temperature range 18–30°C (65–86°F). Trees were weeded as needed and given fertilizer for the first 3 years.

Yields

Trees at age 52 months averaged 5.2 m (17 ft) in height, maximum 6.1 m (20 ft); diameter at breast height averaged 5.8 cm (2.3 in), maximum 6.6 cm (2.6 in)

Crop/tree interactions

Trees were planted in a single-species stand adjacent to stands of milo (*Thespesia populnea*), cocobolo (*Dalbergia retusa*), red bead tree (*Adenanthera pavonina*), and bamboo (*Bambusa arundinacea*). Kamani trees developed a lean toward the light and away from the shading red bead tree and bamboo.

Spacing

Trees were planted in a double row at 1.8 x 3.4 m (6 x 11 ft) spacing.

Example 4

Location

Waiākea, Hilo, Hawai'i

Description

A new plantation was established in 1995 on thin, acid soil derived from organic matter over 'a'ā lava rock, elevation 180 m (600 ft), rainfall 4000 mm (160 in). The soil is a Typic Tropofolist in the USDA soil classification.

Yields

Trees were managed for timber. The trees were 116 cm (45 in) height after 1 year. After 5 years, they reached an average height of 470 cm (15 ft) and diameter at breast height of 7 cm (2.8 in) while still showing 100% survival. After 8 years, the average tree height was 7.2 m (24 ft) and diameter was 9.9 cm (3.9 in), with the largest tree reaching 9.8 m (32 ft) in height with a diameter of 13 cm (5.2 in).

Crop/tree interactions

Adjacent single-species blocks were planted with kou (*Cordia subcordata*), koa (*Acacia koa*), and milo (*Thespesia populnea*). After 8 years, all the other species had failed.

Spacing

Trees were planted at 1.5 x 3 m (5 x 10 ft) spacing.

PUBLIC ASSISTANCE AND AGROFORESTRY EXTENSION

Extension offices for agroforestry and forestry in the Pacific: <http://www.traditionaltree.org/extension.html>.

INTERNET

Canoe plants of ancient Hawai‘i: <http://www.canoeplants.com>.

Native Plant Network Propagation Protocol Database: <http://www.nativeplantnetwork.org/network/search.asp>.

Agroforestree database, World Agroforestry Centre (ICRAF): <http://www.worldagroforestrycentre.org/Sites/TreeDBS/AFT/AFT.htm>.

University of Hawai‘i College of Tropical Agriculture and Human Resources Landscape Series publications on pruning, fertilizing, watering, and more: <http://www.ctahr.hawaii.edu/freepubs>.

How to Prune Trees, USDA Forest Service: <http://www.na.fs.fed.us/spfo/pubs/howtos/ht_prune/prun001.htm>.

Advice on pollarding from the Royal Horticultural Society: <http://www.rhs.org.uk/advice/profiles0204/pollarding.asp>.

A description of pollarding: <http://www.passionfortrees.co.uk/html/pollard.html>.

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Calophyllum inophyllum (kamani)

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Acknowledgments: The authors and publisher thank Robin DeMeo, Nick Dudley, Dale Evans, Eileen Herring, and Art Whistler for their input.

Recommended citation: Friday, J.B., and D. Okano. 2006. *Calophyllum inophyllum* (kamani), ver. 2.1. In: Elevitch, C.R. (ed.). Species Profiles for Pacific Island Agroforestry. Permanent Agriculture Resources (PAR), Hōlualoa, Hawai'i. <http://www.traditionaltree.org>.

Sponsors: Publication was made possible by generous support of the United States Department of Agriculture Western Region Sustainable Agriculture Research and Education (USDA-WSARE) Program; SPC/GTZ Pacific-German Regional Forestry Project; USDA Natural Resources Conservation Service (USDA NRCS); Kaulunani, an Urban Forestry Program of the DLNR Division of Forestry and Wildlife and the USDA Forest Service; State of Hawai'i Department of Land & Natural Resources Division of Forestry & Wildlife; USDA Forest Service Forest Lands Enhancement Program; and Muriel and Kent Lighter. This material is based upon work supported by the Cooperative State Research, Education, and Extension Service, U.S. Department of Agriculture, and Agricultural Experiment Station, Utah State University, under Cooperative Agreement 2002-47001-01327.

Series editor: Craig R. Elevitch

Publisher: Permanent Agriculture Resources (PAR), PO Box 428, Hōlualoa, Hawai'i 96725, USA; Tel: 808-324-4427; Fax: 808-324-4129; E-mail: par@agroforestry.net; Web: <http://www.agroforestry.net>. This institution is an equal opportunity provider.

Cananga odorata (ylang-ylang)

Annonaceae (custard-apple family)

canang odorant **(French);** ***chiráng*****,** ***irang*** **(Palau);** ***derangerang*****,** ***derangirang*** **(Nauru);** ***ilahnglahng*****,** ***ilanlang*** **(Kosrae);** ***ilang-ilang*****,** ***alang-ilang*** **(Guam, CNMI);** ***ilangilang*****,** ***lengileng*****,** ***alangilang*****,** ***pur-n-wai*****,** ***pwurenwai*****,** ***seir en wai*** **(Pohnpei);** ***ilanilan*** **(Marshall Islands);** ***lanalana*** **(Hawai'i);** ***makosoi*****,** ***mokohoi*****,** ***makasui*****,** ***mokosoi*** **(Fiji);** ***mohokoi*** **(Tonga);** ***moso'oi*** **(Samoa);** ***moto'i*** **(Society Islands);** ***moto'oi*****,** ***mata'oi*****,** ***mato'oi*** **(Cook Islands, Niue, Tahiti);** ***motoi*** **(Marquesas–Nukuhiva, Niue);** ***mutui*** **(Marquesas–Fatuhiva);** ***pwalang*** **(Puluwat Atoll);** ***pwanang*****,** ***pwuur*****,** ***pwalang*** **(Chuuk);** ***sa'o*** **(Solomon Islands: Kwara'ae); ylang ylang, perfume tree, cananga (English)**

Harley I. Manner and Craig R. Elevitch

IN BRIEF

Distribution Common throughout Polynesia, Micronesia, and Melanesia; also present throughout its native Indo-Malayan region, and now distributed pantropically.

Size Typically reaches 10–20 m (33–66 ft), with long drooping branches or twigs.

Habitat Lowland, humid tropics, 0–800 m (0–2600 ft) with rainfall of 700–5000 mm (30–200 in).

Vegetation Associated with many cultivated tropical plants.

Soils Prefers light and medium texture soils; tolerates shallow and temporarily waterlogged soils.

Growth rate Fast growing; can exceed 5 m/yr (16 ft/yr).

Main agroforestry uses Homegardens.

Main products Flowers for adornment or oil distillation, timber.

Yields A cultivated tree in full production can yield 20–100 kg (44–220 lb) of flowers per year.

Intercropping Tolerates shade and grows well together with other crops.

Invasive potential Slight; has naturalized in areas where introduced in the Pacific islands, although it is rarely considered a pest.

PHOTO: H. MANNER

Ylang-ylang tree about 9 m (30 ft) in height. Hospital Road, Guam.

INTRODUCTION

Of Southeast Asian origin, *Cananga odorata*, commonly known as ylang-ylang, is a medium-size tree that has been introduced into many islands in the Pacific for its fragrant flowers. This species is often found growing spontaneously in secondary forests and agroforests, where it regenerates easily. It is also a common garden ornamental. In Madagascar and the Comoro Islands, ylang-ylang is valued as the source for ylang-ylang oil, which figures prominently in the perfume industry and aromatherapy.

DISTRIBUTION

Native range

Ylang-ylang is native to Indo-Malaysia and has been widely introduced by Polynesians, Micronesians, and early European explorers into many islands in the Pacific, where in some places it has become naturalized (e.g., Samoa).

Current distribution

There is a degree of uncertainty concerning the antiquity of ylang-ylang in Polynesia. Whistler (1991) noted that the species was probably present in Samoa in pre-European times, but because the Cook expeditions did not visit Samoa, and the species was not collected in western Polynesia until 1839, its status is not clear. Thaman et al. (1994) consider the species to be an aboriginal introduction into Polynesia. Thaman (1993) also suggested that the species is possibly native to the Solomon Islands and the Caroline Islands. However, Fosberg et al. (1979) stated that the species is a European introduction into various places in Micronesia. Moreover, the species is not listed for Yap State, but it is found on the other high islands of Micronesia (Fosberg et al. 1979, Merlin et al. 1996). According to Merlin et al. (1992), this species is a recent introduction to Pohnpei, occurring with early European contact, and is also believed to be a recent (European) introduction to Nauru and the Mariana islands. It was introduced into Guam from the Philippines (Stone 1970). The species is also classified as a recent introduction in New Caledonia (MacKee 1985). It has also been introduced to tropical America (e.g., Costa Rica).

In the Pacific, ylang-ylang is now found in the Mariana Islands (Saipan, Rota, Guam), Nauru, Caroline Islands (Palau, Koror, Faraulep, Chuuk, Pohnpei, Puluwat Atoll), Fiji, Tonga, Samoa, New Caledonia (rare), Hawai'i (rare), Cook Islands, Marquesas Islands, and many other small islands.

BOTANICAL DESCRIPTION

Preferred scientific name

Cananga odorata (Lam.) Hook. F. & Thoms.

Family

Annonaceae (custard-apple family)

Non-preferred scientific names

Canangium fruticosum Craib
Canangium odoratum (Lam.) Baill. ex King
Canangium scortechinii King
Uvaria odorata Lam.

Common names

Oceania

canang odorant (French)
chiráng, *irang* (Palau)
derangerang, *derangirang* (Nauru)
ilahnglahng, *ilanlang* (Kosrae)
ilang-ilang, *alang-ilang* (Guam, CNMI)
ilangilang, *lengileng*, *alangilang*, *pur-n-wai*, *pwurenwai*, *seir en wai* (Pohnpei)
ilanilan (Marshall Islands)
lanalana (Hawai'i)
makosoi, *mokohoi*, *makasui*, *mokosoi* (Fiji)
mohokoi (Tonga)
moso'oi (Samoa)
moto'i (French Polynesia)
moto'oi, *mata'oi*, *mato'oi* (Cook Islands, Niue, Tahiti)
motoi (Marquesas–Nukuhiva, Niue)
mutui (Marquesas–Fatuhiva)
pwalang (Puluwat Atoll)
pwanang, *pwuur*, *pwalang* (Chuuk)
sa'o (Solomon Islands: Kwara'ae)
ylang ylang, perfume tree, cananga, cadmia (English)

Other regions

apurvachampaka, *chettu sampangi*, *karumugai* (India)
ilang-ilang, *alang-ilang* (Philippines)
ilang-ilang, kenanga wood, perfume tree, cananga oil, ylang-ylang (trade names)
kadatngan, *kadatnyan* (Myanmar)
kernanga (Indonesia)
kenanga, chenanga, ylang-ylang (Malaysia)

Form

Ylang-ylang is of medium size 10–40 m (33–130 ft) in height, although rarely over 30 m (100 ft), and typically 10–20 m (33–66 ft). In cultivation, the tree is usually kept short by pruning to about 3 m (10 ft). Branches are pendulous or slightly erect with drooping, leafy twigs. The tree is usually quite straggly, often with long, leafy twigs dangling 3–6 m (10–20 ft). There is a single main trunk that is usually bent to some degree. The bark is smooth and grayish white to silvery.

Flowers

It flowers throughout the year in axillary, umbellate hanging clusters of 4–12 flowers. The flower has three sepals and six petals up to 8 cm (2.4 in) long. The petals are twisted when young, then limp and drooping when mature. Flowers are very fragrant, greenish yellow at first, then turning a deep yellow/yellow brown when mature. Merlin et al. (1993) stated that on Kosrae this plant flowers at the same time as other fruit or nut trees, e.g., breadfruit, pandanus, mango, and Tahitian chestnut (*Inocarpus fagifer*). In Madagascar, the trees flower year-round, but mainly during the rainy season from November to March.

Leaves

Leaves are dark green, up to 20 cm (8 in) in length, alternate, simple, entire, elliptic-oblong, slightly pubescent, and with a prominent midrib and drip tip. As with most members of this family, the leaves are arranged mainly along a plane.

Fruit

Greenish black in color, 1.5–2.5 cm (0.6–1.0 in) in length, containing 6–12 stalked fruitlets, fleshy, olive-like, and borne in axillary clusters. There are 6–12, small, pale brown, flattened ovoid seeds in each fruit.

Similar species

Also in the custard-apple family and with the common name ylang-ylang, *Artabotrys hexapetalus* is a climbing woody shrub from India. The flowers are green, with a fragrance similar to those of *Cananga odorata*. However, the flowers of *Artabotrys* are not showy and much smaller, having six 2.5 cm (1 in) long petals that do not twist. Also, *Artabotrys* is a vine, whereas *Cananga* is a tree.

Arrangement of leaves. PHOTO: H. MANNER

Flowers at various stages of maturity. PHOTO: C. ELEVITCH

Immature fruits. PHOTO: C. ELEVITCH

GENETICS

Variability of species

Two groups are distinguished in cultivation. The first group Cananga (forma *macrophylla* Steenis) has branches perpendicular to the stem (rather than drooping) and large leaves 20 x 10 cm (8 x 4 in). The flowers of this group are the source of the distillate traded as cananga oil; it is cultivated in Java, Fiji, and Samoa. The second group is Ylang-ylang (forma *genuina* Steenis) and has drooping branches and smaller leaves than the first group. This form is the source of the distillate traded as ylang-ylang oil and is cultivated throughout the tropics (Oyen and Dung 1999).

Known varieties

C. odorata var. *fruticosa* (Craib) J. Sincl. is a dwarfed, cultivated form that reaches 2 m (6.6 ft) in height (Backer and Brink Jr. 1963). It often has more numerous and very curly flower petals than usual. This variety is said to never set fruit.

ASSOCIATED PLANT SPECIES

Associated native species

In Indonesia, this species is a component of mixed and teak forests. It is also cultivated for its fragrant flowers in plantations and in backyard gardens as an ornamental.

Species commonly associated in modern times or as recent introduction

It is a commonly planted and spontaneous tree in secondary forests and agroforests in Micronesia and Polynesia. In Pohnpei, this species was cultivated for its essential oil as a plantation or orchard crop at the Ponape Agriculture and Trade School in the mid-1980s. On Guam, ylang-ylang can be found growing in secondary forests containing other introduced species (i.e., *Leucaena leucocephala*, *Spathodea campanulata*, *Areca catechu*, etc.), near roadways.

ENVIRONMENTAL PREFERENCES AND TOLERANCES

Ylang-ylang prefers the humid lowland tropics, although it can be cultivated in the uplands near the equator.

Climate

The tree grows well in the equatorial to subtropical maritime climates of the Indian and Pacific oceans. It is a component of the tropical moist to semi-dry forest.

Elevation range

1–800 m (0–2600 ft); up to 1200 m (3900 ft) near the equator

Mean annual rainfall

700–5000 mm (30–200 in)

Rainfall pattern

Grows in climates with summer, winter, bimodal, and uniform rainfall patterns.

Dry season duration (consecutive months with <40 mm [1.6 in] rainfall)

2 months

Mean annual temperature

18–28°C (64–82°F)

Mean maximum temperature of hottest month

28–35°C (82–88°F)

Mean minimum temperature of coldest month

10–18°C (50–64°F)

Minimum temperature tolerated

5°C (41°F) (estimate)

Soils

Ylang-ylang can be found growing in a wide range of soils, from sands to clay loams and clays. It thrives in rich volcanic or fertile sandy soils and tolerates waterlogging for short periods.

Soil texture

It can grow in light, medium and heavy texture soils (sands, sandy loams, loams, and sandy clay loams, clays, clay loams, sandy clays).

Soil drainage

It requires free drainage.

Soil acidity

The tree tolerates wide variation in acidity (pH 4.5–8.0).

Special soil tolerances

Ylang-ylang an grow in shallow and infertile soils. Saline and alkaline soils should be avoided.

Tolerances

Drought

Ylang-ylang can tolerate a short period of drought (less than 2 months).

Full sun

The tree grows best in full sunlight.

Shade

This species is often a component of the understory in traditional agroforestry systems, so moderate shading is tolerated.

Waterlogging

Ylang-ylang tolerates periods of waterlogging, but permanent marshy conditions are not suitable.

Wind

The limbs are brittle and the tree does not handle strong wind well. However, the tree regrows vigorously even after heavy wind damage.

Abilities

Regenerate rapidly

Ylang-ylang is a pioneer species and can colonize open areas rapidly.

Coppice

The tree is often maintained by heavy pruning to a suitable height for picking flowers (usually 3 m [10 ft]) and readily regrows after cutting. Since even a large tree will coppice after being cut down, trees are often felled for their flowers (Merlin et al. 1992). This species will also coppice after severe limb/trunk breakage due to high winds.

GROWTH AND DEVELOPMENT

Ylang-ylang is classified as a fast grower, more than 2 m (6.6 ft) per year in its early years. It is a spontaneous species in secondary forest fallows.

Flowering and fruiting

At sea level, cultivated seedlings can begin flowering in 1.5–2 years at a height of 2 m (6.6 ft). Wild trees do not begin flowering until they reach 9–12 m (30–40 ft) in height. At maturity, the tree can flower and fruit continuously. When younger or where the rainfall is seasonal, the period of flowering and fruiting seems to be closely associated with the rainy months.

Yields

Topped trees of cv. group Ylang-ylang rarely produce more than 20 kg (44 lb) of flowers per year. The flowers yield about 1–2% distilled volatile oil. In Madagascar, mainly at Nosy Bé, 500 ha (1235 ac) produced 800,000 kg (1,760,000 lb) of flowers which yielded 20,000 kg (44,000 lb) of essential oil per year. In the Comoro Islands, 1 ha (2.5 ac) produced 900–1500 kg (1980–3300 lb) flowers equivalent to 18–30 kg (40–66 lb) oil distillate (MweziNet 2000).

Rooting habit

The tree has a long taproot, and therefore favors deep soils.

Grown among other trees, ylang-ylang grows tall, loses its lower branches, and casts a dappled shade. PHOTO: C. ELEVITCH

Reaction to competition

When ylang-ylang is grown in a competitive situation with other species, it grows tall quickly and sheds its lower branches.

PROPAGATION

Ylang-ylang is commonly propagated by seed. It can also be propagated by cuttings, with varying degrees of success. Direct-seeding in the field is also commonly practiced, which avoids damage to ylang-ylang's long taproot. Another method is to collect small seedlings (10–20 cm, 4–8 in) from under trees in the wild, and grow them out in bags for 2–3 months prior to outplanting.

Propagation from seed

Seed collection

As flowering often occurs year-round, ripe fruits can usually be found at any time. Fruits turn from dark green to black when ripe.

Seed processing

Inside each fruit 2–12 seeds are embedded in an oily flesh. Remove the seeds from the flesh in a sieve under running water. The cleaned seeds should be air-dried in the shade.

Seed storage

The seed is orthodox, meaning it remains viable when dried. Although no data is available, a standard method of storing the dried seeds with desiccant in an airtight container is likely to work well.

Germination

The germination of fresh seeds is said to be erratic. Seeds that are 6–12 months old have a higher germination rate. Hot water treatment has been used successfully to stimulate germination (Oyen and Dung 1999).

Media

A standard light, well drained potting medium is recommended.

Guidelines for outplanting

When the trees have reached an appropriate size for field planting, 20–30 cm (8–12 in) in height, they can be planted out in the field; however, care should be taken not to damage the long taproot.

Direct-seeding

Seeds are commonly direct-seeded. An area is prepared for each planting spot, cleared of weeds, and cultivated to a depth of 50 cm (20 in) if the soil is compacted. Seeds are planted at a depth of 2–3 cm (0.8–1.2 in). Sowing several seeds at each site will allow for selecting the most vigorous seedlings and will help avoid the work of reseeding.

DISADVANTAGES

Potential for invasiveness

Ylang-ylang has become naturalized in many of the Pacific islands where it has been introduced (e.g., Samoa, Pohnpei). The seeds are eaten by birds, bats, monkeys, and squirrels, and are readily dispersed. While the species regenerates spontaneously in cultivated areas and agroforests, it is rarely thought to be a pest and is not considered an invasive species by Pacific Ecosystems at Risk (PIER 2003, PIER 2004).

Pests and diseases

Little is known about pests and diseases of ylang-ylang and none are currently reported from the Pacific islands. Reported problems include stem borers, flower-eating beetles, and insects that cause leaves to wilt (Oyen and Dung 1999).

Other disadvantages

For commercial production, the tree requires quite a lot of hand labor for picking, and yields of distilled oil are low. In homegardens, the labor to collect flowers for decoration is rarely an issue. However, the tree does require periodic pruning in order to assure easy access to the flowers.

AGROFORESTRY/ENVIRONMENTAL PRACTICES

Mulch/organic matter

It is a minor source of mulch (Thaman et al. 2000).

Homegardens

Ylang-ylang is particularly appropriate for planting in homegardens. The tree is a rare to common ornamental in homegardens throughout many islands in the Pacific.

Improved fallows

The tree is a pioneer species and has potential for use in improved fallows.

Native animal/bird food

The fruit is a preferred food of pigeons in Guam, Tonga and Samoa (Stone 1970, Thaman and Whistler 1996). The fruit is also eaten by bats, monkeys, and squirrels.

Host plant trellising

It is used as an understory trellis tree for yam (*Dioscorea* spp.) in Pohnpeian agroforests, where it is sometimes ring-barked. Ring-barking causes the upper part of the tree to die and loose its leaves so that the tree functions as a trellis without blocking sunlight.

Ornamental

The tree is ornamental, and its very pleasant fragrance makes it appropriate in landscaping. Regular top pruning may be necessary to keep the tree from growing too tall in an urban setting. The species is used as a street tree in Malaysia.

Ylang-ylang growing in a mixed Samoan homegarden among bananas, coconuts, and other fruit trees. PHOTO: C. ELEVITCH

USES AND PRODUCTS

In the Pacific, this species has multiple uses. The wood is often used for canoe parts, small canoes (Raulerson and Rinehart 1991), furniture, fuelwood, and cordage. More importantly, the fragrant flowers are used to scent coconut oil and in making lei and mwarmwars (headdresses).

Medicinal

The bark is used in Tonga and Samoa to treat stomach ailments and sometimes as a laxative. In Java, the dried flowers are used against malaria, and the fresh flowers are pounded into a paste to treat asthma. A distillate of the flowers is said to have medicinal value by herbalists and aromatherapists. Aromatherapists claim that oil is useful for depression, distressed breathing, high blood pressure, anxiety, as an aphrodisiac, etc.

Flavoring/spice

The distilled oils are sometimes used to flavor beverages and foods.

Timber

The timber is pinkish, yellowish to light gray, non-durable, and vulnerable to termite attack. The wood is coarse textured and straight grained. In Tonga and Samoa it is used for general construction and canoe making. The timber is used for furniture in Cook Islands (Thaman et al. 2000). The wood is also used for lathe turnings, boxes and crates, clogs/wooden shoes, and fishnet floats (Chudnoff 1984).

Fuelwood

The wood is occasionally used for fuelwood.

Craft wood/tools

It is a minor wood for tool handles (Thaman et al. 2000).

Canoe/boat/raft making

The wood is employed in canoe making in Samoa and Tonga (Thaman and Whistler 1996).

Rope/cordage/string

The bark has very minor use for cordage (Thaman et al. 2000). In Sulawesi, the bark is beaten to make coarse rope.

Body ornamentation/garlands

The tree is a very important source of flowers in Micronesia and Polynesia. The very heavily scented flowers are used for garlands, headdresses and other personal adornment.

Cosmetic/soap/perfume

The primary commercial product is the distilled oil for the perfume industry, much of which is shipped to France. Ylang-ylang oil is said to be the basis for Chanel #5 and perfumes by Guerlain. Ylang-ylang is often used as a scent for coconut oil in the Pacific islands. The special name of potea is reserved for this scented oil in Tonga. When used in moderation, the oil is non-toxic and a non-irritant. However, the oil is an allergen and has been removed from some cosmetics. During the mid-1900s, ylang-ylang oil was used in a popular hair pomade manufactured in Hawai'i. Cananga oil mixed with coconut oil is called Macassar oil and used for hair dressing in Southeast Asia.

Ceremonial/religious importance

The tree has minor ceremonial importance (Thaman et al. 2000). While the plant may be a recent introduction to Tonga, ylang-ylang (mohokoi) is categorized there as a culturally important or sacred plant (akau kakala), along with other sacred or culturally important indigenous plants (Thaman et al. 1993).

COMMERCIAL CULTIVATION

The major commercial product is ylang-ylang oil, which has been produced in the Philippines since the early 1900s. The Comoro Islands and Madagascar are major producers of this oil. In the Pacific islands, the tree is mainly grown for flowers to be used in garlands and other personal adornment. Leis from ylang-ylang are commonly sold in Samoa in the marketplace and by children outside dances and nightclubs.

Spacing

Typical spacing in a commercial ylang-ylang plantation is 6 x 6 m (20 x 20 ft). Closer spacing may result in overcrowding and reduced productivity on lower limbs due to shading.

Ylang-ylang plantation at the Ponape Agriculture and Trade School, Pohnpei, where the tree was being grown for its essential oil. FSM, August 1989. PHOTO: H. MANNER

Management objectives and design considerations

To allow for ease of harvesting the flowers, the tree is topped at 3 m (10 ft) after 2–3 years of growth. This allows for plenty of light to reach the branches that droop naturally or are tied down to pegs in the ground. After first opening, the flowers have no fragrance. Most fragrance develops 15–20 days after opening, when the flower has turned from green to yellow. Flowers are best collected in the early morning hours before much of the fragrance dissipates.

Estimated yield

Topped trees of cv. group Ylang-ylang rarely produce more than 20 kg (44 lb) of flowers per year. Yields from cv. group Cananga (grown in Java, Fiji, and Samoa) can reach 30–100 kg (66–220 lb) per year.

On-farm processing methods

The flowers should be distilled immediately after harvesting. If there is a delay, the flowers can be laid out under cover to avoid fermentation, although the delay reduces the quantity of oil extracted. Water or steam distillation is used. Small traditional stills yield about 1% oil, while large modern stills can yield 2%.

Markets

The market for the distilled oil is the French perfume industry and herbalists and aromatherapists in the developed world.

INTERPLANTING/FARM APPLICATIONS

During establishment of ylang-ylang plantations, the young trees are often interplanted with short-term food crops. Also, the tree fits in nicely as an understory species in traditional agroforests, although reduced productivity of flowers can be expected with increased shade.

Example system (Raynor 2004)

Location

Pohnpei, Federated States of Micronesia.

Description

In the mid-1980s, the Ponape Coconut Products company (PCP), which was at that time part of the Ponape Agriculture and Trade School, planted 1 ha (2.5 ac) of ylang-ylang for essential oil to use as perfume in their coconut soap products. The company had been importing ylang-ylang oil for a high price from France and hoped to substitute locally-produced oil. Another 1 ha (2.5 ac) was planted and managed by collaborating farmers, and a distillery was funded by a German group. After 3 years, the project was terminated for several reasons:

1. The yield of flowers at any one time was small, making the distillery operation difficult and inefficient.

2. The yield of essential oil was a very small percentage of the flowers by weight (<1%).
3. The poor return to farmers (about $0.50/hour for labor) was a disincentive to harvesting.
4. The overall cost of production was greater than the cost of importing the oil.

Crop/tree interactions

About 0.4 ha (1 ac) of the ylang-ylang plantation was intercropped with commercial bananas and black pepper (grown on fern posts), at the same spacing as the trees, to help shade weeds and provide some income while the company waited for the ylang-ylang trees to bear flowers.

Spacing/density of species

The plantation was laid out on a 4 x 4 m (13 x 13 ft) spacing. However, by the end of the project (3 yr) it was obvious that the trees were spaced too closely (branches of adjoining trees were intertwined). Since the project was abandoned, no action was taken and the plantation was allowed to revert to secondary forest.

Local farmers were less enthusiastic about planting new tress, with most converting their plantations to secondary forest, topping the existing wild ylang-ylang trees, and planting yam under the other tree species, which they ringbarked. They also interplanted banana in their plantations.

PUBLIC ASSISTANCE AND AGROFORESTRY EXTENSION

Extension offices for agroforestry and forestry in the Pacific: http://www.traditionaltree.org/extension.html

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Cananga odorata (ylang-ylang)

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Acknowledgments: The authors and publisher thank Dale Evans, Bill Raynor, and Art Whistler for their input. The example system contributed by Bill Raynor is greatly appreciated.

Recommended citation: Manner, H.I., and C.R. Elevitch. 2006. *Cananga odorata* (ylang-ylang), ver. 2.1. In: Elevitch, C.R. (ed.). Species Profiles for Pacific Island Agroforestry. Permanent Agriculture Resources (PAR), Hōlualoa, Hawai'i. <http://www.traditionaltree.org>.

Sponsors: Publication was made possible by generous support of the United States Department of Agriculture Western Region Sustainable Agriculture Research and Education (USDA-WSARE) Program; SPC/GTZ Pacific-German Regional Forestry Project; USDA Natural Resources Conservation Service (USDA NRCS); State of Hawai'i Department of Land & Natural Resources Division of Forestry & Wildlife; and the USDA Forest Service Forest Lands Enhancement Program. This material is based upon work supported by the Cooperative State Research, Education, and Extension Service, U.S. Department of Agriculture, and Agricultural Experiment Station, Utah State University, under Cooperative Agreement 2002-47001-01327.

Series editor: Craig R. Elevitch

Publisher: Permanent Agriculture Resources (PAR), PO Box 428, Hōlualoa, Hawai'i 96725, USA; Tel: 808-324-4427; Fax: 808-324-4129; E-mail: par@agroforestry.net; Web: <http://www.agroforestry.net>. This institution is an equal opportunity provider.

April 2006
ver. 2.1

Canarium indicum var. *indicum* and *C. harveyi* (canarium nut)

Burseraceae (torchwood family)

canarium nut (English), galip nut (Papua New Guinea: pidgin), *nangai* (Vanuatu), *ngali*, *ngali* nut (Solomon Islands)

Lex A. J. Thomson and Barry Evans

IN BRIEF

Distribution Native to eastern Indonesia, Papua New Guinea, Solomon Islands, and Vanuatu.

Size Typically 20–30 m (66–100 ft) tall with canopy diameter of 15–20 m (50–66 ft) at maturity.

Habitat Lowland, subhumid to humid tropics, very warm temperatures throughout the year, elevation 0–600 m (0–2000 ft), annual rainfall 1800–4000 mm (70–160 in).

Vegetation Widely planted around villages and settlements.

Soils Favors medium to heavy-textured soils of moderate to high fertility.

Growth rate Slow during the first year, 0.6–2 m (2–6.6 ft), but rapid thereafter, often 2.5–3 m/yr (8–10 ft/yr) for the next 5–6 years.

Main agroforestry uses Homegarden, windbreak, mixed woodlot.

Main products Nuts, timber, traditional medicine.

Yields Estimated at up to 4–7 mt kernel-in-testa/ha/yr (1.8–3.1 t kernel-in-testa/ac/yr).

Intercropping Interplanting with crops that can provide rapid returns, such as root crops, banana, papaya, kava, etc., is recommended.

Invasive Potential Minor potential to become invasive.

PHOTO: B. EVANS

Typical canarium nut tree shape and form when grown in the open, Vanuatu.

INTRODUCTION

Canarium nut (*Canarium indicum* var. *indicum*) is a large tree that grows to 40 m (130 ft) in height and 30 m (100 ft) in canopy diameter, with a trunk diameter of 1–1.5 m (3.3–5 ft) at breast height (dbh). It is native to humid, lowland zones of eastern Indonesia, Papua New Guinea, the Solomon Islands, and Vanuatu, where it favours medium to heavy-textured soils of moderate to high fertility, with free to slightly impeded drainage and neutral pH. Canarium nut is mainly found in lowland rainforest, secondary forest, old garden areas, and it is widely planted around villages and settlements. Traditionally, nut trees are selected, tended, or cultivated in or around coastal village sites. It has been and continues to be a very important food tree in Melanesia and was an important component in one of the world's first known permanent agricultural/arboricultural systems.

Canarium nut has long been regarded as a species well suited to community forestry and mixed arboricultural systems. The species is capable of rapid growth, with kernel-in-testa yields of up to 4–7 mt/ha/yr (1.8–3.1 t/ac/yr) expected from mature plantations. It has potential for inclusion in various agroforestry practices, including homegardens, windbreaks, perimeter plantings, and silvopastoral systems.

The species has a great, as yet largely untapped, economic potential for commercial development and export, mainly because of its abundance and non-perishable nut-in-shell. However, the present resource base of canarium nut in native forests is widely scattered, poorly known and documented, and includes a wide diversity of nut morphotypes and sizes. The latter complicates processing and marketing, and nuts from trees with lower kernel-in-shell ratios add to transportation and overall production costs. A concerted replanting effort, with superior nut types, is considered necessary in order to develop a future nut export industry.

Collection and utilization of nuts from native forests is more intensive in times of high market demand and in years when planted stands have lower yields. Nuts from native forests will also be useful in maintaining and building up the export industry, prior to planted stands becoming mature and achieving maximum production.

The species has no major drawbacks that mitigate against its wider planting in Melanesia and other parts of the Pacific. It has only minor potential to become an environmental weed.

Canarium nut has been cultivated in Melanesia for thousands of years and is an extremely important tree in traditional, customary life. Stories, songs, and dances relating to the tree have been recorded, and in parts of the Solomon Islands the traditional calendar is based around the trees' flowering and fruiting cycle. The trees are frequently planted as tribal boundaries and commemorative markers, and rights to harvest individual trees are traded within and among clans. Canarium nut groves are often the only evidence left of pre-Christian inland villages and their associated taboo sites.

DISTRIBUTION

Native range

Canarium nut is native to eastern Indonesia, Papua New Guinea, the Solomon Islands, and Vanuatu; it is widespread and common in the latter two countries. It is mainly found in the lowland humid zones.

Current distribution

The species has been introduced into Fiji, where it is cultivated for its edible nuts and is possibly semi-naturalized. It is uncommon in cultivation in Samoa, where it is known locally as *lama palagi*. Some small plantations have been planted in far north Queensland, Australia, using seed from PNG.

BOTANICAL DESCRIPTION

Preferred scientific name

Canarium indicum L.

Family

Burseraceae (torchwood family)

Non-preferred scientific names

Synonyms include *C. amboinense* Hochr., *C. commune* L., *C. mehenbethene* Gaertn., *C. moluccanum* Blume, and *C. zephyrinum* Rumphius

The existing taxonomy of *Canarium* is based almost exclusively upon the gross morphology of dried herbaria material. This taxonomy, particularly that of the cultivated taxa, is inaccurate, and is likely to be significantly changed once the taxa are subjected to thorough DNA analysis.

Common names

canarium nut (English)
galip nut (pidgin, Papua New Guinea)
nangai (Vanuatu)
ngali, *ngali* nut (Solomon Islands)

The standard common name in the Pacific is canarium nut. In Papua New Guinea it is known widely in pidgin as galip nut, but also referred to as *lawele* (New Britain) and *hinuei* (New Ireland). In the Solomon Islands, it is mainly known by the Kwara'ae name of *ngali* or *ngali* nut. Other local names include *angari* (Santa Ana), *ngari* (Kausage/Simbo and Varisi), *ngoeta* (Marovo), *nolepo* (Garciosa Bay), *nyia nyinge* (Ayiwo), *okete* (Roviana), *sela* (Guadalcanal) and *voi'a* (Vaiakau). In Vanuatu the local Bislama name for *Canarium* species (including canarium nut) is *nangai*. Other recorded local names in Vanuatu include *bunnige*, *punnige* and varieties *nige kava* and *nige karia* (Epi Island/Moriu) *nanae*, *vanae* (Santo Island/Sarete Village), *nangae* (Santo Island/Narango Village), *nangrau* (Aneityum Island/Anelghowat Village), *negerdove* (Loh Island/Lungharagi Village), *ngaetua* (Maewo Island/Naone Village), *ngapor*, *ngaqov* (Gaua, Banks Group/Lambot, and Namasari Villages), *ngeta*, *ngev tentel* (Vanua Lava, Banks Group/Mosina Village), *ngna*, *nangan*, *nanga* (Santo Island/Hog Harbour), and *vungaingai*, *vungigae* (Malo Island/Naviaru Village).

Size

Canarium nut is a large tree that can attain 40 m (130 ft) in height, 30 m (100 ft) in crown diameter, and 1–1.5 m dbh (3.3–5 ft). Most mature trees are 20–30 m (66–100 ft) tall and 15–20 m (50–66 ft) across with a dbh of 50–100 cm (20–40 in).

Form

The form typically is a reasonably well formed tree with short–medium length bole to about half the tree height, with heavy lateral branches and a dense canopy. The trunk is commonly buttressed, with steep or even buttresses up to 1.5 m (5 ft) high.

Flowers

The flowers are arranged in terminal panicles, 15–40 cm (6–16 in) long, with stipules at the base and bracts of flowers, the latter soon deciduous. Flowers are small, ca. 1 cm (0.4 in) across, and yellowish white. Perianth parts, sepals and petals, are arranged in threes, densely and finely hairy on the outside. In PNG and the Solomon Islands, the species is dioecious, with separate male and female flowers being borne on different trees. In Vanuatu trees may also bear either hermaphrodite flowers (sexually-functionally male and female) plus female flowers; or hermaphrodite flowers plus male flowers. The proportion of hermaphrodite and unisexual flowers varies considerably from one tree to another, but unproductive non-fruiting "male" trees are very rare in Vanuatu.

Flowering appears to be initiated by changes in day length. Accordingly, the onset of flowering depends on latitude, such that at about 3–4°S it starts in about April, while at 11°S its starts around September. In Vanuatu cyclones in the previous year can lead to earlier flowering in the following year, e.g., starting in July–August. In the Solomon Islands canarium nut trees generally flower at the beginning of the year during the wet season.

Under good conditions trees commence flowering about 5–7 years after planting.

Leaves

The leaves are bright to dark green, imparpinnate with (3–) 6–8 (–10) pairs of leaflets on a rachis to 30 cm (12 in) long. Individual leaflets are oblong-obovate to oblong-lanceolate, and typically 7–28 cm long by 3.5–11 cm wide (2.7–11 in long by 1.4–4.3 in wide). Stipules are persistent, ovate with toothed or notched margins, large and conspicuous (typically 1.5–6 x 1.3–4 cm [0.6–2.4 x 0.5–1.6 in], but up to 10 x 5 cm [4 x 2 in]) and located at the junction of the petiole and branch.

Fruits of canarium nut. PHOTO: C. ELEVITCH

Fruit

Fruits are borne on erect or slightly drooping stems, which are held clear of the canopy. The fruit is an ovoid to obovoid drupe, 3–6 x 2–4 cm (1.2–2.4 x 0.8–1.6 in) and generally green when unripe, turning deep dark green to black when ripe. In PNG the fruiting season, which lasts about 3 months, is reported to be fairly constant from year to year (May–July). In the Solomon Islands fruits start to mature in August, with production peaking between September and October. Trees in the Western Province fruit a little earlier than those in more eastern provinces. In Vanuatu the normal fruiting season is between October and January with a peak in November. Fruiting commences at about 7 years after planting.

Nut terminology (after Evans 1996)

Fruit	The outer skin (exocarp) and flesh (mesocarp), the nut-in-shell and kernel-in-testa
Nut-in-shell (NIS)	The shell (endocarp) and kernel-in-testa
Kernel-in-testa (KIT)	The edible kernel (seed) and testa
Testa	Skin surrounding the kernel
K:N ratio	Ratio of nut-in-shell that is kernel-in-testa
Kernel oil	The oil pressed from the kernel
Kernel cake	The residue after oil extraction

Seeds

The nut-in-shell (NIS) is three- to six-sided or rounded with one (or sometimes two or three) kernels. Nut properties vary considerably, e.g., NIS range of 28–62 mm long by 20–35 mm wide (1.1–2.4 in long by 0.8–1.4 in wide), with a fresh weight of 8–20 g (0.3–0.7 oz) in the Solomon Islands. The same figures for NIS of selected nut trees in Vanuatu were 36–56 mm long by 23–34 mm wide (1.4–2.2 in long by 1–1.3 in wide), with a fresh weight of 9–18 g (0.3–0.6 oz).

The fleshy mesocarp of the fruit is an important food for many animals, in particular flying foxes and pigeons, who act as seed dispersal agents.

Similar species

Canarium nut is closely related to three species in the taxonomic group vulgare, namely *C. vulgare* (from Indonesia) and *C. ovatum* and *C. luzonicum* (from Philippines). However, only *C. vulgare* shares a common distribution in eastern Indonesia and western New Guinea. Canarium nut can be distinguished in the field by the number of paired leaflets (six to eight) and its large stipule with toothed margin found at the conjunction of the petiole and branch. In *C. vulgare* the stipule margin is smooth. In *C. harveyi* and *C. salomonense*, two other edible species that have overlapping distributions, the stipules are smaller and located on the petiole, and there are fewer pairs (two to four) of leaflets.

Look-a-likes *C. harveyi* (left) and *C. indicum* (right). *C. indicum* has much larger stipules (the leafy appendages at the leaf bases), with toothed margins. PHOTOS: C. ELEVITCH

GENETICS

Variability of species

Intensive selection in the Solomon Islands and Vanuatu has produced selections with potentially valuable economic characteristics, such as thin shells and large kernels. In Vanuatu there are at least five "folk" varieties of canarium nut, which vary in shape, size, fruit color at maturation, and flesh (mesocarp) color and texture.

Known varieties

In addition to numerous local selections, two varieties of canarium nut have been formally recognized, namely the

Nuts-in-shell, Vanuatu. In natural populations there is tremendous variation in size and shape of nuts, as well as quality of the edible kernel. PHOTO: B. EVANS

type variety *indicum* and another variety *platycerioideum*. The latter, uncommon, variety occurs in West Papua (Indonesia) and has larger leaves and fruits.

ASSOCIATED PLANT SPECIES

Canarium nut is reasonably widespread throughout its native range in lowland rainforest, secondary forest, and old garden areas and is widely planted around villages and settlements. Traditionally, nut trees are selected, tended, or cultivated in or around coastal village sites. Only very rarely are the cultivated edible species found growing wild in the bush. Most so-called "wild" trees in the inland bush are remnant trees from past village sites.

Associated species commonly found in native habitat

Associated native species include *Barringtonia* species (*B. edulis* and *B. procera*), *Artocarpus altilis*, *Cocos nucifera*, *Dendrocnide latifolia*, *Dracontomelon vitiense*, *Ficus* spp., *Flueggea flexuosa*, *Hibiscus tiliaceus*, *Inocarpus fagifer*, *Macaranga* spp., *Metroxylon* spp., and *Pometia pinnata*.

Species commonly associated as aboriginal introduction in Pacific Islands

Commonly associated aboriginal introductions include *Citrus* species, *Musa* species, *Spondias dulcis*, and *Syzygium malaccense*.

Species commonly associated in modern times or as recent introduction

Commonly associated more recent introductions include *Mangifera indica* and *Theobroma cacao*.

ENVIRONMENTAL PREFERENCES AND TOLERANCES

Climate

The species is found in the lowland, subhumid to humid tropics. Temperatures are very warm to hot throughout the year. Tropical cyclones occur at periodic intervals throughout canarium nut's range in SE Solomon Islands and Vanuatu, mainly during the months of November through to March. The entire range is frost free.

Elevation range

0–600 m (0–2000 ft). The elevation range is usually from near sea level to 250 m (820 ft), but the tree may be planted up 600 m (2000 ft), with an extreme recorded elevation of 1850 m (6070 ft).

Mean annual rainfall

1800–4000 mm (70–160 in), although usually 2500–3500 mm (100–140 in).

Rainfall pattern

Canarium nut prefers climates with summer or uniform rainfall patterns.

Dry season duration (consecutive months with <40 mm [1.6 in] rainfall)

0–1 month

Mean annual temperature
25–28°C (77–82°F)

Mean maximum temperature of hottest month
29–32°C (84–90°F)

Mean minimum temperature of coldest month
17–24°C (63–75°F)

Minimum temperature tolerated
Likely to be sensitive to temperatures below 5–7°C (41–45°F).

Soils
Canarium nut generally occurs on medium to heavy-textured soils, of moderate to high fertility, with free to slightly impeded drainage and neutral pH.

Soil texture
It prefers medium and heavy soils loams, sandy clay loams, clays, clay loams, and sandy clays.

Soil drainage
The tree tolerates soils with free or impeded drainage.

Soil acidity
It prefers neutral to alkaline soils (pH 6.1–7.4).

Special soil tolerances
Canarium nut does not tolerate shallow, infertile, or saline soils.

Tolerances

Drought
Likely to be only tolerant of short droughts of less than 3–4 months duration.

Full sun
Mature trees produce maximum nut yields when grown in close to full sunlight.

Shade
Can tolerate 25–70% shade. Young plants are sensitive to full sun and ought to be planted under shade (at least 50% shade). After 3–4 years the level of shade may be progressively reduced, through thinning or ring-barking unwanted overstory plants.

Fire
Likely to be intolerant of fire due to volatile resin in bark.

Waterlogging
The species is not well adapted to waterlogged conditions, but may tolerate impeded drainage for several months.

Salt spray
The species sometimes grows within a short distance of the sea and is likely adapted to light salt spray.

Wind
The trees have overall good tolerance of both steady and strong winds. During cyclones some large branches may be broken off and most other branches pruned of excessive woody twigs, but such damage is not highly detrimental. Trees damaged by cyclonic winds typically respond by producing early and vigorous floral growth from broken branches.

Maturing fruit and female flowers on the same branch of a cyclone damaged Nangai tree (MS111, *C. indicum*) in Narango village, South Santo, 24 September 1999. Trees damaged by cyclonic winds respond by producing early and vigorous floral growth from their broken-off branches. PHOTO: B. EVANS

Abilities

Self-prune
Trees display intermediate self-pruning ability.

Pollard

Trees regrow well following removal of large branches either during harvesting of nuts or breakage during cyclones.

GROWTH AND DEVELOPMENT

Plants grow relatively slowly during the first year, e.g., 0.6–2 m (2–6.6 ft), but thereafter grow rapidly under suitable conditions, e.g., 2.5–3 m/yr (8–10 ft/yr) for the next 5–6 years. After 5 years trees may attain a mean dominant height of 14 m (46 ft) and dbh of 15 cm (6 in). Height and dbh increase rapidly up to at least 15–20 years of age.

Flowering and fruiting

Trees begin to flower and fruit more heavily and regularly from about age 7–8 years.

Rooting habit

The tree has a deep taproot (Chaplin 1988).

Reaction to competition

Mikania and *Merremia* vines can stunt growth when seedlings are first planted out in open spaces, but mature trees are among the tallest in Melanesian forests so are able to compete well.

PROPAGATION

The species is readily propagated from seed, either as nursery-raised seedlings or by direct-seeding into the field. Limited success with grafting (cleft and splice) as well as air-layering has been reported (Evans 2004).

Seed collection

Fruits should only be collected from healthy, high-yielding trees with good nut characteristics including high kernel/nut ratios, large and preferably single-seeded nut-in-shell, thin shells, and sweet-tasting kernels. Collection time varies by location (country/latitude) and from year to year, but usually collection can be carried out in the second half of the year. Fruits turn deep dark green to black when ripe.

Seed processing

Propagation is from seeds (nut-in-shell) extracted from freshly collected mature fruits. There are about 50–200 seeds (nut-in-shell) per kg (23–91 seeds/lb). The outer fleshy mesocarp is removed by wetting and/or rotting.

Seed

Canarium seed is recalcitrant, which means it does not retain viability when dried or stored for extended periods. Seeds should be sown as soon as possible after collection. If seeds need to stored for a few weeks, then the outer flesh should be removed and the nut-in-shell stored in a shaded, cool (e.g., 15–25°C [59–77°F]), dry place, secure from rodents and other pests.

Pre-planting treatments

Seeds should be soaked in fresh water for 24 hours prior to sowing. Discard any nuts that float or that do not sink completely to the bottom.

Growing area

The seed (nut-in-shell) may be sown in the nursery or directly sown into the final field position. Seedling germination should be undertaken in a rat-proof, shaded area (25–50% sunlight) with pots watered regularly until at least first-true-leaf emergence.

For direct sowing, three or four seeds should be sown the final location. A small triangular plastic tree guard can provide a well protected and good microclimate for germination and help to mark the planting site.

Germination

Seed should be sown 1 cm (0.4 in) deep on their sides directly into large pots or polybags, e.g., 20–30 cm (8–12 in) deep and 10–20 cm (4–8 in) diameter. Some seeds can be simultaneously sown into germination trays for transplanting into those pots where seeds fail to germinate.

Media

The growing medium should be a well drained soil or potting mix: sand or sandy loam mixed with well composted organic matter is ideal.

Time to outplanting

Plants grow very rapidly in the nursery and are ready for field planting about 3 months after germination. However, during dry periods plants should be kept in the nursery until the start of the next wet season. Seedlings should be hardened prior to outplanting, e.g., by placing them in higher light levels (e.g., 50% sunlight) for 1–2 months prior to planting.

Approximate size at time of outplanting

Plants should be about 25–30 cm (10–12 in) tall at outplanting. Smaller seedlings about 20–25 cm (8–10 in) high may also be used.

Other comments on propagation

It is also possible to carefully uproot and transplant wildlings (naturally germinated seeds, usually from under superior mother trees). The best success with wildlings is obtained with smaller, younger plants and during wet, overcast weather.

Guidelines for outplanting

Some leaves of the seedlings may be cut off or cut in half immediately prior to planting to reduce evapotranspiration. This may reduce the stress of outplanting.

Seedlings survive and grow best under intermediate light levels (e.g., 25–50% full sunlight). They may be planted in secondary or primary forest that is progressively thinned to allow more light to reach the seedlings.

In more open situations young plants are prone to sunburn. Some overstory cover should be established prior to outplanting of seedlings. This may be quickly achieved by planting four or five poles or live posts of species such as *Hibiscus tiliaceus*, *Gliricidia sepium*, and *Pterocarpus indicus* around each planting hole. This should preferably be done at least 6 months prior to planting of *Canarium*.

Seedlings should be planted into well prepared holes in which topsoil and/or organic matter is incorporated. In more open situations it may be useful to provide some temporary shade, using leafy branches, coconut or fern fronds. In the absence of follow-up rains, artificial watering may increase survival (e.g., 10 l [11 qt] per plant every 2 weeks would be beneficial).

Seedlings should be weeded regularly as needed. This may be as often as every month in better-lit situations and where vines such as *Merremia* and *Mikania* are present. Cut weeds and other vegetation should be mulched back around the seedling, leaving a gap of about 10 cm (4 in) from the trunk. Mulching conserves moisture, lowers soil temperature, provides nutrients, and helps prevent weed germination. With good aftercare and maintenance, high seedling survival will be obtained, usually over 90–95%.

DISADVANTAGES

The main disadvantages are:

- Difficulty in obtaining superior germplasm, a problem that is exacerbated by canarium nut's recalcitrant seeds that make international transfer of seed more problematic.
- Long time between planting and first returns from nuts, e.g., 7–8 years.
- Lack of on-farm storage technologies that would allow nuts-in-shell to be locally cracked and permit the high-value, low-volume kernels-in-testa to be more readily transported to central processing units.

Potential for invasiveness

Canarium nut has minor potential to become an invasive species. It may have naturalized along roadsides in Fiji.

Diseases and pests

The species does not appear to be highly susceptible or damaged by any particular pest or disease. Recorded insect pests include *Amblypelta cocophaga*, *Coccus hesperidum* and *C. longulus*, *Ectatorhinus magicus*, *Pinnaspis buxi*, and *Pseudococcus solomonensis*. Fungal diseases include *Coleophoma* sp., *Phellinus noxius*, *Phyllachora canarii*, and *Skierka canarii*.

AGROFORESTRY/ENVIRONMENTAL PRACTICES

Crop shade

Mature trees cast a heavy, wide shade and are only suitable for providing crop shade to the most shade-tolerant crops, such as cocoa.

Alley cropping

The species is not especially amenable to inclusion in alley cropping systems due to its shade requirement in the first few years.

Homegardens

Canarium nut is a good candidate for inclusion in aboriculture systems and tree homegardens, e.g., at the rate of one to three trees per garden. The trees provide nuts for local consumption from an early age, coupled with reasonably good stability during strong winds and cyclones.

Improved fallows

Not very well suited to inclusion in improved fallows, due to the long period between planting and fruiting and the high value of trees once they come into nut production (which would preclude their cutting to allow light for agricultural crops).

Boundary markers

Good boundary marker due to high value (i.e., likely to be "valued" on both sides for nuts) and longevity.

Windbreaks
An excellent species for inclusion in the upper story layer in windbreaks.

Silvopasture
Likely to have some potential for growing in silvopastoral systems, providing shade for livestock, and recycling nutrients from deeper soil layers, but trees would need to be grown at wide spacing, e.g., 10–25 per ha (4–10 trees/ac) to allow enough light for pasture to grow beyond the edge of the canopy.

Woodlot
A good species for inclusion in mixed- or single-species woodlots for provision of timber and/or nuts.

Native animal/bird food
Birds and bats consume the fleshy mesocarp of fruits.

Ornamental
An attractive, long-lived tree well suited to ornamental and amenity plantings, especially for shade.

USES AND PRODUCTS
Canarium nut is one of the Melanesia's most useful multipurpose trees, providing food (nuts), timber, and oil. The nuts constitute an important seasonal food and appear to have been important in the diet of New Guineans for at least 6000 years. Considerable selection by local peoples of individual trees with desired fruit characters has taken place in the Solomon Islands and Vanuatu. These selections have been made on the basis of kernel size and taste, ease of opening, thin pericarp, oil content, and, rarely, taste of the flesh and productivity. In the Solomon Islands, canarium nut is considered by villagers to be the most important fruit- or nut-producing species in five of six provinces surveyed, namely, Makira, Malaita, Isabel, Choiseul, and Western. It is also considered to be one of the most important timber species, providing cash income in Makira and Malaita Provinces, and to a lesser extent in Choiseul Province. It is also the major indigenous tree species that villagers plant, tend, or transplant in the Solomon Islands. Other traditional uses include production of wood for canoes and wooden articles such as custom bowls, collection of a resin for light, or used as canoe caulk and various uses in traditional medicines, mainly involving preparations from the bark. Nowadays, within its natural range, canarium nut is commonly cultivated for its edible nuts. The nuts are of considerable sustenance and commercial importance, including sale in local markets, processing, and export.

Fruit
The mesocarp (outer fleshy skin) of some cultivars is edible.

Nut/seed
The kernels are an important seasonal food in Melanesia. They are nutritious and have a high protein content (8–14%). They are consumed either fresh or roasted or smoked. They may be eaten as a snack food or incorporated into various cooked dishes.

Medicinal
In the Western Province of the Solomon Islands, a preparation is made from the bark for the treatment of chest pains.

Flavoring/spice
The crushed kernel of canarium nut can be used as a topping on ice cream.

Timber
The wood is suitable for light construction (in low-decay situations), moldings, veneer, and numerous interior purposes. The wood of *C. indicum* is fine textured and pink-brown. It has a medium density of 430–560 kg/m^3 (27–35 lb/ft^3) and is non-durable when exposed to weather. The wood of *C. harveyi* may have potential as veneer, as its figure and color can be very decorative.

Fuelwood
Suitable for fuelwood and sometimes burned.

Craft wood/tools
Traditionally used to make bowls and other wood articles.

Canoe/boat/raft making
The wood is traditionally used in canoe manufacture.

Resin/gum/glue/latex
Resin oozes from wounds on the trunk caused by a variety of natural factors such as pests/diseases, damage during cyclones, etc. In Melanesia this resin was formerly collected for use as canoe caulk.

Tannin/dye
The soot from burning resin was formerly used as a ceremonial black face paint in Melanesia.

Cosmetic/soap/perfume
An oil extracted from the kernel has various local uses. It may be substituted for coconut oil and has potential in

skin-care products.

Illumination/torches

In Melanesia the resin was formerly collected and burned for light.

Ceremonial/religious importance

Burning resin is aromatic and was used in traditional ceremonies and churches.

COMMERCIAL PRODUCTS

Canarium nut can make a substantial contribution to local food and wood supplies, and, importantly, to sustainable rural incomes through the high export market potential of its nuts. The main commercial product of canarium nut is the nut kernel for human consumption, and in Melanesia commercial interest in canarium nuts is high. Marketing operations range from private and community-based production, processing, and marketing of kernel oil for cosmetic and medicinal use, to government-backed nationwide purchasing of kernels for sale as confections and oil. In Vanuatu there are two commercial companies purchasing nuts. The buying price is about US$0.25–0.50/kg (US$0.11–0.22/lb) of nut-in-shell or US$4–5/kg (US$1.82–2.27/lb) for kernel-in-testa. In Port Vila, the dried, roasted, honey-coated kernels are retailed in plastic bags and glass jars for the equivalent of more than US$16/kg (US$7.27/lb). Another company exports dry whole and half kernels in bulk to France for secondary processing and sale in the luxury confectionery and pâtisserie market. Consumer demand for all of the products is high, and supply, both quantity and reliability, is constricting marketing efforts. Fresh canarium nut kernels-in-testa are sold in local markets in Vanuatu in bundles or skewered on sticks (palm frond spines) for the equivalent of US$10–17/kg (US$4.55–7.73/lb).

In the Solomon Islands, canarium nut is considered by villagers to be the most important fruit/nut producing species in five of six provinces surveyed: Makira, Malaita, Isabel, Choiseul, and Western.

A secondary and much less important commercial product is sawn timber, mainly for local use in house construction and furniture. However, in parts of the Solomon Islands it is considered to be one of the most important timber species, providing cash income in Makira and Malaita Provinces, and to a lesser extent in Choiseul Province.

Because of the potential of canarium nut as a high-value export crop for nuts (for confections) and/or oil extraction, some research is being done on its taxonomy, production, and marketing. Additional research needs include selection, evaluation, and improvement of promising varieties for timber production, investigation of silvicultural aspects, phenological studies, and vegetative propagation.

Spacing

Nuts

The suggested spacing is 9–10 x 9–10 m (30–33 x 30–33 ft), i.e., 100–123 trees/ha (40–50 trees/ac). The area required for commercial production is likely to be at least 1 hectare (2.5 acre) for an individual grower. A well managed and consolidated plantation area of 100 ha (250 ac) (made up of one, several, or many growers), could provide about 500 mt (550 t) of KIT per year and support commercial processing and export.

Nuts and timber

The suggested initial spacing for joint production of nuts and timber is close within rows (about 2 m [6.6 ft]) and wide between rows (9–10 m [30–33 ft]), i.e., 500–555 trees/ha (200–220 trees/ac), thinned down to a final spacing of about 100–150 trees/ha (40–60 trees/ac) by removal of poorer formed individuals in one or two operations at age

The food composition per 100 g of raw *Canarium indicum* nut

Water (g)	35.4	Protein (g)	8.2	Fat (g)	45.9	Sugar (g)	0.2
Starch (g)	0.3	Ash (g)	2.6	Fiber	10.6	β-car. eq. (μg)	165
Retinol (μg)		Thiamin (mg)	0.13	Riboflavin (mg)	0.06	Niacin (mg)	1.7
Vit. C (mg)	8	Na (mg)	18	K (mg)	627	Ca (mg)	44
Fe (mg)	3.5	Mg (mg)	284	Zn (mg)	2.4	Cu (mg)	1.6
Mn (mg)	1.1	Edible portion*	13%	Energy	439 kcal/1838 kJ		

* The inedible material is the hard shell of the nut

Source: English et al. 1996

3–6 years.

Some advantages of *C. indicum* for nut production over the other main edible *Canarium* species, *C. harveyi,* in Melanesia are as follows:

- The nuts of *C. indicum* are suitable for drying and exporting, whereas the dried kernels of *C. harveyi* are considered to have a somewhat unpleasant turpentine taste (Evans 1999).
- The recorded average annual yield of NIS per tree is much greater for *C. indicum* (113 kg [250 lb]) than the observed yields for *C. harveyi* (Evans 1999a).
- *C. indicum* is far more widespread than *C. harveyi* in both the Solomon Islands and Vanuatu, and it appears to possess great ecological adaptability.
- Excessive consumption of fresh nuts of *C. harveyi* can cause nausea and vomiting.

Management objectives

Nuts

Pruning is best carried out in conjunction with harvesting of fruits on reproductively mature trees. Fruit set will be lessened the year following by heavy pruning, but pruning of half the trees in any given year may be done to induce a more uniform annual production of nuts from a given plantation or group of trees.

Nuts/Timber

The aim of management is to maximize nut production while concentrating wood increment on a straight, lower bole (i.e., butt log of 6 m [20 ft]).

Design considerations

For commercial production of nuts it is recommended that plantings be located near major marketplaces or processing centers within 20–50 km (12–30 mi) by road.

Yields

High yields of nuts from 1 ha (2.5 ac) of canarium nut plantation at a spacing of 206–625 trees/ha (83–253 trees/ac) are estimated to commence in the seventh year at about 750 kg (1650 lb) kernel-in-testa (KIT). Yields are expected to rise sharply to about 4–7 mt KIT/ha/yr (1.8–3.1 t KIT/yr) at age 10–15 years.

On-farm processing methods required to access market

Compared with manual cracking, mechanical cracking of nuts can considerably improve efficiency of cracking, but too wide a range of nut sizes can lower the percentage of whole kernels obtained by mechanical/electrical crackers. Unfortunately there is a lack of on-farm storage technologies which would allow nuts-in-shell to be cracked in villages or on-farm and permit the high-value, low-volume kernels-in-testa to be later transported to central processing units. Kernels-in-testa need to be kept dry, cool, and airtight to avoid oxidation and rancidity.

On-farm processing methods

Drying, smoking, or roasting nuts enables them to be stored for periods of about 3–12 months, depending upon the quality of the nuts and storage containers and conditions. Roasting would preferably be done at a central unit, with suitable equipment, trained personnel, and good quality control.

Markets

Nuts

The size of the international market for canarium nuts is large. Canarium nuts, like *Terminalia catappa* nuts, have the potential to behave as under-supplied niche commodities with a highly inelastic demand commanding a price equivalent to macadamia nuts (currently >US$10/kg [US$4.55/lb] wholesale), providing packaging and quality are similar. High-value niche markets could be secured and enhanced by organic certification, promotion of canarium nut as an exotic commodity, and direct, internet-based marketing. Marketing opportunities and constraints for Pacific tree nuts will depend on quality control, packaging, continuity of supply, and targeting marketing toward specific groups, such as tourists.

Timber

Markets for timber of planted canarium nut timber will be mainly the local timber markets for general-purpose timber and will vary considerably in volume. Through selection and breeding it may be possible to eventually develop individuals which produce not only good quality nuts but also decorative timber (with attractive figure and color), which might command a high price for furniture manufacture.

Canarium harveyi

Introduction

In the Santa Cruz Islands (Solomon Islands) and Banks Group (Vanuatu) the kernels of *C. harveyi* are an important food crop (Evans 1999a). Fresh nuts are seasonally important foods and preserved through smoking to provide food throughout the year. Many different superior nut forms have been produced during thousands of years of domestication, and var. *nova-hebridiense* is believed to have arisen as a result of human selection. The species is a less important food source in other parts of its range, such as Fiji and Tonga, where wild types with smaller nuts predominate. In these areas it is considered a useful timber tree.

Native range and current distribution

Canarium harveyi is native to the Solomon Islands, Vanuatu, Fiji, Tonga, and Niue. Var. *nova-hebridiense* appears to be the product of long-term selection and is native to the Santa Cruz Islands (in SE Solomon Islands) and in the adjacent Banks Group in northern Vanuatu. Var. *harveyi* is found throughout the rest of the native range, including central and southern Vanuatu, while var. *scandens* (from Fiji) probably does not warrant varietal rank. In Tonga it is found in forests and garden areas on all island groups (Yuncker 1955). In Niue, trees of the type variety are reported to be moderately common but scattered on the Lower Terrace and in more open secondary forest further inland. In Fiji the elevation range is from near sea level to 600 m (1970 ft) (Smith 1985). The species is not known to have been planted as an exotic.

An 8-year-old *C. harveyi* tree. PHOTO: C. ELEVITCH

BOTANICAL SUMMARY

Preferred scientific name *Canarium harveyi* Seem.

Family Burseraceae, torchwood family

Non-preferred scientific names

Canarium sapidum Hems.

Common names

canarium nut (English)
'ai (Tonga)
ai (Niue)
kaunicina, *kaunigai* (Fiji)
nangai, *nangae* (Vanuatu)
Santa Cruz ngali nut (Solomon Islands)

In Vanuatu the local Bislama name for *Canarium* species (including *C. harveyi*) is *nangai* or *nangae*. Other recorded local names in Vanuatu for *C. harveyi* include *angai, gamagamba, hamkamba, nanae, nergervot, negertowo, ngatimbi, ngai, nge dun, ngev mum, nangai hos, nagrau, nengai, nenge, ningi, vanae*, and *vosai facau* (Siwatibau et al. 1998). On Mota Lava (Banks Group) it is known as *nange d* (Evans 1999a).

In the Solomon Islands, *C. harveyi* is known locally by the names Santa Cruz *ngali nut* (Solomon Islands Pidgin), *nyinga* (Ayiwo, Ree Is., Santa Cruz), and *nolepo* (Graciosa Bay, Nendo, Santa Cruz) (Evans 1999a).

In Fiji the species is mainly referred to as *kaunicina* and *kaunigai*, with other local names including *dawadawa* (Gau) and *yaga* (Fulaga, Lau) (Smith 1985). Local names recorded for *C. harveyi* in Fiji by Thaman et al. (2000) were *kaunicina*, *kaunigai*, *kai ni cina* (Nausori, Viti Levu), and *yagai* (Karoko, Vanua Levu; Naiiviivi, Qamea). In Tonga and Niue the species is referred to as *'ai* and *ai*, respectively (Tupoulahi-Fusimalohi 1999, Sykes 1970).

Characteristics

Canarium harveyi is a medium-sized tree, 10–22 m (33–72 ft) tall with a dbh up to about 1 m (3.3 m). The trunk may occasionally be buttressed, with reasonably equal plank-like or branched buttresses. Trees are characterized by a dense canopy, with a short deciduous phase at fruit maturity (Solomons) or during the dry season (Tonga). The bark is light grey and generally smooth (Evans 1999a).

The leaves are bright to dark green, pinnate with two to four pairs of leaflets and often with one terminal leaflet. Stipules are arranged in pairs on the petiole (5–20 mm [0.2–0.8 in] from the base). They are relatively small compared with *C. indicum* (5–10 x 6–10 mm [0.2–0.4 x 0.24–0.4 in]), auricle shaped, with entire or toothed margins. They soon fall off, leaving distinctive twin scars.

Fruits of domesticated trees are oval-shaped drupes 6–9 cm (2.4–3.6 in) long by 4–5 cm (1.6–2 in) wide, green when immature, turning deep purple or black at full maturity. Wild trees have smaller fruits, about 4 cm (1.6 in) long by 2.8 cm (1.1 in) wide in Niue (Sykes 1970). Fruit production varies considerably between trees and ages. Production varies from numerous fruiting spikes loaded with up to 40 fruits to few fruiting spikes with only two to six fruits (Walter and Sam 1996).

Top: The number of paired leaflets for *C. harveyi* is usually two to four, compared with six to eight for *C. indicum*. This *C. harveyi* tree in Tonga has three-paired leaflets. Bottom: *C. harveyi* flowers. PHOTOS: C. ELEVITCH

Ripe *C. harveyi* fruits are 3–6 cm (1.2–2.4 in) long and 2–4 cm (0.8–1.6 in) wide. PHOTO: B. EVANS

The nut-in-shell (NIS) is ellipsoid to oval-shaped, two- to three-sided in cross section, with one kernel or seed (or sometimes two or very rarely three) per NIS. The sterile cells are almost totally or strongly reduced. The kernel-in-testa (KIT) is an edible nut, ovate with longitudinal grooves, consisting of two intimately entwined cotyledons enclosed in a protective testa (Evans 1999a). The average NIS varies from 42 mm (1.7 in) long by 29 mm (1.1 in) wide in Vanuatu to 61 mm (2.4 in) long by 33 mm (1.3 in) wide in the Solomon Islands (Walter and Sam 1996, Evans 1991). More complete botanical descriptions are available in Smith (1985, vars. *harveyi* and *scandens*) and Evans (1999a, var. *nova-hebridiense*).

ENVIRONMENTAL PREFERENCES

Climate

The species is found in the lowland, subhumid to humid tropics. The mean annual rainfall is 1800–4000 mm (70–160 in) distributed rather uniformly or with a summer maximum. Temperatures are very warm to hot throughout the year. The mean annual temperature is around 23–28°C (73–82°F), the mean maximum temperature for the hottest month is 27–32°C (81–90°F), and the mean minimum temperature of the coldest month is 15–24°C (59–75°F). The absolute minimum temperature is 8–19°C (46–66°F). Tropical cyclones occur at periodic intervals throughout its range in Vanuatu, Fiji, Tonga, and Niue, mainly during the months of November to March.

Soils

It generally occurs on medium- to heavy-textured soils with free to slightly impeded drainage and neutral pH.

Vegetation types

C. harveyi is reasonably widespread throughout its native range in lowland rainforest, secondary forest, old garden areas, and it is widely planted around villages and settlements. Traditionally, nut trees are selected, tended, or cultivated in or around coastal village sites (Evans 1999). Only very rarely are the cultivated edible types found growing wild in the bush. Most "wild" trees in the inland bush, are remnant trees from past village sites (Evans 1999).

PROPAGATION

Canarium harveyi is propagated from seed that is recalcitrant and should be sown as soon as possible after collection. Seedlings grow quickly in the nursery and are ready for planting after 3–5 months (see propagation section for *C. indicum* for further information).

MANAGEMENT

Trees may be heavily pruned during fruit collection. This results in a low fruit set the following year, followed by a very heavy crop the year after. Accordingly trees can be differentially managed through pruning to produce a more uniform yield of nuts each year from a given plantation or group of trees.

USES

Land use, environmental, and service aspects

This tree is a frequent component of the middle canopy in multistory food garden systems in Santa Cruz (Evans 1999a). It is also an important shade tree in Vanuatu and useful for coastal protection (Sam et al. 1999).

Products

In both the Solomon Islands and Vanuatu the timber is used for canoe construction, custom and food bowls, and for firewood (Evans 1999a, Siwatibau et al. 1998). It is recorded as a timber tree in Fiji (Smith 1985)

Local consumption of nuts is the most important use for *C. harveyi* trees, and the species is an important food source in the Santa Cruz Islands (SE Solomon Islands) and in the Banks Group in northern Vanuatu. In Niue the nuts are regarded as the best quality among the native trees (Sykes 1970).

Fresh fruits or nuts are opened using a stone, and the kernel is eaten fresh. Kernels may also be preserved by slow and continuous drying and smoking in baskets or storing them on racks hung over kitchen fires (Henderson and Hancock 1988, Walter and Sam 1996). This enables kernels to be stored and edible for up to 12 months (Evans 1999a). In Vanuatu the oily nuts are often sprinkled on tuber pudding (Walter and Sam 1996).

The nut-in-shell (NIS) characteristics of *C. harveyi* in the Solomon Islands are generally superior to *C. indicum*, but certain *C. indicum* trees have similar kernel-to-nut ratios to the average for *C. harveyi* (Evans 1999a), and this trait is likely to be improved in an appropriately designed breeding program. Generally the nuts of *C. harveyi* are easier to split by hand than those of *C. indicum*.

In former times and infrequently the oily kernels were used as primitive candles, and the oleoresin is occasionally used as lighting oil and incense (Evans 1999a, Siwatibau et al. 1998). The species is recorded as being used in traditional medicine on Malekula and Ambrym (Siwatibau et al. 1998). The nut shells are highly flammable and occasionally used as cooking fuel.

COMMERCIAL POTENTIAL

The commercial potential of *C. harveyi* is considered to be less than that of *C. indicum* for a number of key reasons:

- the kernels have a somewhat unpleasant turpentine taste, especially when dried, which can cause nausea if too many are eaten
- nut-in-shell yield appears to be less than that measured for *C. indicum* (Chaplin and Poa 1988)
- the trees, especially the highly cultivated var. *nova-hebridiense*, are less widespread, appear less adaptable, and are more prone to pests and disease.

INTERPLANTING/FARM APPLICATIONS

An advantage of growing canarium nut in a polyculture (together with other food and timber trees) is that consequences of canarium nut failure in a particular year can be minimized through production and sale of products from other species. Furthermore, there is a long waiting period (at least 7 years) before canarium plantations begin to provide commercial returns. Therefore, interplanting of crops that can provide more rapid returns such as root crops, banana, papaya, kava, *Barringtonia procera*, and *Terminalia catappa* may be necessary for cash-strapped farmers. It is recommended that a moderately shade-tolerant, nitrogen-fixing shrub legume, such as *Flemingia*, be interplanted to help maintain soil nitrogen levels.

Example interplanting system

In Melanesian tree gardens canarium nut trees, which often have tall, straight boles making them difficult to climb, are frequently planted alongside smaller "living ladder" trees such as *Barringtonia* spp. and *Inocarpus fagifer*. These allow easier access to the canopy for early harvesting (before dispersal by fruit bats and pigeons) and for pruning. The living ladder trees are planted 1–2 m (3.3–6.6 ft) away from the canarium nut trees.

GERMPLASM RESOURCES

The Pacific Basin Agricultural Research Center has a research collection of many *Canarium* species, including *C. indicum* and *C. harveyi*.

Pacific Basin Agricultural Research Center
P.O. Box 4459
Hilo, Hawaii 96720
Tel: 808-959-4301; Fax: 808-959-5470
Web: http://pbarc.ars.usda.gov/pages/research/tpgrmu/canarium.shtml

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Species Profiles for Pacific Island Agroforestry (www.traditionaltree.org)

Canarium indicum var. *indicum* and *C. harveyi* (canarium nut)

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Acknowledgments: The authors and publisher thank Roberto Coronel, Dale Evans, Roger Leakey, Diane Ragone, and Francis Zee for their input.

Recommended citation: Thomson, L.A.J. and B. Evans. 2006. *Canarium indicum* var. *indicum* and *C. harveyi* (canarium nut), ver. 2.1. In: Elevitch, C.R. (ed.). Species Profiles for Pacific Island Agroforestry. Permanent Agriculture Resources (PAR), Hōlualoa, Hawai'i. <http://www.traditionaltree.org>.

Sponsors: Publication was made possible by generous support of the United States Department of Agriculture Western Region Sustainable Agriculture Research and Education (USDA-WSARE) Program; SPC/GTZ Pacific-German Regional Forestry Project; USDA Natural Resources Conservation Service (USDA NRCS); State of Hawai'i Department of Land & Natural Resources Division of Forestry & Wildlife; and the USDA Forest Service Forest Lands Enhancement Program. This material is based upon work supported by the Cooperative State Research, Education, and Extension Service, U.S. Department of Agriculture, and Agricultural Experiment Station, Utah State University, under Cooperative Agreement 2002-47001-01327.

Series editor: Craig R. Elevitch

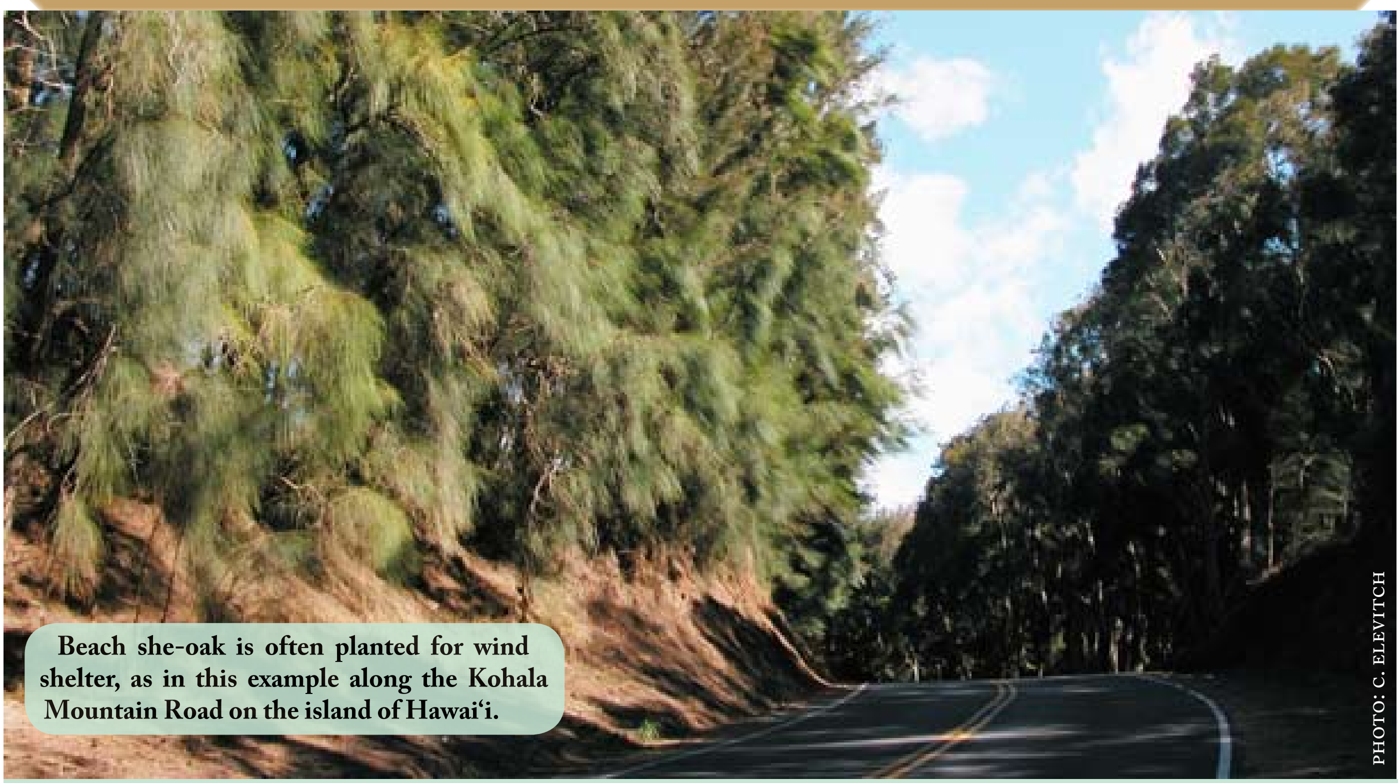
Publisher: Permanent Agriculture Resources (PAR), PO Box 428, Hōlualoa, Hawai'i 96725, USA; Tel: 808-324-4427; Fax: 808-324-4129; E-mail: par@agroforestry.net; Web: <http://www.agroforestry.net>. This institution is an equal opportunity provider.

Casuarina equisetifolia (beach she-oak) *C. cunninghamiana* (river she-oak)

Casuarinaceae (casuarina family)

'aito **(Societies, Australs), beach she-oak, beefwood, casuarina, ironwood, she-oak (English),** ***burukam*** **(Kiribati),** ***gago*** **(Guam),** ***laash, lach, nach*** **(Yap),** ***mejinoki*** **(Marshall Islands),** ***ngas*** **(Palau),** ***nokonoko*** **(Fiji),** ***paina*** **(Hawai'i),** ***toa*** **(Tonga, Samoa, Niue, 'Uvea, Futuna, Cooks, Marquesas),** ***weeku*** **(Chuuk)**

W. Arthur Whistler and Craig R. Elevitch



Beach she-oak is often planted for wind shelter, as in this example along the Kohala Mountain Road on the island of Hawai'i.

PHOTO: C. ELEVITCH

IN BRIEF (C. EQUISETIFOLIA)

Distribution Introduced to most Pacific islands and found throughout the tropics in cultivation.

Size Often grows to 20–30 m (65–100 ft).

Habitat Typically found near sea level to 800 m (2600 ft), with rainfall of 200–5000 mm (8–200 in); tolerates drought well for 6–8 months.

Vegetation Often found growing together with trees common in coastal and lowland areas.

Soils Capable of growing on a wide range of soils (coastal and lowland lava flows, poor soil of fernlands, limestone soils); tolerates poor soils because it is a nitrogen fixer.

Growth rate Very fast growing; can grow 3 m (10 ft) in the first year.

Main agroforestry uses Windbreak, soil stabilization, coastal protection, screen/hedge.

Main products Timber, fuelwood, medicine, dye.

Yields 37,000–74,000 kg of fuelwood per hectare (40 to 80 tons per acre) in 7–15 years.

Invasive potential High invasive potential; naturalized and a pest in many areas where introduced; *C. cunninghamiana* may be a less invasive alternative for many situations.

INTRODUCTION

Beach she-oak (*Casuarina equisetifolia*) is native from Australia eastward into Melanesia and westward to coastal Southeast Asia, but it was also an ancient introduction over a much larger range. It is a tall, fast-growing tree that can, in as little as 12 years, reach a height of 20 m (66 ft). It has a very hard, heavy, dark red-brown wood, hence one of the common names, ironwood. In the past, its wood was used extensively for making house parts, posts, fish hooks, and various other tools and artifacts. However, its extreme hardness makes it difficult to be sawn or worked with tools, and it is therefore unsuitable timber for carving when other more favorable woods are available. Because it is very strong and needs little processing, it is ideal for posts and rough house construction. It is also useful for fencing, piling, and roofing shingles. The rapid growth of the tree and the fine quality fuelwood it produces (it is one of the best firewoods in the world) makes it excellent for use in fuelwood plantations, its main commercial importance today, especially in Asia and Africa. It burns with little smoke, produces little ash, and is excellent for making charcoal. It is also an important species for the control of erosion, especially on coasts (its natural habitat) and sand dunes, and on poor inland soils, where it does well because of its ability to fix nitrogen. This latter ability makes it ideal for interplantings with other crops to enrich the soil and provide light-to-moderate shade. The tree is important culturally since its bark is widely used in traditional medicines for treating digestive tract problems and other ailments. The tree can be very invasive, however, as it is a pioneer species in some habitats (e.g., new lava flows), so care must be taken when introducing this tree to new places.

DISTRIBUTION

Native range

The native range of beach she-oak is uncertain, but the tree probably originated in Australia as a littoral species. It appears to be native westward from Australia to Thailand and the Nicobar and Andaman Islands.

Current distribution

Beach she-oak was carried by ancient voyagers eastward into the Pacific as far as the Marquesas but is a modern introduction to Hawai‘i and probably Micronesia and, in more recent times, throughout the tropics, where it is now one of the most common trees on beaches, fernlands, and other inland areas of poor soil. In the U.S., it is naturalized in Florida and Hawai‘i.

BOTANICAL DESCRIPTION

Preferred scientific name *Casuarina equisetifolia* L.

Family Casuarinaceae (casuarina family)

Non-preferred scientific names
Casuarina litorea L.

Common names

Pacific islands:

‘aito (Societies, Australs)
beach she-oak, beefwood, horsetail casuarina, ironwood, she-oak, (English)
burukam (Kiribati)
gago (Guam)
laash, lach, nach (Yap)
mejinoki (Marshall Islands)
ngas (Palau)
nokonoko (Fiji)
paina (Hawai‘i)
toa (Tonga, Samoa, Niue, ‘Uvea, Futuna, Cooks, Marquesas)
weeku (Chuuk)

Other regions:

agoho (Philippines)
arbe de fer, bois de fer, filao, pin d’Australie (French)
arbol de hierro (Spanish)
filao (Vietnam, West Africa, West Indies)
ru (Malaysia)

Size

Reaches up to 30 m (100 ft) or more in height and up to 1 m (39 inches) in basal diameter, with a symmetrical or irregular conical crown.

Form

Monopodial with upward-curving branches when young but with an open, irregular crown when mature; buttresses variable, thin, and plank-like. The species exhibits a high degree of variation in characters such as shape of crown, angle of branches, length of branchlets, size and shape of cones, and production of cones. The tree tends to be more branchy and crooked on exposed shores and tall and straight with a single trunk in protected environments.

Bark

The bark is light gray-brown, smooth on younger trees, turning rough and deeply furrowed on older trees.

Buttresses on beach she-oak. PHOTO: C. ELEVITCH

Flowers

Inflorescence of unisexual flowers occur in pistillate heads and staminate spikes; the trees are monoecious. Female heads are ovoid to subglobose, up to ca. 1 cm (0.4 in) long, many-flowered, borne laterally at the nodes of the branches, each flower subtended by one bract and two bracteoles, perianth absent; ovary superior, with a bifid style bearing two elongate, red, linear stigmas; male flowers are sometimes present on the peduncle. Staminate spikes elongate, 8–70 mm (0.3–2.8 in) long, borne mostly at the ends of the branches, with each flower subtended by two awl-shaped bracteoles and two tepals; one stamen, exserted. Flowering apparently occurs throughout the year.

Leaves

Leaves are reduced to lanceolate scales 0.5–1 mm (1/50 to 1/25 of an inch) long, united at the base into sheath-like whorls of about seven around the nodes.

Fruit

Fruit is a woody, ovoid to subglobose, cone-like head 1.2–2.2 cm (0.5–0.9 in) long, formed from the persistent, valve-like bracteoles pubescent on the outside, these separating at maturity to release the nut.

Fruit and flower, approximately life size. PHOTO: C. ELEVITCH

Seeds

Seed is enclosed within a nut borne in the cone; it is 4–5 mm (ca. 0.2 in) long, most of it a membranous wing called a samara.

Similar species

The tree is often mistaken for a conifer. However, it can be distinguished by the stems (that look superficially like pine needles) that bear whorls of about seven tiny lanceolate scales. The needle-like stems can be pulled apart at the nodes, unlike pine needles, which have no nodes. Two similar species are found in the Pacific, *Casuarina glauca* (longleaf casuarina) and *Casuarina cunninghamiana* (river she-oak). The three species can be distinguished from each other as follows:

Casuarina equisetifolia

Distribution Common to locally abundant throughout the Pacific.

Cones Nearly round to elongate, 1.2–2 cm (0.5–0.8 in) in diameter.

Branches Pineneedle-like, 23–38 cm (9–15 in) long, ca. 1 mm (1/25 in) wide, with 6–9 (usually 7) lengthwise ridges ending in a ring of tiny, teeth-like scale leaves.

Casuarina glauca

Distribution Occasional to locally common in scattered places in Hawai'i, but uncommon elsewhere in the Pacific islands.

Cones Nearly round, flat-topped, 0.7–1.3 cm in diameter.

Branches Pineneedle-like, 30–40 cm (12–16 in) long, ca. 2 mm (1/16 in) wide, with 10–18 lengthwise ridges ending in a ring of tiny, teeth-like scale leaves. The twigs are longer and thicker than the other two species.

Casuarina cunninghamiana (see pages 12–14 for more information about this species)

Distribution Native to Australia, but of scattered distribution in the Pacific. It is present in Hawai‘i, but not reported to be naturalized there.

Cones Nearly round to elongate, 0.7–1.3 cm (0.3–0.5 in) in diameter. This species has smaller cones than the other two.

Branches Pineneedle-like, 7.5–18 cm (3–8 in) long, ca. 1 mm (1/25 in) wide, with 8–10 lengthwise ridges ending in a ring of tiny, teeth-like scale leaves.

In summary, if the pineneedle-like branches are thin and average less than 20 cm (8 in) long and the cones are small, then the species is *C. cunninghamiana*. If the branches are more than 20 cm long, relatively thick, and are marked by 10–18 lengthwise ridges, then the species is *C. glauca*. If the branches are more than 20 cm long and are marked by 6–8 lengthwise ridges, then the species is *C. equisetifolia*, by far the most common and widespread of the three species.

GENETICS

Variability of species

Two subspecies are known, var. *equisetifolia* (the common one) and var. *incana* (restricted mostly to Australia). Much of the variability present in different places is probably due to differences in soil and climate. The tree is known to hybridize with other species of the genus.

Known varieties

No named varieties are recognized.

Culturally important related species in the genus

This species is the only one of cultural importance, but *Casuarina junghuhniana* and *Casuarina grandis* have potential as fast-growing timber trees. *Casuarina glauca* is planted and naturalized in Hawai‘i, and *Casuarina cunninghamiana* is also planted there but is not reported to be naturalized (see text inset box on *C. cunninghamiana*)

Genetic resources

Collections of beach she-oak are stored at CSIRO in Australia. Seeds are readily obtained, however, throughout the range of the species.

ASSOCIATED PLANT SPECIES

In its native habitat, beach she-oak is associated with littoral vegetation. In fernlands, where it is often common (as on Rarotonga and Hawai‘i), it is often the dominant tree (and sometimes virtually the only tree) in a matrix of false-staghorn fern (*Dicranopteris linearis*). It is also a pioneer species on new lava flows, where it is often the dominant species.

Associated species commonly found in native habitats

In its native habitat, beach she-oak is a littoral tree found together with trees such as sea almond (*Terminalia catappa*), *Guettarda speciosa*, *Barringtonia asiatica*, beauty leaf (*Calophyllum inophyllum*), etc.

Species commonly associated in modern times or as recent introduction

It grows with other common lowland and coastal trees, such sea almond, leucaena (*Leucaena leucocephala*), coconut (*Cocos nucifera*), etc. It is also found with *Miscanthus floridulus* on acid soils (e.g., in Guam), and with naupaka (*Scaevola sericea*) on beaches.

ENVIRONMENTAL PREFERENCES AND TOLERANCES

Climate

Beach she-oak is found throughout the tropics and is able to tolerate a wide extreme of warm climates. It is limited to the tropics and subtropics since it is intolerant of frost, and it occurs between 22° N and 32° S (although one source mentions “extensive plantations” of it in Portugal). Although it prefers a seasonal climate (in its natural habitat there is often a 6–8 month dry season), it can tolerate dry climates (particularly if it has access to ground water supplies) with as little as 200–300 mm (8–12 in), and wet climates with as much as 5000 mm (200 in) of annual precipitation.

Elevation range

Lower: near sea level
Upper: 800 m (2700 ft) or more, but plantations of it have been reported up to 1500 m (5000 ft) or more.

Mean annual rainfall

Lower: 200 mm (8 in)
Upper: 5000 mm (200 in) or more

Rainfall pattern

It does well in most rainfall regimes but prefers a seasonal rainfall pattern.

Dry season duration (consecutive months with <40 mm [1.6 in] rainfall)

Its native range can have 6-8 months of dry season.

Mean annual temperature

10–30°C (50–86°F). It is not known to be limited by high temperature.

Mean maximum temperature of hottest month

30–40°C (86–104°F)

Mean minimum temperature of coldest month

10–24°C (50–75°F)

Minimum temperature tolerated

>5°C (41°F). It is intolerant of frost.

Soils

It is capable of growing in a wide range of soil conditions but is particularly common on coastal and lowland lava flows, poor soils of fernlands, and on limestone soils near the shore. Since the tree is able to fix nitrogen in a symbiotic association with the bacteria *Frankia* sp., it can also grow in infertile lateritic soils, mine tailings, sand dunes, calcareous soils, coastal lava rocks, and other places where other tree species cannot. It is also able to tolerate a wide range of soil pH, up to 9.5 in some cases, as well as relatively saline groundwater.

Soil texture

Beach she-oak tolerates light to heavy textured soils (sands, sandy loams, loams, sandy clay loams, sandy clays, clay loams, and clays).

Soil drainage

Grows in soils with free drainage.

Soil acidity

pH 4.5–9.5

Special soil tolerances

It can grow in shallow, saline, and infertile soils.

Tolerances

Drought

It is very tolerant of dry climates, especially if it has time to establish and its roots can grow down to the water table.

Full sun

It is very tolerant and in fact prefers sunny places (as evidenced by its dominance as a pioneer species on new lava flows).

Shade

The tree is intolerant of shade.

Fire

It is intolerant of fire, and in some places, its extent in wetlands (the Florida Everglades) and fernlands (e.g., in Guam) is limited by periodic fires.

Frost

It is intolerant of frost, which limits it to the tropics and subtropics.

Waterlogging

Beach she-oak is somewhat tolerant of waterlogging, as evidenced by its sometimes being found on coastal rocks submerged during part of the time in sea water.

Salt spray

It is very tolerant of salt spray, and it is often one of the trees growing closest to the coastline. This is at least partly due to the protected location of the stomata (aeration pores) within furrows on the leafless stems. Excessive salinity may, however, decrease growth.

Wind

Beach she-oak is very tolerant of wind and is oftentimes planted as a windbreak. Unlike most other trees, it has the ability to grow upright on windswept coasts.

Abilities

Fix nitrogen

The tree forms woody, spherical nodules up to 10 cm (4 inches) in diameter, in which are found a filamentous bacterium, *Frankia* sp., which fixes nitrogen. This allows it to thrive in areas of nutrient-poor soil.

Regenerate rapidly

The tree is able to regenerate by seed in areas favorable to its growth.

Coppice

It coppices only very weakly.

Pollard

The tree is sometimes planted in rows and trimmed to make a dense, attractive hedge.

GROWTH AND DEVELOPMENT

The seeds germinate shortly after they are mature and released, and the young growth is very rapid (up to 3 m or 10 ft in the first year), which allows it to outgrow most weeds (although not if the weeds are already established). Rapid growth continues throughout the first 10 years, and in one study, biomass production peaked after 12 years. Some studies suggest that the trees are not very long-lived (plantations on coastal dunes in Senegal began dying within 20–40 years after establishment).

Growth rate

Based upon experiments done in China, trees planted from seed can reach 3 m (10 ft) in height in a year. After 4 years, they averaged 7–8 m (ca. 25 ft) in height and 13–17 cm (5.2–6.8 in) in diameter. Based on experimental plantings carried out in coastal Kenya, trees 9 years old attained a mean height of 20 m (66 ft) and a diameter of 12 cm (4.8 in). In an experimental planting carried out in Indonesia over the period from 11 to 13.5 years of age, the trees averaged 1.8–2.1 m (ca. 6 ft) annual height increase and 1.6–2 cm (0.6–0.8 in) in diameter increase.

Flowering and fruiting

Flowering and fruiting occur throughout the year, although not at a constant rate. The cones mature 18–20 weeks after anthesis. Peak flowering in the Northern Hemisphere is usually from April to June, and the opening of the fruits there occurs mostly from September to December.

Yields

In experimental plantings done along the coast in India, plantations harvested on a 7–15 year rotation yielded 37,000–74,000 kg of fuelwood per hectare (40–80 tons/acre).

Rooting habit

Beach she-oak can root on the surface, as when it is on hard substrates such as lava flows, but in softer soil it forms a taproot that can grow down to the water table.

Reaction to competition

Beach she-oak can do well in competition with other trees, especially in areas of poor soil where its symbiotic association with nitrogen-fixing bacteria gives it an advantage, but it does not do so well when the competition trees shade it out. The seedlings likewise do not compete well with established and dense weeds.

Diseases and pests

Since the tree has been grown in commercial plantations, much is known about its diseases and pests. The most serious disease is the fungus *Trichosporum versiculorum* (black blister disease), which causes stem and leaf wilt, cracking of the bark, and formation of black blisters on the trunk. The fungus *Botryosphaeria dothidea* causes basal and trunk cankers, a yellowing of the crown changing to red, and eventual death. It is believed that the host must be predisposed to infection by drought-induced stress. A wilt disease caused by the bacterium *Pseudomonas solanacearum* attacks the roots of trees grown in Chinese plantations. Another disease caused by a fungus, *Phomopsis* sp., reportedly attacks seedlings in China. Insects, such as *Lymantria xylina*, *Zeuzera multistrig*, and *Brachytrupes portentosus*, are also reported to damage *Casuarina* trees in China. Other insects, including the twig borer *Oncideres cingulata*, the spittlebug *Clastoptera undulata*, and the leaf notcher weevil *Artipus floridanus*, are reported to attack these trees in Florida. Termites and ants are reported to eat the seeds, and the termites to attack adult trees. Elsewhere, the Australian pine borer *Chrysobothris tranquebarica*, the borer *Macroteoma palmata*, the black borer *Apate monachus*, and the larva of *Coleosterna scabrata*, *Arbela tetraonis*, and *Phassus malabaricus* damage the trees. Other pests include some caterpillars and crickets.

LORE

In Tahiti, the tree was the emblem of warriors and the warrior god Oro, whose images were made from its hard wood. According to Neal, Tahitians claim it sprang from the bodies of warriors, with the red sap representing their blood and the pineneedle-like branches their hair. There is a Cook Island legend (from the island of Mangaia) that the tree, which had great evil powers, was brought there from Tonga. It caused the death of several men who tried to cut it down in order to rid the island of its demonic powers. Finally, a god from Tonga, Ono, came and destroyed the demon in the tree.

PROPAGATION

Beach she-oak can be propagated by seed, stem cutting, and air-layering. It is most commonly propagated by seeds, however, as these are readily available and this method is less labor intensive than the others.

Propagation by seed

Seeds collection

The seeds are collected from the maturing (brown) cones, before they fully ripen and release the seeds. The cones are either picked by hand or shaken onto canvas sheets and later processed. The seeds are usually ready about 18–20 weeks after flowering, which occurs at various times of the year depending upon location and climate. Larger cones and seeds are often selected, as they are believed to produce individuals that have the highest vigor, although this has not been substantiated.

Seeds processing

Cones collected from the tree can be dried in racks in the sun or in ovens or kilns to open the cones, and the seeds are then extracted. Screens are sometimes used to separate the seeds from cone debris.

Seed storage

The seeds start losing their viability starting within 2 weeks from being released. If they are to be stored, the typical methods of storage are used, i.e., at near-freezing or subfreezing (–6°C, 21°F) temperatures. The seeds can be stored from 6 months to a year in this condition.

Pre-planting propagule treatments

No special propagule treatments are standard, but the seeds are sometimes soaked for 24 hours before planting in water or in 1.5% KNO or 7.5% $CaOCl_2$ to stimulate germination. Fungicides are not needed if sterile soil or an artificial medium is used. Seed predation by ants can sometimes be a major problem, but these pests can be controlled by an application of a carbolic acid solution or other insecticides.

Growing area

The seeds are usually planted in well lighted places, but in brighter climates some shading may be needed. Light, well drained soils should be used to prevent increased susceptibility to diseases and pests.

Germination

Germination rates often range from 30 to 90% for fresh seeds and much less for seeds stored under ideal (cool) conditions for up to a year, and germination starts after 4–22 days after sowing, or up to 40 days according to some authors.

Media

The seeds are then sown in trays under about 5 mm (0.2 in) of sterilized nursery soil or artificial growing medium, which prevents attack by fungi, preferably at 215–320 seeds/m^2 (20–30 seeds/ft^2). A mixture of sand and peat moss is often used for this purpose.

Time to outplanting

Seedlings are usually planted out when 3–4 months old, typically with 1 x 1 m (3.3 x 3.3 ft) spacing, and are thinned out in the second year to 2.5 x 2.5 m (8 x 8 ft). Some sources recommend as much as 4 x 4 m (13 x 13 ft) spacing, but the closer spacing will allow earlier returns.

Approximate size for outplanting

The seedlings are typically 30–50 cm (12–20 in) in height when they are outplanted.

Other comments on propagation

In areas where the tree is not native, the roots must be inoculated with a culture of the bacterium *Frankia* sp. Several techniques have been used successfully. In one simple method, surface soil collected from under beach she-oak trees is mixed with the medium used as potting soil. In another more complicated method, root nodules from established trees are collected and then soaked in 70% ethanol for a few seconds to eliminate pathogenic organisms. The nodules are then washed and crushed, and the suspension is filtered before being applied to the roots of seedlings or injected into the soil. More complicated techniques can be used, but they require expensive equipment and expertise. Beach she-oak trees also form symbiotic associations with ectomycorrhizal and endomycorrhizal fungi (particularly with the genus *Glomus*), which are needed for good growth. Mycorrhizae inoculant can be introduced in the growing medium to speed early growth in the field.

Propagation by stem cutting

Seedlings are the preferred method of growing beach she-oak, but cuttings are sometimes used instead. Cuttings have the disadvantage of being more labor intensive, but when the resulting offspring are desired to be identical to some superior form of the tree, cuttings are preferential. Shoot cuttings can be taken from stems 1–2 mm (0.04–0.08 in) in diameter and 10–15 cm (4–6 in) long. Any one of several rooting hormones can be used to enhance rooting. The rooted cuttings should be inoculated with the bacterium *Frankia* sp. when introducing the tree to new areas. Stem cuttings can be rooted in sunlight, but in brighter climates some shading is needed. Light, well drained soils should be used to prevent increased susceptibility to diseases and pests. The cuttings can be outplanted when they form roots, which takes 4–6 weeks.

DISADVANTAGES

The tree grows poorly on sites with impeded drainage. It is intolerant of fire, does not compete well with weeds, and has poor coppicing ability. The tree is relatively short-lived, with peak biomass production (growth) around 12 years of age, which makes it unsuitable where long-lived trees are desired. Few of these trees live beyond 50 years. Although the wood is hard and heavy, it is not easily worked and is not favored for carving or for timber. The tree can be invasive, especially in areas of poor soils (which is not always a bad thing).

Potential for invasiveness

The tree can be very invasive, especially in marginal habitats. It is readily dispersed by means of wind-blown seeds. This spreading can be useful in areas where few other trees grow, such as on sand dunes needing protection from soil erosion, but harmful in areas of native vegetation. It can also spread by rooting along branches that touch the ground. It has been reported to be an invasive weed in Hawai'i, the Bahamas, Florida, Nauru, and elsewhere in the tropics.

Susceptibility to pests/pathogens

It is susceptible to a number of pathogens, but perhaps no more than other tree species.

Other disadvantages or considerations for using this plant in agroforestry

Many people believe that beach she-oak is competitive with crops, because it can lay down a thick layer of needles that often excludes ground cover species.

Many *Casuarina* species are considered highly invasive, and should not be introduced to new areas. Here beach she-oak invades open pasture, Waimea, island of Hawai'i. PHOTO: C. ELEVITCH

AGROFORESTRY/ENVIRONMENTAL PRACTICES

Mulch/organic matter

The trees produce a copious leaf, stem, and cone litter, which often stifles germination of other seedlings. This is used for fuel in India.

Soil stabilization

The trees are often planted on eroded hillsides of poor soil, as few other trees can survive in this habitat. It is particularly good for coastal sand dunes, where few other tree species can survive.

Crop shade/overstory

Not usually used for this purpose because it has a thin canopy, but in New Guinea it has been used as a shade tree in coffee plantations.

Homegardens

It can easily be grown around houses for local fuel consumption or, as is probably often the case, for use of the bark in traditional medicines.

Improved fallows

Since the plant produces nitrates in association with a symbiotic bacterium, it is a useful tree to improve soil.

Living fences

It can be used for this purpose, and is sometimes trimmed into hedges.

Fence posts

The wood can be used for fence posts with moderate longevity.

Boundary markers

It can be used for this purpose, but its relatively short life span may be a drawback.

Windbreaks

It makes excellent windbreaks, even in harsh conditions where other trees wouldn't survive. It can maintain erect growth in windy places where other trees become bent.

Silvopasture

Not typically used in silvopasture, but its nitrogen-fixing capability may make it desirable for improving soil in pas-

Windbreak spacing is typically 2 x 2 m (6 x 6 ft). PHOTO: C. ELEVITCH

Noni (*Morinda citrifolia*) growing under beach she-oak. PHOTO: M. BONIN

tures.

Animal fodder

Not useful for animal fodder.

Woodlot

It is fast growing and is useful for firewood (and its debris for kindling).

Coastal protection

It is a very useful tree for coastal protection, as this is its native habitat and it does well in areas of salty sea winds. It is particularly useful on coastal sand dunes.

Ornamental

Its form is often straggly and unattractive, but it can be trimmed into a pleasant, dense hedge.

USES AND PRODUCTS

The very hard, heavy, red wood was traditionally favored for making house timber, posts, war clubs, tool handles, spears, tapa beaters, digging sticks, throwing discs, large fish hooks, canoe parts, and other artifacts throughout the Pacific islands, but other woods (some of them imported or introduced) are favored for these purposes today. The tree makes a good fuelwood, commonly used in Asia rather than the Pacific islands. The bark of the tree still has important uses for traditional medicine, especially for treating digestive tract ailments. The plant found minor use as a dye plant, and is still used for this purpose to a small degree.

Medicinal

In Tonga, an infusion of the bark is commonly taken as a potion or squeezed into the mouth of infants with mouth infections. It has an emetic effect, which induces vomiting or coughing to bring up phlegm. It is also sometimes used there for treating stomachache. Minor medicinal uses are also reported from Samoa (possibly since the tree is uncommon there). In the Cook Islands, the grated inner bark is made into a solution for treating thrush and urinary tract problems, and at stronger concentrations, it is taken to induce vomiting. In Fiji, an extract of the bark is taken internally for treating rheumatism or as an emetic. In Yap (Ulithi), the inner bark is used to treat diarrhea and other digestive tract ailments.

Timber

The heartwood is heavy and dark red-brown. The wood is very hard and heavy, and when dry it is difficult to work with because of this density and hardness. It is moderately durable when used as posts in the ground and when exposed to the weather. The heartwood is resistant to dry-

Beach she-oak makes a very good hedge, visual barrier, or windbreak, and can be repeatedly pruned as is done here in Nuku'alofa, Tonga. PHOTO: C. ELEVITCH

wood termites. Poles are used as masts for fishing boats, boat oars, piles, and posts.

Fuelwood

The wood makes excellent firewood and charcoal.

Craft wood/tools

The hard, heavy, red wood was traditionally favored for making house timber, posts, war clubs, tool handles, spears, tapa beaters, digging sticks, throwing discs, large fish hooks, canoe parts, and other artifacts throughout Polynesia and in Fiji, but is not easily worked because of its hardness.

Canoe/boat/raft making

The wood is too heavy for making canoe hulls or outriggers, but is sometimes used for other parts of canoes where strength is needed and weight is not a drawback.

Tannin/dye

The tree was valued as a dye plant in some parts of Polynesia because of its dark red sap. Two forms of the tree were recognized in Tahiti—a dwarf form called 'aito hiri that grows on the hills, and the taller one called 'aito ra'u hiri that grows in forest. A deep red dye called hiri was made from the former and was used to dye cloth, nets, and fishing lines by steeping these in a cold solution of the dye. The plant was used to produce a brown dye for staining house posts in Tonga. Elsewhere in the Pacific the tannin in the bark is still used to tan fishing nets and dye fabrics a dull reddish color.

Ceremonial/religious importance

In Tahiti, the tree was the emblem of warriors and the warrior god Oro, whose images were made from its hard wood. Elsewhere in Polynesia, the tree is called toa, which is the same word as for warrior.

COMMERCIAL PRODUCTS

The main use of the tree is for its very hard, heavy, red wood that was traditionally favored for making house timber, posts, war clubs, tool handles, spears, tapa beaters, digging sticks, throwing discs, large fish hooks, canoe parts, and other artifacts throughout the Pacific. Because of its hard wood that is worked only with difficulty, it is not often used for cut timber.

Spacing for commercial production

Spacing of 2 x 2 m (6.6 x 6.6 ft) to 4 x 4 m (13 x 13 ft) is recommended for the trees when grown in plantations, depending upon how fast the yield is desired and the local climate (especially rainfall or groundwater).

Management objectives

The trees are often thinned after a few years. Fertilizer is sometimes used in infertile soils, particularly for phosphorus, which promotes growth. Nitrogen is not needed in the fertilizer, because the tree produces its own nitrates. The information on the effect of competition of weeds is not clear, but weeding may be needed to control grasses at the early stages of *Casuarina* growth. It does not self prune, and pruning may be needed to make the plantations accessible.

Advantages and disadvantages of growing in polycultures

The tree is advantageously used in polycultures because its ability to fix nitrogen enriches the soil. However, when too densely planted, its leaf litter can inhibit the growth of low plants. The litter may contain toxic amounts of selenium, silica, and salt.

Estimated yields

In monoculture trials in coastal India, plantings harvested on a 7–15-year rotation yielded 37,000–74,000 kg of fuelwood per hectare (40–80 tons per acre).

Markets

The wood is rarely taken to market and even more rarely exported; it is mostly used locally for firewood, house posts, and some carving.

INTERPLANTING/FARM APPLICATIONS

Example (Midgley et al. 1983)

Location

India

Description

Casuarina firewood plantations are interplanted during the first year with groundnut, sesame, pulses, cucumbers, and melons. Bananas and cassava are planted where irrigation is available. Returns are greater than *Casuarina* alone.

Crop/tree interactions

The trees share the benefits from the cultural practices given to the crop plants and provide wind protection to the crops. The *Casuarina* trees improve the soil. On sterile coastal sand, agricultural cropping is done after removal of the trees. But for silvicultural purposes, agriculture would not be possible.

Spacing

Densities of 1600–10,000 trees/ha (5280–13,200 trees/ac) are planted with 1–2.5 m (3.3–8.3 ft) between trees. Rotations of 5–15 years are achieved, depending on spacing. Yields are 50–200 mt/ha (22–90 t/ac).

A dense planting of beach she-oak makes a good woodlot for fuelwood and charcoal. PHOTO: C. ELEVITCH

Casuarina cunninghamiana (River she-oak)

river she-oak, river oak, creek oak, Cunningham casuarina, ironwood, small cone ironwood, Australian pine (English)

River she-oak (*C. cunninghamiana*) is a long-lived, relatively fast-growing, and handsome tree to 35 m (120 ft). Its agroforestry uses include windbreaks for crops and livestock, riverbank stabilization, and woodlots. It tolerates moderate droughts, periodic waterlogging, acidic to moderately alkaline soils, moderate salinity, and even occasional sub-freezing temperatures. Its green-gray, pendulous foliage is considered to be ornamental by many. Because of the tendency of beach she-oak (*Casuarina equisetifolia*) to become invasive, river she-oak may be a suitable alternative in many environments. River she-oak has been widely planted in Hawai'i but is not reported to be naturalized.

DISTRIBUTION

Native range and current distribution

River she-oak is native to Australia, from New South Wales through Queensland into the Northern Territory. The endemic latitudinal range is 12–38° S. Because of its wide adaptability, it has been introduced for reforestation throughout the world in Africa, Asia, and in Central, South, and North America, and throughout Australia, New Zealand, and elsewhere. In the Pacific region it has been encouraged for use in windbreaks in Hawai'i.

BOTANICAL SUMMARY

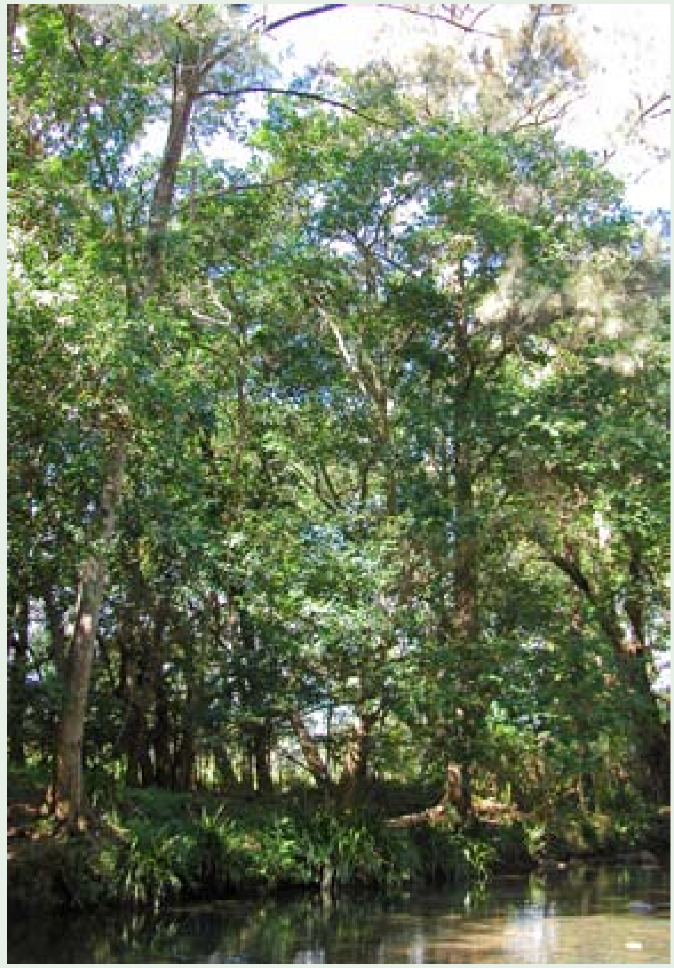
Preferred scientific name *Casuarina cunninghamiana* Miq.

Family Casuarinaceae, Casuarina family

Non-preferred scientific names
Casuarina tenuissima Sieb. ex Spreng.

Common names

river she-oak, river oak, creek oak, Cunningham casuarina, ironwood, Australian pine (English)
casuarine de Cunningham (French)
pino australiano, *pino de Australia* (Spanish)



River she-oak is at home along watercourses, although it is widely adaptable. Queensland, Australia. PHOTO: C. ELEVITCH

Characteristics

River she-oak is the largest species in the genus Casuarina in Australia. There are two recognized subspecies. Attaining heights of 20–35 m (66–120 ft) and stem diameters up to 1.5 m (5 ft), subsp. *cunninghamiana*, is a riverine species that attains its best development in southeastern Australia. Subsp. *miodon* from the Northern Territory and northwestern Queensland is a shorter tree, reaching 12 m (39 ft) in height with a straggly appearance. The bark of river she-oak is finely fissured, scaly, and gray-brown.

The branches are pineneedle-like, 7.5–18 cm (3–8 in) long, ca. 1 mm (1/25 in) wide, with 8–10 lengthwise ridges ending in a ring of tiny, teeth-like scale leaves. The cones are nearly round to elongate, 0.7–1.3 cm (0.3–0.5 in) in diameter. This species has smaller cones than *C. equisetifolia*. River she-oak is mostly dioecious, with individuals bearing unisex flowers in an approximate 1:1 mix of both sexes

Left: Fruits and female flowers of *C. cunninghamiana*. Right: Male and female river she-oak. The males appear brownish when in flower. Queensland, Australia. PHOTOS: C. ELEVITCH

ENVIRONMENTAL PREFERENCES

River she-oak is found in its native range at 0–1000 m (0–3300 ft). It is typically a riverine species growing along freshwater streams and rivers. The annual rainfall is 360–2200 mm (14–87 in) a year, although since the tree often grows along watercourses, rainfall alone is not an indication of moisture availability. The tree is mainly found in the warm subhumid climatic zone with the mean maximum temperature of the hottest month of 25–40°C (77–104°F), and the mean minimum of the coldest month of 0–15°C (32–59°F). It tolerates up to 50 frosts per year and temperatures down to –8°C (17°F).

Soils

It generally occurs on well drained, light-textured sandy or gravelly soils, although it is occasionally found growing in clayey soils. The pH is acidic to neutral. The tree

A windbreak of *C. cunninghamiana* protecting crop land. Waimea, island of Hawai'i. PHOTO: C. ELEVITCH is moderately tolerant of salt. It reportedly becomes chlorotic when growing on highly calcareous soils.

Vegetation types

River she-oak is often a dominant species in riverine vegetation. In its native habitat, surrounding vegetation types are open forest, woodland, and open woodland eucalypts together with *Melaleuca*. In introduced environments, the tree is widely adaptable and grows together with numerous cultivated species.

PROPAGATION

The tree is usually propagated by seed using the same methods as used for *C. equisetifolia*, although it can also be propagated vegetatively using cuttings.

AGROFORESTRY/ ENVIRONMENTAL PRACTICES

Agroforestry uses are similar to those of *C. equisetifolia*. Because river she-oak is currently presumed to be less of a risk of invasiveness, it is the preferred tree for windbreaks and other practices in Hawai‘i.

USES AND PRODUCTS

The wood makes an excellent fuelwood and charcoal. Although very difficult to work, the wood can be sawn into planks and cured using special methods. The wood has also been used for casks, tool handles, turnery, flooring, and as a general utility farm timber. Particleboard has also been made from the wood. The heartwood is said to be durable in contact with the ground for 15–25 years. The foliage can be used as a low-grade animal fodder during times of shortage. A dye can be made from the leaves. The flowers are an important source of pollen for bees. A recent introduction to Pacific islands, there are no known traditional uses in the region.

Clear, straight trunk of an older river she-oak. PHOTO: C. ELEVITCH

DISADVANTAGES

Seedlings require protection from browsing animals and fire when young. River she-oak is not as tolerant of saline and calcareous soils as *C. equisetifolia*.

PUBLIC ASSISTANCE AND AGROFORESTRY EXTENSION

Extension offices for agroforestry and forestry in the Pacific: http://www.traditionaltree.org/extension.html

INTERNET

Casuarina equisetifolia: <http://www.hort.purdue.edu/newcrop/duke_energy/Casuarina_equisetifolia.html>

Casuarina equisetifolia: an old timer with a new future: <http://www.winrock.org/forestry/factpub/FACTSH/C_equisetifolia.html>

Casuarina equisetifolia (Casuarinaceae): <http://members.lycos.co.uk/WoodyPlantEcology/docs/web-sp2.htm>

Casuarina cunninghamiana: <http://www.winrock.org/forestry/factpub/FACTSH/C_cunninghamiana.html>

Casuarina glauca: <http://www.winrock.org/forestry/factpub/FACTSH/C_glauca.html>

Invasive nature of beach she-oak: <http://www.hear.org/pier/species/casuarina_equisetifolia.htm>

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Traditional Tree Initiative—Species Profiles for Pacific Island Agroforestry (www.traditionaltree.org)

Casuarina equisetifolia (beach she-oak) *C. cunninghamiana* (river she-oak)

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Acknowledgments: The authors and publisher thank Robin DeMeo, Dale Evans, Bob Joy, and Bill Null for their input. A photo contribution by Mark Bonin and Scot C. Nelson is greatly appreciated.

Recommended citation: Whistler, W.A. and C.R. Elevitch. 2006. *Casuarina equisetifolia* (reach she-oak) and *C. cunninghamiana* (river she-oak), ver. 2.1. In: Elevitch, C.R. (ed.). Species Profiles for Pacific Island Agroforestry. Permanent Agriculture Resources (PAR), Hōlualoa, Hawai'i. <http://www.traditionaltree.org>.

Sponsors: Publication was made possible by generous support of the United States Department of Agriculture Western Region Sustainable Agriculture Research and Education (USDA-WSARE) Program; SPC/GTZ Pacific-German Regional Forestry Project; USDA Natural Resources Conservation Service (USDA NRCS); State of Hawai'i Department of Land & Natural Resources Division of Forestry & Wildlife; and the USDA Forest Service Forest Lands Enhancement Program. This material is based upon work supported by the Cooperative State Research, Education, and Extension Service, U.S. Department of Agriculture, and Agricultural Experiment Station, Utah State University, under Cooperative Agreement 2002-47001-01327.

Series editor: Craig R. Elevitch

Publisher: Permanent Agriculture Resources (PAR), PO Box 428, Hōlualoa, Hawai'i 96725 USA; Tel: 808-324-4427; Fax: 808-324-4129; E-mail: par@agroforestry.net; Web: <http://www.agroforestry.net>. This institution is an equal opportunity provider.

Species Profiles for Pacific Island Agroforestry
www.traditionaltree.org

April 2006
ver. 2.1

Citrus (citrus) and *Fortunella* (kumquat)

Rutaceae (rue family)

C. aurantifolia	lime	*C. limon*	lemon	*C. paradisi*	grapefruit
C. aurantium	sour orange	*C. macroptera*	wild orange	*C. reticulata*	mandarin
C. grandis	pummelo	*C. medica*	citron	*C. sinensis*	sweet orange
C. hystrix	Kaffir lime	*C. mitis*	calamondin	*Fortunella* spp.	kumquat

Harley I. Manner, Richard S. Buker, Virginia Easton Smith, Deborah Ward, and Craig R. Elevitch

IN BRIEF

Distribution Widely distributed and cultivated worldwide including throughout Oceania.

Size Depending on species and cultivar, trees reach heights of 3–15 m (10–50 ft).

Habitat In the subtropics 0–750 m (0–2450 ft); in the tropics 0–1600 m (0–5250 ft); without irrigation, rainfall of 900–3000 mm (35–120 in) is needed.

Vegetation Associated with a wide range of cultivated tropical and subtropical species.

Soils Tolerates a wide range of soils; however, does not stand waterlogged soil, and grow best in freely draining soils; pH 5–8.

Growth rate 0.1–0.3 m/yr (4–12 in) in height.

Main agroforestry uses Homegardens, bee forage (excellent honey), animal fodder, craft and fuel wood.

Main uses Fruit, medicine, cosmetics.

Yields Vary greatly depending on variety and growing conditions; mature trees of oranges and grapefruit can bear 125–204 kg/tree (275–450 lb/tree) in commercial situations.

Intercropping Can be intercropped with a wide variety of species in homegardens and mixed farm systems.

Invasive potential Citrus species are not considered to be invasive.

Citrus is a favorite fruit in Pacific island homegardens and has commercial potential in local markets.

INTRODUCTION

Citrus species are small to medium-size shrubs or trees that are cultivated throughout the tropics and subtropics. They are native to parts of India, China, northern Australia, and New Caledonia. All species are aboriginal, early European, or modern introductions throughout Oceania. Most species have been given names in many native languages of the Pacific, attesting to how citrus has been embraced by native cultures. Citrus is adaptable to many subtropical and tropical environments and soils and has traditionally been cultivated in homegardens together with other important species such as coconut, breadfruit, papaya, and numerous others. One could say citrus is an essential component of any Pacific island (and subtropical or tropical) homegarden.

Citrus is primarily valued for the fruit, which is either eaten alone (sweet orange, tangerine, grapefruit, etc.) as fresh fruit, processed into juice, or added to dishes and beverages (lemon, lime, etc.). All species have traditional medicinal value. Citrus has many other uses including animal fodder and craft and fuel wood. Although commercial production for export markets has not been significant in Oceania, there is potential for small farmers to supply local markets with fresh fruit and unique varieties.

DISTRIBUTION

Native range

The genus *Citrus* is native to the tropical and subtropical regions of India and southern China to northern Australia and New Caledonia. The cultivation of oranges and pummelo dates back to 2400 BC in China.

Current distribution

Some species can still be found in a wild state, but most species are today known only in cultivation. Citrus has been distributed widely and cultivated worldwide for fruit and juice. All species are present in Oceania today as aboriginal, early European, or recent introductions.

BOTANICAL DESCRIPTION

Genus

Citrus L.

Family

Rutaceae (rue family)

Subfamily

Aurantoideae

Subgenera

The genus *Citrus* is further subdivided into subgenera: *Citrus* and *Papeda*, with the difference being the presence of acrid oil droplets in the pulp vesicles of *Papeda*. Of the species covered here, most belong to the subgenus *Citrus*, with *C. hystrix* and *C. macroptera* belonging to *Papeda* (Stone 1985).

Species origins and Pacific island introductions

Species	Common name	Native origin	**Time of Pacific island introduction** (Thaman and Whistler 1996)
C. aurantifolia	lime	Malesia	early European introduction to Pacific islands, including atolls
C. aurantium	sour orange	S. China and Indochina	early European introduction to Pacific islands
C. grandis	pummelo	Malesia	aboriginal introduction to Fiji, western Polynesia, and Tonga; early European introduction to other Pacific islands
C. hystrix	Kaffir lime	Malesia	early European introduction to many Pacific islands; recent introduction to Kiribati and Tuvalu
C. limon	lemon	SE Asia	early European introduction to Pacific islands
C. macroptera	wild orange	Malesia, Melanesia	Polynesian introduction Vanuatu, New Caledonia, and Polynesia (Walter and Sam 2002)
C. medica	citron	India	early European introduction to Pacific islands
C. mitis	calamondin	China	recent introduction to many Pacific islands
C. paradisi	grapefruit	West Indies	recent introduction to many Pacific islands
C. reticulata	mandarin	SE Asia	recent introduction to many Pacific islands
C. sinensis	sweet orange	S. China, Indochina	recent introduction to many Pacific islands

Preferred and non-preferred scientific names

C. aurantifolia (Cristm.) Swingle (lime)

Non-preferred names
Limona aurantifolia Cristm.
Citrus lima Lunan
Citrus acida Rsxb.
Citrus hystrix var. *acida* (Roxb.) Engler
Citrus medica var. *acida* (Roxb.) Hook. F.
Citrus medica sensu Catala, Guillaumin, non L.

C. aurantium L. (sour orange)

Non-preferred names
Citrus vulgaris Risso

C. grandis L. (pummelo)

Non-preferred names
Citrus aurantium var. *grandis* L.
Citrus aurantium var. *decumana* L.
Citrus maxima (Burm.) Merr.
Citrus decumana (L.) Murr.

C. hystrix DC (Kaffir lime)

Non-preferred names
C. bergamia (Duhamel) Risso

C. limon (L.) Burm. f. (lemon)

Non-preferred names
C. medica var. *limon* L.
C. limonum Risso
C. limonia Osbeck

C. macroptera Montrouzier (wild orange)

Non-preferred names
C. aurantium spp. *sapnacea* Saff.

C. medica L. (citron)

Non-preferred names
C. medica var. *genuina* sensu Bryan
C. aurantium L. var. *medica* Wight & Arnott
C. crassa Hasskarl

C. mitis Blanco (calamondin)

C. paradisi Macf. (grapefruit)

C. reticulata Blanco (mandarin)

Non-preferred names
C. nobilis sensu auct. Micr. Non Lour.
C. nobilis Andrews
C. deliciosa Tenore
C. chrysocarpa Lushington

C. sinensis Osbeck (sweet orange)

Non-preferred names
C. aurantium var. *sinensis* L.
C. aurantium ssp. *sinensis* (L.) Engl.

EXAMPLE OF EARLY PACIFIC ISLAND INTRODUCTION

Commenting on the citrus species on Niue, Smith (1902) wrote: "The orange (*Moli*) grows well and bears fine sweet fruit, but the natives here have not planted it to any extent. It bears the same name in Fiji, Samoa, Tonga, Futuna, Rarotonga, and Tahiti. The lemon, lime, citron and shaddock also flourish very well in Niue, particularly the lemon (*Tipolu*)."

Size

Citrus are shrubs to medium-size trees up to about 6 m (20 ft) in height, although some species can reach 15 m (50 ft). Rootstocks can greatly affect the height of grafted trees. Trees have thin, smooth, and gray-brown to greenish bark. Most species are single-trunked with very hard wood. Canopy widths range from slender to broad, depending on species. Many cultivated species are pruned so that the canopy is as wide as the tree is tall.

Species	common name	Size and spines
C. aurantifolia	lime	shrub/small tree to 4 m (13 ft), spiny
C. aurantium	sour orange	tree to 10 m (33 ft), short spines
C. grandis	pummelo	tree to 12 m (40 ft), spiny
C. hystrix	Kaffir lime	tree to 5 m (16 ft), short spines
C. limon	lemon	tree to 6 m (20 ft), stout spines
C. macroptera	wild orange	tree to 5 m (16 ft), spiny
C. medica	citron	shrub to 3 m (10 ft)
C. mitis	calamondin	tree to 12 m (40 ft), spiny
C. paradisi	grapefruit	tree to 15 m (50 ft)
C. reticulata	mandarin	tree to 9 m (30 ft), usually spiny
C. sinensis	sweet orange	tree to 12 m (40 ft), often spiny stems

Form

Tree growth and form varies depending on the genetic background and whether the tree was established by seed or grafting. Some lemon varieties can produce vigorous canopies (e.g., 'Bearss'), while other varieties are spreading in nature. Generally, limes have a low-growing habit and long branches that arch outward. The typical form of sweet orange tends to be a conical shape, narrowing to-

Common Names

C. aurantifolia (lime)

Yap: *remong*
Marshall Islands: *laim*
Nauru: *deraim, derem*
Guam: *limon*
English: lime, Tahiti lime, key lime, W. Indian lime, acid lime
French: *citronnier*
Kiribati: *te raim*
Tonga: *laimi, moli laimi*
Palau: *malchianged*
Pohnpei: *karer*
Kosrae: *laim*
Chuuk: *laimes, nayimis*
Fiji: *moli laimi, laimi*
Tahiti: *taporo*
Marquesas: *ihitoro, hitoto*
New Caledonia: *le limier*
Samoa: *moli tipolo, tipolo, tipolo lamolemole*

C. aurantium (sour orange)

Fiji: *moli jamu*
Guam: *kahet*
English: sour orange, Seville orange
Hawai'i: *'alani*
Tubuai: *anani, bigarade*
Swains Island: *moli*
New Caledonia: *l'oranger*
Samoa: *moli 'aina*
Tonga: *kola*
Futuna: *moli kai*

C. grandis (pummelo)

Fiji: *moli kana*
Palau: *jabong*
Guam: *kahet magas, lalangha*
English: pummelo, shaddock, jabon (Hawai'i)
French: *pamplemoussier*
New Caledonia: *le pamplemoussier*
Fiji: *moli kana*
Tonga: *moli Tonga*
Samoa: *moli Tonga, moli meleke, moli 'ai suka, moli suka*

C. hystrix (Kaffir lime)

Guam: *limon admelo*
English: Kaffir lime, Mauritius papeda, rough lemon, wart lime
Palau: *debechel*
Yap: *gurgur gurgumimarech*
Samoa: *tipolo patupatu*
Tonga: *lemani, moli lemani*
Kiribati: *te remen*
Tuvalu: *laim*

C. limon (lemon)

Palau: *debechel*
Hawai'i: *lemi*
Kiribati: *te remen, te remon*
Tonga: *moli lemani, lemani*
Fiji: *moli karokaro, moli sosoriatia, moli ni vavalagi*
Guam: *limon real*
English: lemon
Pitcairn: *rough-skinned lemon*
Hawai'i: *lemi, kukane*
Samoa: *moli tipolo, moli*
Niue: *tipolu*
Cook Islands: *tiporo*
New Caledonia: *le citronnier*

C. macroptera (wild orange)

Guam: *kahet*
English: wild orange, melanesian papeda
Tonga: *moli uku*
Samoa: *moli u'u*
Fiji: *moli kau*
Vanuatu: ghost lime (eng.), *moli* (Ambae, Malo), *mol* (Efate, Pentacost, Santos), *ngoli* (Maewo), *na-moli* (Tongoa)

C. medica (citron)

Guam: *setlas*
English: citron
Swains Island: *tipolo*
Samoa: *tīpolo, tīpolo patupatu*

C. mitis (calamondin)

Palau: *kingkang*
Samoa: *tipolo Iapani*
Hawai'i: *'alani'awa'awa*
English: calamondin, calamondin orange

C. paradisi (grapefruit)

English: grapefruit, pomelo
Fiji: grapefruit
Pitcairn: grapefruit

C. reticulata (mandarin)

Fiji: *moli madarini, madarini, narangi*
Palau: *kerekur*
Yap: *goligao*
Guam: *kahe na kikiki, lalanghita*
English: mandarin, tangerine, dancy tangerine, kid glove orange, clementine, satsuma orange
Hawai'i: *alani-pake, tacibana*
Kosrae: *muhsrisrik*
New Caledonia: *le mandarinnier*
Samoa: *moli saina*
Tonga: *moli peli*

C. sinensis (sweet orange)

RMI: *woan*
Yap: *gurgur*
Palau: *meradel*
Kiribati: *te aoranti*
Fiji: *moli unumi, moli ni taiti, molidawa, molilecau, molitaiti, mitha nimbu*
Guam: *kahet*
English: sweet orange, common orange, china orange, navel orange
French: *oranger doux*
Kosrae: *muhluhlahp*
Pitcairn: tree-orange
Samoa: *moli 'aina, moli 'aiga*
Tonga: *moli kai, moli inu*
Futu: *moli*
Nuie: *moli*
Cook Islands: *anani*
Rapa: *anani*
Society Islands: *arani*
Hawai'i: *alani Hawai'i*, Ka'u orange, Waialua orange
New Caledonia: *l'oranger*

ward the top of the tree, with upright medium to large, compact horizontal branches. Grapefruit produces large trunks (0.5–0.75 m [1.5–2.5 ft] in diameter) and a large conical head. Trees produced from seed tend to have more thorns and upright branch growth than trees produced from grafting.

Flowering

Flowers are 2–4 cm (0.8–1.6 in) in diameter, axillary, fragrant, single, few or cymose, and often perfect (having both functional stamens and pistils) or staminate. The calyx is 4–5 lobed and there are usually five petals with oil glands. Stamens number between 20 and 40. Petal colors range from white to pinkish in Kaffir lime to pinkish to purplish externally in citron and reddish in lemon varieties. The subglobose ovary is superior, with 8–18 locules (cavities), with 4–8 ovules per locule in two rows.

All citrus flowers are fragrant (pummelo flowers pictured).
PHOTO: C. ELEVITCH

Leaves and branches

Leaves are entire, 4 to 8 cm (1.6–3.2 in) in length, unifoliate, fairly thick, with winged petioles. Leaves are ovate, oval or elliptical, with acute to obtuse tips, and glands containing oils in glands, which are released when crushed. Young twigs are angled in cross-section, green, and axillary single-spined, while older twigs and branches are circular in cross-section and spineless.

Fruit

The fruit is a hesperidium, a fleshy, indehiscent berry that ranges widely in size, color, shape, and juice quality. Citrus fruit range in size from 4 cm (1.6 in) for lime to over 25 cm (10 in) in diameter for pummelo. Fruits are globose to ovoid in shape (for more details see Appendix A). The fleshy endocarp is divided into 10–14 sections containing the stalked pulp and separated by thin septa. Each section contains pulp (juice vesicles) that contains a sour or sweetish watery juice. A whitish "rag" or mesocarp (also known as the albedo) covers the endocarp. In turn, the thin outer section of the leathery peel or exocarp containing many oil glands is known as the flavedo (Purseglove 1974).

Seeds

Seeds are pale whitish to greenish, flattened, and angular. The seeds are usually polyembryonic, meaning they have multiple embryos that can germinate. The embryos are either "zygotic" or "nucellar." The zygotic embryos are derived from pollination of the ovary, i.e., sexual reproduction, and therefore are not always similar in horticultural qualities to the parent tree. The nucellar embryos are derived wholly from the mother plant and display very similar characteristics to the parent plant.

Rooting habit

Over 70% of citrus tree roots are in the top meter (3.3 ft) of soil. Citrus trees produce a taproot that can extend 2 m (6.6 ft) below the surface. Fibrous roots commonly extend well beyond the canopy.

Look-a-like species

All citrus species have dark green, waxy leaves with a characteristic citrus odor, and sweet-smelling flowers. Most species are easy to differentiate by their fruit. Kaffir lime and wild orange are often mistaken for each other. According to Walter and Sam (2002), Stone (1970) distinguished the two from each other on the basis of the fruit and the

WATER TENNYSON SWINGLE

Walter Tennyson Swingle (1871–1952) conducted much of the pioneer research that forms the foundation of our present knowledge about *Citrus* and *Fortunella* species. He described many of the citrus species, varieties and relatives he collected on extensive world travels, conducted research on citrus diseases, and conducted hybridization studies that led to new groups such as the Minneola tangelos and citranges. Dr. Swingle's work with nucellar (true to type) seedlings of citrus led to the clones of commercial varieties now planted throughout the citrus-growing regions of the world. After retiring, Dr. Swingle's publication *The Botany of Citrus and its Wild Relatives of the Orange Subfamily* represented the culmination of 50 years of taxonomic botany on this important cultivated species.

Popular citrus fruits include (clockwise from upper left): calamondin, navel orange, pummelo, grapefruit, and tangerine. PHOTOS: C. ELEVITCH

From top to bottom: New varieties of mandarins, Valencia oranges, and grapefruit. photos: CITRUS RESEARCH AND EDUCATION CENTER

petiole shape. Wild orange fruit has a smooth skin, and the petiole wings are entire. Kaffir lime fruit has bumpy skin, and the petiole wings are crenulate (toothed). The leaves of sour orange have a petiole that is much larger than that of sweet orange (about the size of grapefruit petiole). See Appendix A for more detail about fruit and leaf characteristics.

GENETICS

Variability of species

Citrus species are highly variable. Also, members of the group can hybridize readily and are generally graft- and cross-compatible. For example, some "tangerine hybrids" are tangelos (tangerine × grapefruit), tangors (tangerine × orange), and tantangelos (tangerine × tangelo).

Varietal selections are usually propagated by grafting to produce trees that are identical to the parent material. Some variation can sometimes occur even in grafted trees from natural mutations in buds ("bud sports").

Known varieties

There are many, many varieties. For example, sweet orange alone contains four groups of cultivars. These groups and their cultivars are:

- Common or round oranges (e.g., 'Valencia', 'Hamlin', 'Parson Brown', 'Pineapple')
- Blood oranges (e.g., 'Tarocco', 'Moro')
- Navel Oranges (e.g., 'Washington')
- Acidless oranges (e.g., 'Succari', 'Lima')

For more information on varieties, see Variety Table, Appendix B.

ASSOCIATED PLANT SPECIES

In general, the flora of the native habitats of citrus consists of tropical to subtropical species in humid to subhumid environments. Most citrus species are associated with the Indomalayan flora. One exception is wild orange, which is also native to Melanesia and is therefore associated with the Melanesian floristic region.

Species commonly associated as aboriginal introduction in Pacific islands

In the Pacific, most citrus species are found in cultivated areas, orchards, and homegardens. A typical high island backyard garden may have two to three species or cultivars of citrus (e.g., pummelo, mandarin, lime, etc.), coconut,

A large orange tree planted in an agroforest by Palauan migrants to Guam. This agroforest is located on the sloping area to the Agana Swamp which is being used for cultivation of swamp taro, true taro, breadnut, bananas, cassava, yams, coconuts, and other species. PHOTO: H. MANNER

mango (*Mangifera indica*), guava (*Psidium cattleianum* and *Psidium guajava*), lychee (*Litchi chinensis*), fig (*Ficus carica*), papaya (*Carica papaya*), cassava (*Hibiscus manihot*), breadfruit (*Artocarpus altilis*), and jackfruit (*A. heterophyllus*), to name a few. On atolls, citrus is less frequently found, but when present it is found in association with coconuts, breadfruit (either *A. altilis* or *A. mariannensis*, or both), papaya, and mango.

ENVIRONMENTAL PREFERENCES AND TOLERANCES

Climate

Suitable climates for citrus are the tropical and subtropical humid regions of the world. The fruit is said to achieve its highest flesh quality in subtropical humid climates or the drier regions (i.e., Mediterranean climates) with irrigation (Rieger 2002). Limes seem to be the citrus best adapted to atoll environments (Thaman and Whistler 1996). Kaffir lime is also well suited to atolls and is one of the most important sources for disease-free rootstocks for atolls.

Elevation

In the subtropics, citrus grows between sea level and 750 m (2450 ft) above sea level. In the tropics, citrus does well below 1600 m (5250 ft).

Mean annual rainfall

900–3000 mm (35–120 in). Without irrigation, 900 mm (35 in) per annum is typically needed for any significant fruit production.

Rainfall pattern

Species grow in climates with summer, winter, bimodal, or uniform rainfall.

Dry season duration (consecutive months with <40 mm [1.6 in] rainfall)

1–3 months. (The dry season in Mediterranean climates where citrus is often grown is up to 4 months.)

Mean maximum temperature of hottest month

31–32°C (88–90°F) in Florida. Optimum daytime temperatures are 25–30°C (77–86°F), but temperatures can reach 43°C (110°F) in Southern California and other citrus-growing regions.

Mean minimum temperature of coldest month

8–14°C (47–57°F) in Florida. Low temperatures typically limit the range in which citrus can be grown. Citrus becomes quiescent at temperatures below 13°C (55°F).

Minimum temperature tolerated

The fruit is killed by 30 minutes of temperatures at –3––2°C (26–28°F). Stems and leaves can be killed by a few minutes at –7––3°C (20–26°F) (Rieger 2002). This is dependent on previous climatic conditions and age of fruit, leaves and branches.

Soils

Citrus tolerates a wide range of soils, from almost pure sands to organic mucks to heavy clay soils (Rieger 2002). The trees do not stand waterlogged soils but grow well in freely draining soils. They are sensitive to excessive boron, sodium carbonate, and sodium chloride (Purseglove 1968).

Soil texture

Citrus grows in a wide range of light, medium, and heavy soils (sands, sandy loams, loams, sandy clay loams, clays, clay loams, and sandy clays).

Soil drainage

Performs better on freely draining soils compared with poorly drained soils, and does not tolerate waterlogging.

Soil acidity

Citrus grows in acid to neutral soils with pH 5–8; however, their growth is greatest at pH 6–7. Trees on Swingle rootstock will grow in pH 5–7.5 and do not perform well on soils with high pH as a result of high calcium content.

Special soil tolerances

Growing on appropriate rootstocks, citrus can tolerate soils that are too dry to be productive for other crops (soybean, cotton, wheat, sugarcane, etc.).

Tolerances

Drought

Growth in Mediterranean climates where the rainfall averages less than 250 mm/yr (10 in/yr) or less and summers are dry is only possible with irrigation. Citrus can generally tolerate 3–4 months of minimal rainfall. Drought tolerance depends on temperatures, soils, wind, and the desired level of fruit production. Citrus loses productivity in drought and requires irrigation during the summer months, e.g., in Florida and Central and Southern California, to sustain intense fruit production.

Full sun

It is well adapted to high sunlight as evidenced by the presence of citrus groves in Mediterranean climates and even more arid (high net radiation) desert climates with irrigation.

Shade

Citrus can tolerate minimal shading. Shading or low light levels will affect the fruit bearing of trees (Jiffon and Syvertsen 2002). Grapefruit is more susceptible to shading than oranges. Fruit productivity may be reduced by up to 50% by shading for more than 6 months.

Fire

Trees can handle minimal amounts of smoke and heat from fires. Fires that raise the internal tree temperatures above 54°C (130°F) will damage the trees.

Frost

The species do not tolerate frost well. Previous environmental conditions dictate the trees' level of cold tolerance. When trees experience consistently cooler temperatures with little rainfall before a freeze, they can demonstrate greater tolerance of the subfreezing conditions than trees that have been actively growing. In Florida and other subtropical climates where citrus is grown commercially, smudge pots are used to maintain air circulation during frost events. When available, micro-sprinkler irrigation is the preferred method of cold protection. Irrigation water is applied prior to the arrival of freezing temperatures to warm the soil, and then again during the freezing events to provide heat to the trees that is released during the formation of ice crystals.

Waterlogging

Citrus does not tolerate waterlogging. When temperatures are over 24°C (75°F), fibrous root death from lack of oxygen (anoxia) can begin within 7–14 days. As citrus roots die, trees develop water stress symptoms such as leaf wilting, yellowing, and drop. How quickly water stress develops depends on water movement, soil pH, and the amount of hydrogen sulfide present. Hot weather will speed up the development of visible symptoms. Moving water delays the development of anoxic symptoms, so it is important to start drainage operations as soon as possible. If drainage reduces water levels 10–15 cm (4–6 in) per day, root loss can be avoided. Even circulating water within a block is better than allowing water to stagnate. Hydrogen sulfide (H_2S) minerals produced by anaerobic bacteria have an odor of rotten eggs (in acid soils but not in all cases), which is an indication that fibrous roots are dying. This process can be slower at higher soil pH. Swingle and Carrizo rootstocks tend to tolerate flooding better than sour orange and Cleo.

Salt

Citrus does not tolerate salinity well. For this reason, most citrus grows poorly in coastal and atoll environments. High levels of salt in water will increase the osmotic pressure and reduce the ease of water uptake by trees (Boman and Stover 2002). Citrus species are differentially sensitive to salt depending on the type of salt (Mass 1992).

Wind

Citrus trees are susceptible to leaf, branch, and fruit damage in strong winds.

GROWTH AND DEVELOPMENT

During the first year after planting, tree growth is usually minimal. Assuming adequate moisture and nutrients, trees will greatly increase in height and diameter between the second and fourth year after planting. For grafted trees, during the first 3–4 years after planting, the tree undergoes primarily vegetative growth, but fruit may occasionally be produced. Vegetative growth flushes occur during the spring and summer months. While citrus is an evergreen, there are annual periods of necessary quiescence, which normally occur during the winter months when lower temperatures are experienced. Once trees enter into regular fruit bearing, vegetative growth and the annual increase in tree height and diameter will slow. The desired tree size is typically achieved between ten and fourteen years after planting. Fruiting typically declines from its peak after 20–25 years, but trees are known to survive and bear fruit for 250 years (Hume 1938).

Growth rate

Growth rates are highly variable based on climate, cultural practices, tree spacing, scion, and rootstock (Wheaton et al. 1999). Younger trees (approximately 5–10 years old) tend to have greater growth rates in relation to beginning tree size. In a California study, trees grew 10 cm/yr (4 in) in height between 3 and 6 years. Comparatively, trees between 6 and 12 years grew at a rate of 30 cm/yr (12 in) in height. Trunk cross-sectional areas can increase from 5 to 33 cm^2 (0.8–5.1 in^2) each year. Roots of citrus trees less than 5 years old were found to extend between 2 and 5 mm/day (0.08–0.2 in/day) depending on the soil moisture levels.

Flowering

Flowering can occur within the second year after planting, but regular flowering occurs 4 years after planting. Seasonal flowering occurs after the winter months when trees have experienced a period of quiescence. Over 300 hours of temperature below 20°C (68°F) followed by warm temperatures will induce flowering. Multiple blooms each year can be experienced on trees growing in tropical conditions. Only a small percentage of flowers produce fruits; large numbers of flowers drop after opening, and large numbers of fruits drop 10–12 weeks after pollination. Fruits take 7–14 months to mature (Purseglove 1974).

Reaction to competition

Citrus trees have demonstrated resiliency to competition from some annual broadleaf weeds. In the first year after planting, trunk and canopy growth of citrus trees were affected by Spanish needle (*Bidens bipinnata*). The canopy is more affected by competition than the trunk growth (Buker 2005). Between 5 and 8 years after planting, trees are still susceptible to competition with annual grasses. Season-long competition reduced fruit yields 30% (Carvalho et al. 2003). The greatest reported impact by weeds on citrus yields was from a perennial grass; Bermuda grass (*Cynodon dactylon*) reduced yields 50% after season-long competition (Jordan 1981).

PROPAGATION

Citrus can be propagated by many methods including seeds, cuttings, air-layering, grafting by many methods, and tissue culture. Although some cultivars can be reproduced by seed, this method is considered inferior. Varieties that are reproduced by seed require more time to produce fruit, are more susceptible to diseases, are more difficult to keep true to type, and tend to produce more thorns than grafted varieties. Their fruit is also harder to pick as a result of the upright and thorny growth. In commercial practice, citrus is commonly propagated by grafting an individual bud of a selected variety onto a rootstock seedling.

Vegetative propagation known as "T-budding"

Budding uses a bud cut from the parent tree (scion) that is grafted onto a seedling rootstock. Once the bud is in place, the foliage of the rootstock above it is cut off or tied down to "force" the bud growth. There are several horticultural advantages to budding. A major advantage is the known success in reproducing the characteristics of the parent tree (for more information, see Williamson and Jackson 1994). Producing trees through budding allows the selection of rootstocks that can impart disease tolerance and allow production in soils not suited for the scion.

Budwood collection

Select branches that are mature, vigorous, round (rather than angular), and close to or smaller than the diameter of the rootstock in which the bud will be grafted. Adequate maturity can often be identified by formation of lignified tissue in the green bark (lines of wood formation). Branches earmarked for budwood production should be regularly inspected and treated to keep them free of pathogens and

PATHOGEN WARNING

Before any propagation effort is attempted, thorough efforts should be made to determine local and international regulations.

Devastating pathogens can be inadvertently spread through propagation of seeds and vegetative material used for grafting. Before propagating a tree, the local regional (county, state, etc.) agricultural authorities should be contacted regarding the presence of pathogens in the area. Most countries have strict regulations about the import of citrus, and government agricultural quarantine departments must be consulted prior to import. When buying commercial citrus plants, make sure the nursery has followed applicable regulations for disease-free propagation.

Left: A recent bud graft, showing callous formation around the edge. PHOTO: J. WILLIAMSON **Right: Grafting scion wood to the top of a seedling (wedge or cleft grafting) is also a common method of propagating citrus varieties.** PHOTO: C. ELEVITCH

insects.

Cut the selected limbs from the parent tree so that 20–25 cm (8–10 in) of desirable buds will remain after removing the new flush and all leaves. When removing the leaves, a small portion of the petiole that is adjacent to the bud should remain attached to the bud as a handle until the budding process is completed (Williamson and Jackson 1994).

Bud preparation

Budding can be achieved with very little equipment. A sharp knife is needed to cut buds from the parent tree. In addition, polyethylene wrap is needed to keep the bud secured to the rootstock and to seal in moisture and seal out rain or irrigation water.

Budwood storage

Budwood cut from the parent tree is best used shortly after cutting. However, if stored moist in a sealed plastic bag in a cool place, budwood can survive for 2–3 months after cutting from the parent plant. Once individual buds are cut from the budwood, they should be used immediately for best grafting success, although individual buds may remain viable for a few hours when stored cool and moist.

Pre-grafting treatments

No pretreatments are necessary for successful budding of healthy scions.

Propagation area

Survival of budded plants is greater in protected environments. If available, shade houses or greenhouses with adequate water are advisable.

Early growth

Buds that are successfully growing will be green and have callus forming around the edges 14–21 days after cutting. Wraps can be removed at this time.

Rootstock propagation

Seed removed from the fruit and cleaned and dried can be stored for a year in a cool, dry atmosphere (Williamson and Jackson 1994). Rootstock seedlings should germinate within days of planting, and are ready to bud to as soon as they have a stem about 6 mm (0.15 in) in diameter. Growth media should have good drainage and moderate water-holding capacity. Poly bags have been used successfully as pots if they have drain holes at the bottom. Media that are high in organic material (>50%) can create problems and should be avoided if possible.

Time to outplanting

Trees may be ready to plant 6–12 months after budding, however, the longer they remain in a protected environment, the greater the chance of survival. Larger plants grown in larger containers bear fruit sooner after outplanting than smaller plants.

Approximate size at outplanting

Trunk diameter and tree height vary with variety. Trees are normally 0.5 m (20 in) in height and trunk diameter is usually 1–2 cm (0.4–0.8 in).

Guidelines for outplanting

If replanting into a site that had citrus trees, soil fumigation prior to planting is advised. Nematodes, *Phytophthora*, and blight risk are reduced by fumigation. Regrowth of previous rootstocks can be expected if they are not completely removed or destroyed. Survival rate of newly planted trees when properly cared for is 95% or higher.

Other comments on propagation

Cuttings, especially from young branches, root well. This method can be used to preserve varieties until suitable rootstock is available.

DISADVANTAGES

Genetic variation in cultivation is limited, as vegetative propagation is the primary method of producing new plants. The limited genetic variation renders citrus plants susceptible to pathological and entomological pressures. Skin irritants contained in the peel may cause dermatitis or other chronic skin conditions in people who have constant contact with citrus oil or skin.

Potential for invasiveness

Although some species have naturalized on some Pacific islands, this is rarely considered a problem. Most species grown in the Pacific islands are restricted to cultivated areas.

Pests

Citrus is affected by numerous species of insects, mites, and disease pathogens that infest the leaves, flowers, bark, fruit, and branches of citrus.

Insects and mites

Mites

Several species of mites are pests of citrus, most notably the citrus rust mite, *Phyllocoptruta oleivora*, which causes minimal damage to foliage but extensive damage to fruit. They move from the leaves to the young fruit when it sets and extract the cell contents from the skin. The damage is generally minor in regard to production but causes a russetting of the fruit, making it unmarketable. Other mite pests are the citrus bud mite, *Eriophyes sheldoni*, the red spider mite, *Panonychus citri*, and the broad mite, *Polyphagotarsonemus latus.*

Scales, mealybugs, and whiteflies

This group of related insects is very common, and they feed on the foliage, fruit, and roots of citrus. Generally, they pierce plant cells with their needle-like mouthparts and suck out the liquid; many then secrete honeydew. Ants, such as the longlegged ant, *Anoplolepis longipes,* feed on the honeydew and protect the pest insects from predators. Sooty mold (a fungus) also grows on the honeydew and reduces light penetration to the leaf (and thereby photosynthesis) but does not infect the leaf.

There are numerous pest species of these insects, but among the ones causing the most damage are the California red scale, *Aonidiella aurantii*, which attacks fruit, foliage and twigs; black scale, *Saissetia* species; the citrus mealybug, *Planococcus citri*; the citrus whitefly, *Dialeurodes citri*; the citrus blackfly, *Aleurocanthus woglumi*; and the woolly whitefly, *Aleurothyrixus floccosus*.

Aphids, psyllids, and sharpshooters

This group of insects causes similar damage to that caused by the group above but is notable due to their ability to transmit diseases agents such as viruses and bacteria. They usually feed on new leaves and stems and can cause significant damage; however, the diseases vectored are usually more serious than the feeding damage. Many species of aphid affect citrus; one of the most widespread is the brown citrus aphid, *Toxoptera citricida*, which is known to carry citrus tristeza virus. *Diaphorina citri*, the Asian citrus psyllid, is a carrier of the pathogen causing greening disease. The glassy winged sharpshooter, *Homalodisca coagulata*, is also a pest of citrus.

Fruit flies

The Oriental fruit fly, *Bactrocera dorsalis,* and the Mediterranean fruit fly, *Ceratitis capitata*, are the main fruit fly pests of citrus. The major problem they pose is that they deposit their eggs in the fruit as soon as there is any color break, and the larvae burrow into the fruit and feed. This makes the fruit unpalatable as well as having the potential to introduce these pests, which cause serious damage to numerous agricultural products, into new areas.

Other insect pests

The citrus leafminer, *Phyllocnistis citrella*, Chinese rose beetle, *Adoretus sinicus*, thrips such as *Scirtothrips citri*, and other insects feed on citrus causing varying levels of damage.

Clockwise from top left: Mites on lemons showing fruit bronzing symptom; mealybugs; nutrient deficiency leaf symptoms, probably iron; leaf miner. PHOTOS: S. C. NELSON

Diseases and disorders

Physiological disorders (not caused by pathogens)

Fruit splitting

This disorder is common on fruits with thin peels such as navel oranges (Washington navels are particularly prone to this) and tangerines. Although its specific cause is unknown, no pathogen has been associated with it, and it is likely due in part to uneven growth caused by weather or by erratic irrigation and fertilization. Addition of potassium fertilizer (foliar spray) will reduce splitting in some years (Tucker et al. 1994).

Root rot

There are many possible causes of root rot, but one common cause is watering too frequently. Root rot can be a direct result of the lack of oxygen in the root zone due to over-irrigation or an indirect result when over-irrigation predisposes the roots to infection by a root rotting pathogen.

Nutrient deficiencies

Nutrient deficiencies can be caused by leaching due to excessive irrigation or rain, by naturally low soil nutrient levels, by soil nutrient imbalances, improper pH, or insufficient or incorrect fertilizer application. Nitrogen, zinc, magnesium and iron deficiencies are common and correctable.

Diseases caused by pathogens

Citrus is prone to many diseases of the leaves, roots, wood and fruit; some of the more common ones are listed below.

Root rot and Phytophthora gummosis

There are many pathogenic species of the *Phytophthora* fungus causing root rots that prevent the plant from taking up sufficient water and nutrients. The leaves will turn yellow, wilt, and may drop; the tree slowly declines, and often will die.

Gummosis, another disease caused by *Phytophthora* spp., affects the base of the trunk and lower limbs from which a clear gum is secreted. The bark dries upward, hardens, and cracks; the lesions spread and often girdle the branch or trunk. Most scion wood is very susceptible to this disease; be sure the graft union is well above the soil level at planting.

Melanose

Melanose is widespread but is a problem only when inoculum levels are high and there is extended rainfall during early fruit development. The symptoms begin as small, brown, sunken spots, which become raised as they develop, on the leaves and fruit. On the fruit the spots may combine and expand to become relatively large diseased areas, depending on the stage of fruit development when they are infected.

Greasy spot

Greasy spot, a common disease in hot, humid areas, is caused by the fungus *Mycosphaerella citri*. It produces brown to black lesions on the undersides of leaves, which appear as grease-soaked spots, and very small lesions on the skin of the fruit. If severe, the disease causes defoliation leading to a significant reduction in yield.

Scab

Citrus scab, caused by *Elsinoe fawcetti*, is the most widespread of three scab diseases. Infection causes a small bulge on one side of the leaf and a corresponding depression on the other side. Raised, brown pustules form on the fruit rind, becoming corky as they develop. The symptoms resemble scaring from wind; scab and wind scar may occur together where a leaf is in contact with the fruit.

Top: Scab symptoms on fruit. Bottom: Canker symptoms on leaves and fruit. PHOTOS: S. C. NELSON

Black spot

Black spot infects leaves and fruit but is only a problem as a disease of the fruit. Leaves infected by *Guignardia citricarpa* may develop small necrotic spots with a gray center but most often do not show symptoms. On fruit, the black spots may take various forms, making the disease difficult to identify. The spots make the fruit unmarketable as fresh fruit but they can be used for processing. When the infection is severe, fruit may drop prematurely.

Citrus canker

All the previously discussed diseases are caused by fungi; citrus canker is caused by a bacterium, *Xanthomonas axonopodis* pv. *citri*. Symptoms of canker are lesions on young fruit and leaves from which bacterial ooze is exuded under humid conditions. On leaves the lesions begin as circular, pinpoint-size spots which enlarge and become irregularly shaped pustules surrounded by a characteristic yellow halo. An even more reliable symptom is a water-soaked edge that develops around the lesion. The size of the leaf spots can vary with cultivar and time of infection but will be approximately the same on each leaf. On fruits the lesion size varies but will be otherwise similar to the leaf lesions.

Greening

Greening, one of the most devastating citrus diseases, is caused by a bacterium which grows in the bark, leaves, and veins of infected trees. It had previously been thought to be caused by a virus, but the pathogen has now been identified as *Liberobacter* species. Affected fruit do not color properly or remain green, consequently the name, greening. Other names for the disease, yellow dragon and yellow shoot, may be more descriptive, because newly infected trees produce shoots that are yellow. Leaf symptoms on chronically infected trees may resemble nutrient deficiencies. Trees will die back and decline severely.

Tristeza

Tristeza virus is one of the most serious pathogens of citrus and is widespread throughout citrus-growing areas. Symptoms are highly variable among citrus species and cultivars and are affected by the strain of the virus and the environmental conditions. Stunting, stem pitting, vein clearing, leaf cupping, yellowing, and reduced fruit size are common symptoms. Vein clearing (disappearance of green color in or along the leaf veins, visible when the leaf is held up to light) and stem pitting (small holes in the stem underneath the bark) can often be used to diagnose this disease. Tristeza is often severe, resulting in significantly reduced yields and often tree death.

Psorosis-ringspot

Psorosis-ringspot, a widespread problem particularly in old-line trees, is a complex of several diseases. Although not fully understood, the disease is believed to be caused by a virus or virus-like pathogen. Bark scaling and flaking on trunks and limbs of sweet orange, grapefruit, and occasionally mandarins is a classic symptom of one form of the disease. Young leaves may show various symptoms including yellow flecks, leaf mottling, or distinct light green patterns, and young shoots may die back. Mature leaves may have raised ring-spots (a yellowish ring with green tissue in the center) or large, irregular yellowish or light green patterns; fruits may also show ring-spots.

Nematodes

Several nematode species infect citrus and cause mild to serious damage depending on the species of nematode and citrus, the age of the plants at infection, and the environmental conditions. The only species that is found worldwide is the citrus nematode, *Tylenchulus semipenetrans*, which is most damaging in dry areas with moderate temperatures. Due to the low rate of population growth of the citrus nematode and the slow development of symptoms, the disease it causes is called citrus slow decline. Other nematodes that are pathogens of citrus are the burrowing nematode, *Radopholus* species, causing spreading decline; the lesion nematode, *Pratylenchus* species, causing citrus slump; and the root-knot nematode, *Meloidogyne* species, causing rootknot. Because these nematodes infest the roots of the plant, they interfere with the uptake of water and nutrients, causing symptoms such as reduced leaf and fruit size, wilting, canopy thinning, and a general, slow decline.

Postharvest diseases

Some common postharvest fungus diseases of citrus are stem-end rot (*Lasiodiplodia theobromae* or *Diaporthe citri*), green mold (*Penicillium digitatum*), sour rot (*Galactomyces citri-aurantii*), anthracnose (*Colletotrichum gloeosporioides*), *Alternaria* stem-end rot (*Alternaria citri*), and brown rot (*Phytophthora palmivora* and *P. nicotianae*).

AGROFORESTRY/ENVIRONMENTAL PRACTICES

Homegardens

Citrus trees are very common in homegardens, where three to four species are often found for fruit, juice, flavorings, and as ornamentals.

Living fences

Thorny types may be useful for living fences, especially when hedged.

Bee forage

Many citrus species including lime, sour orange, Kaffir lime, and calamondin are known to be good forage plants for bees (Thaman et al. 2000).

Ornamental

Most citrus species have an ornamental appearance and serve this purpose in Pacific island mixed homegardens.

Top: Sweet orange growing over coffee in Kona, Hawai'i. PHOTO: C. ELEVITCH
Bottom: Citrus growing among other tree crops including sago palm and coconut in Aopo Village, Savai'i, Samoa. PHOTO: H. MANNER

USES AND PRODUCTS

Fruit

All species are extremely important for their fruit, which is eaten fresh or processed in numerous ways.

Nut/seed

An industrial extract of grapefruit seeds and pulp is used to produce a potent topical antibacterial and fungicidal agent.

Beverage/drink/tea

Fruit juices of all species can be used in beverages. Lemon and sweet orange leaves are boiled to make tea. In Egypt and elsewhere, sour orange juice has been fermented to make wine.

Medicinal

Citrus species are important in traditional Pacific island medicine. In Samoa, a leaf infusion made from sweet orange is used against mouth sores in infants (Goethesson 1997). Citron leaves are used together with other plant parts to make infusions for treating stomach and skin ailments (Whistler 1996). Also in Samoa, a sweet orange bark infusion is used to treat postpartum sickness, serious flu, and internal injuries (Whistler 1996). In Tonga, an infusion of sweet orange leaves, usually together with leaves of mango, *Glochidion ramiflorum*, *Diospyros major*, and/or the bark of breadfruit, is used as a potion to treat "relapse sickness," mostly affecting postpartum women (Whistler 1992). In Tahiti, citrus leaves are used for internal ailments and fractures. In Fiji, the scraped root of pummelo is used to treat hemorrhoids. In the United States, citrus is suggested as part of a healthy diet because of its high vitamin C content and its lycopene and flavonoids, which are known to reduce prostate and breast cancer risk, reduce viral effects and inflammation, and improve capillary activity and cholesterol levels.

Flavoring/spice

Most species have value as flavorings. For example, lime and lemon are commonly used to marinate raw fish and to flavor food. Whole limes are also pickled as a relish (achar) for curry. Sour orange skin and flesh is used to make marmalade. Kaffir lime leaves are used as a flavoring in cooked sauces.

Honey

Citrus is one of the most important honey plants in many parts of the world. In California, for example, citrus has been said to constitute 25% of honey production (Morton 1987).

Animal fodder

The pulp and other by-products from juice production are used as cattle feed. The seeds and peels are dried, then physically pressed and cooked into pellet-shaped feed for cattle in the United States. Birds are known to feed on varieties with seedy fruit.

Beautiful/fragrant flowers

All species have fragrant flowers, which are very pleasant in a homegarden.

Timber

Pummelo and sweet orange wood is used in light construction (Clarke and Thaman 1993). Sour orange wood is hard, fine grained, and valued for cabinetry and turnery (bowls, etc.). In Cuba, sour orange is made into baseball bats (Morton 1987).

Fuelwood

Citrus as fuelwood is generally of minor importance in the Pacific islands. Pummelo wood is considered a good firewood.

Craft wood/tools

Wood of wild orange was used for axe handles and canes in Samoa (Walter and Sam 2002). Lemon wood is used for tool handles (Clarke and Thaman 1993). Wild orange wood is used as the anvil in tapa pounding in Samoa (Whistler 2000). Wood of Kaffir lime and pummelo has been noted as having importance for craft wood (Thaman et al. 2000).

Body ornamentation/garlands

Sweet orange and Kaffir lime flowers are sometimes used in garlands in the Pacific islands (Thaman et al. 2000 and Clarke and Thaman 1993).

Toxin/insecticide/fish poison

Kaffir lime has been noted as having potential in this regard (Thaman et al. 2000).

Cosmetic/soap/perfume

The macerated pulp and leaves of wild orange were used as a shampoo in Guam, Samoa, and Fiji (Walter and Sam 2002). In Guam, Stone (1970) noted that the pulp was used for washing clothes and hair. Stone (1970) also wrote that Kaffir lime has the same uses as wild orange and sour orange.

In Chuuk, the pounded roots of a citrus species known locally as kurukur, are mixed with the leaves, bark, and fruit of other plants to make a perfumed precipitate (called soonen ayis) for scenting necklaces, headbands, hair, and body (Merlin and Juvik 1996).

Oil/lubricant

Oils in the peel, leaf, and flower are used in cosmetics and as medicinals. The flowers of sour orange yield neroli oil, which is very important in the perfume industry (Morton 1987). Solvents extracted from citrus peels, particularly oranges, are used in general-purpose cleaners, hand cleaners, furniture polishes, soaps, and pet shampoo. Orange oil is also used for fragrance in air fresheners, candles, and aromatherapy.

Other

The whole fruits of pummelo are used for toys (wheels, etc.). In Samoa, the fruits of sour orange are used in a game called te ‘aga, wrapped with a piece of beach hibiscus (*Hibiscus tiliaceus*) bark fiber (Whistler 2000).

URBAN AND COMMUNITY FORESTRY

Citrus can be an excellent option for urban planting. Final tree height is not excessive, and the root systems are not disruptive to permanent structures or other trees. Citrus is sensitive to ozone affects and has some basic requirements for air quality. Trees thrive in locations with drainage that does not allow water to stand for more than a week. Citrus is highly suitable for use in a homegarden for fruit and juice. Its abundant, fragrant flowers are a visually and aromatically pleasing addition to the landscape, especially when situated along paths, near lanais, or outside windows.

If planting is desired in temperate climates, then careful site selection can allow citrus to be grown outside of its natural range. Citrus trees should be planted where natural or structural windbreaks will prevent prevailing cold winds from chilling trees during freeze events and where walls can reflect heat back onto the trees.

Size

Size varies with species and variety. Generally, annual pruning is used to maintain tree size and shape, while stimulating fruit production. Another method of maintaining a small size is to plant varieties that are grafted to dwarfing rootstocks, or, if space is very limited, by growing the trees

Left: Grafted trees in cultivation, such as this navel orange, are usually pruned to a size and shape that facilitates picking. Right: Picking an abundant crop of tangerines in a homegarden. PHOTOS: C. ELEVITCH

in large containers (Wheaton et al. 1999).

Rate of growth in a landscape

Depending on climate, soils, and care, tree growth during the early years can reach 30 cm/yr (10 in/yr), slowing to 10 cm/yr (4 in/yr) as the tree attains its mature size.

Roots

The majority of citrus roots are found within the top 1 m (3.3 ft) of soil. Their rooting systems are extensive enough to strongly compete with other plants in the area. The individual roots of citrus are not as large as some trees, and they typically do not disrupt man-made structures. It is unlikely that citrus roots interfere with pipes, as underground irrigation has been used extensively for citrus worldwide.

Products commonly used in a household

Fruit for eating or juicing is the main product from citrus grown in a landscape. Other products include leaves for cooking (e.g., Kaffir lime leaves in Thai food) and cut flowers for fragrant flower arrangements.

Light requirements

Most citrus species require full sunlight to grow well and produce fruit. Shading greatly decreases plant vigor and productivity.

Water/soil requirements

Adequate soil moisture is very important for quality fruit production. Dry conditions can mean smaller fruit, premature fruit drop, and dry and grainy fruit. Consistent, but not too frequent, irrigation may be necessary for optimal health and productivity. Mulching can help keep the soil moist by reducing evaporation of soil moisture. Most rootstocks generally do poorly on soils excessively high in organic matter (Histosols).

In areas with shallow, poorly drained soils, good site preparation can allow citrus to be successfully grown. Use of either drain tiles under the tree that lead to a holding pond or bedding (mounding of surrounding soil on top of existing soil where tree is to be planted) can allow trees to grow.

Life span

Trees growing on favorable soils that are well maintained (watered and fertilized regularly) can last 30 years before they lose some of the full beauty of the foliage.

Varieties favored for use in a homegardens or for street trees

Sweet Orange: 'Navel', 'Parson Brown', 'Pineapple', 'Sunstar', 'Gardner', 'Midsweet', 'Valencia'.

Grapefruit: 'Duncan', 'Marsh', 'Redblush', 'Thompson', 'Flame', 'Ray Ruby'.

Specialty: 'Satsuma', 'Robinson', 'Fallglo', 'Sunburst', 'Orlando', 'Dancy', 'Minneola', 'Temple', 'Murcott', 'Kumquat'.

Seasonality of leaf flush, flowering, fruiting

In tropical climates, flowering and fruiting can occur nearly year round. A main flowering tends to occur in the spring.

Use as living fence, hedge, or visual/noise barrier

Citrus can be used as a barrier hedge when trees are planted close together. Many varieties are spiny, which can enhance the effect of a hedge as a barrier. However, when hedged it takes time for trees to regrow full foliage, and if the trees do not receive ample sunlight, the regrowth occurs primarily in the tops, leaving the trunks exposed.

Bird/bee/wildlife

Citrus supports bees, which produce honey. Birds often build nests within the canopy, and some will feed on the seeds, fruit, or the insects that feed on tree foliage. Snakes, where present, are commonly found within the canopies.

Maintenance requirements

Once the tree has reached the desired height, annual pruning may be required to maintain the height, thin the growth, and promote prolific fruiting. Most fruit is set on wood that is less than 2 years old. Pruning is least damaging to tree yields when done on a regular basis to wood (branches) on the outside of the canopy. Wood can and should be removed if the section has died or has begun to decay.

Special considerations regarding leaf, branch and fruit drop

If the fruit is not harvested, it will fall off the tree, rot, attract fruit flies, and produce slightly offensive odors. Trees with heavy fruit crops are susceptible to breakage in high winds. Tangerines are particularly susceptible to breakage and splitting in windstorms.

Nuisance issues: Poisonous parts, thorns/spines, foul smell

Some species (e.g., limes) have many thorns. Sweet orange trees produced from seed will have fewer thorns as they

Left: Citrus' surface roots can easily be exposed by erosion, especially on rocky soils. Right: Fallen fruit should be removed to avoid attracting and fostering pests. PHOTOS: C. ELEVITCH

WHEN TO HARVEST FRUIT

Although it is commonly thought that citrus should be picked after turning color, this is not necessarily true, especially in tropical climates. Many types of citrus fruits, such as grapefruits and mandarins, do not fully turn color when ripe, and commercial producers use special treatments to induce full color break to make the fruit more appealing to consumers. In other words, skin color is a poor indicator of ripeness. Also, waiting for the skin to fully turn color also can greatly increase fruit fly damage. The best way to check for ripeness is by tasting a fruit or two that appear to be fully developed.

mature.

Common pest problems

Climates that receive moderate to high rainfall, temperatures, and humidity will experience more insect, weed, and disease pressure. Regardless of the pest management program (IPM, organic, or conventional) the success of the program will be greatly influenced by selecting the proper variety (Inserra et al. 2003).

As with any plant, keeping citrus healthy and vigorous will reduce the effects of insects and diseases in two ways, making them less likely to be infested as well as more able to withstand the pest. This includes

- Fertilize plants on a regular schedule
- Keep weeds under control
- Prune to maintain vigor
- Increase air and light penetration
- Remove any diseased wood
- Provide an adequate and consistent supply of water
- Do not irrigate too frequently to avoid disease infestation
- Observe trees for signs of insects, disease, or other problems

Several species of mites, scales, aphids, mealybugs, and fruit flies are common pests of citrus. Diseases of citrus that are often found are root rot, gummosis, melanose, greasy spot, scab, black spot, and citrus canker. Nematodes and viruses also cause several diseases of citrus.

See "Susceptibility to pests/pathogens" above for more information.

COMMERCIAL PRODUCTS

The fruits and juice of all citrus are a local cash crop on all Pacific islands. Lime, lemon, grapefruit, mandarin, and sweet orange have been export crops for a number of Pacific islands.

Spacing for commercial production

Tree spacing for areas with greater soil depth will be wider than for areas with shallow soil depth. Likewise, trees with more vigorous rootstocks should be spaced further apart than trees with less vigorous rootstocks. A common range for tree spacing is 6–7.5 m (20–25 ft) between rows and 3–4.5 m (10–15 ft) within rows. Use wider spacing for more vigorous trees (see, e.g., Tucker et al. 1994b).

Management objectives

Pruning should be done when trees are young to establish the basic shape and continued as trees mature. In commercial orchards, pruning facilitates normal daily operations and increases yields. Where trees have outgrown their allotted space, pruning can increase the bearing surface. Trees that grow too close together will shade out the lower canopy portions and in return decrease fruit set. When pruned to allow light to reach the top and lower sides of tree, the increased bearing surface results in greater fruit set. Any sprouts arising from the rootstock (i.e., from below the graft union) should be removed. Pruning of the scion of young trees will only delay growth and extend the juvenility.

Pruning is conducted to either encourage growth (thinning) or reduce tree size (heading back). Thinning of bearing trees encourages vegetative growth, and removal of interior branches can encourage the outward growth into the allotted area planned for the mature tree to occupy. Heading back reduces the outward canopy growth through top-

There is no shortage of exciting citrus varieties to try. Here, Tahitian pompelmous is displayed as a new commercial crop in Kona, Hawai'i. PHOTO: C. ELEVITCH ping and hedging of branches.

Pruning can have negative effects on bearing. When wood is removed, carbohydrates and nitrogen are removed from the tree, upsetting the natural balance. Withholding fertilization before pruning can reduce excessive flushing by ensuring that more carbohydrates are present in the tree than nitrogen. Pruning deadwood is not the same as pruning viable shoots, as there are no carbohydrates or nitrogen available in deadwood. Thus, it is not necessary to withhold fertilizer when deadwood pruning is planned. Further information should be sought before conducting pruning (see, e.g., Tucker et al. 1994a).

Fertilizers containing N and K are best applied in small applications several times over the course of the year rather than all at once and best placed in holes dug around the drip line of the canopy of the trees. If feasible, monthly foliar applications of micronutrients is helpful. Overuse of high-nitrogen fertilizers will encourage a proliferation of piercing-sucking insects, including aphids, scales, and mealybugs, and will foster sooty mold. The most effective fertilization strategy is developed by first testing the soil of the planting site.

Alternately or in addition to inorganic fertilizers, well composted manures or other organic fertilizers can be added to the planting hole and spread around the base of the tree occasionally. Citrus responds very well to additions of organic matter. Compost, composted manures (such as composted steer manure mixed in the planting hole with the soil at planting) combined with regular irrigation during the first 3 months will ensure vigorous plant growth in the first year.

Trees benefit greatly from mulching, which slowly adds organic matter to the soil, helps retain soil moisture, and suppresses weeds. However, deep mulch should be kept from directly contacting the trunk.

Design considerations

The desired eating quality of fruits must be considered when planting. For example some varieties ('Nova', 'Clementine', 'Aflourer', etc.) must be planted in solid blocks of one variety to produce seedless fruit. If other citrus is nearby, cross pollination will occur and produce seedy

Top: Selecting the proper tree spacing and rootstock to match the environmental conditions can reduce pruning requirements and fruit yield fluctuations. PHOTO: R. BUKER **Bottom: Deadwood such as at the top of this grapefruit tree should be removed.** PHOTO: C. ELEVITCH fruit.

Estimated yields

In any given year, yields of well fertilized and watered mature trees are typically between 41 and 184 kg (90–400 lb) per tree. As trees increase in age, the typical yield should also increase. Once the canopy is fully developed, yields stabilize. In Florida, typical commercial yields for early and mid-season maturing varieties ('Hamlin', 'Parson Brown', 'Pineapple', 'Early Gold', etc.) are 182 kg/tree (400 lb/tree), Navel and Valencia oranges 125 kg/tree (275 lb/tree), white grapefruit 204 kg/tree (450 lb/tree), and red grapefruit 185 kg/tree (410 lb/tree). These yields represent collective averages over the 4 years 2000–2004 in Florida.

On-farm processing

The best method of preventing fruit decay is to selectively harvest and pack fruit. Once decaying fruit has been removed, water can be used to sanitize the fruit. Water above 71°C (160°F) or an approved sanitizing agent (e.g., chlorine, peroxyacetic acid, etc.) can be used to treat equipment that is used to store fruit. Cleaned fruit should be kept in a very cool (not freezing) location until utilized.

Citrus exports from the Pacific islands

In contrast to the mainland United States and other countries, the Pacific islands are small producers and exporters of citrus fruit and products. Consequently, statistical data on the export of citrus and citrus products from the Pacific islands are often unavailable, non-existent, or highly variable from one year to the next, and from one database to the next. Appendix C is a compilation of recent citrus fruit and products export for some Pacific islands.

INTERPLANTING/FARM APPLICATIONS

Example system

Location

Kona, Hawai'i

Description

Small-scale farmers growing coffee frequently interplant fields with citrus, banana, avocado, mango, and other fruit trees. The fruit trees are usually grown along boundaries and in marginal areas where coffee picking and tree maintenance are inconvenient. Citrus trees grown include pummelo, tangerine, sweet orange, lemon, lime, and calamondin.

Yields/Benefits

The citrus trees provide fruit for households, without reducing coffee yields significantly.

Crop/tree interactions

The citrus trees provide heavy shade in their immediate vicinity, but because there are few trees per unit area, coffee yields are not greatly affected. In hotter, drier areas, the citrus may even benefit the coffee by moderating temperatures.

Spacing

There is no fixed spacing, but there may be 5–10 citrus trees per farm, mostly planted along boundaries and near homes.

Citrus trees such as this calamondin are commonly interplanted with coffee in Kona, Hawai'i. PHOTO: C. ELEVITCH

Fortunella species (kumquat)

Kumquat (*Fortunella* spp.) is an evergreen shrub or small tree. The fruits are eaten out of hand, used as decorations, or preserved in syrups and marmalades. The trees thrive in the subtropics, but can tolerate freezing and subfreezing periods, remaining dormant for some time following the cold shock. Resembling tiny oranges, kumquat fruits are distinguished from *Citrus* spp. primarily by their soft, thin, edible peel and by their small number of segments, usually three to five. The peel is sweet, and the flesh is sour; the combined flavors provide a pleasant dessert at meal's end.

Distribution

Native range

Native to South East China and tropical Malaysia, the kumquat (kam kwat in Cantonese) was honored by royalty and peasants alike.

Current distribution

Kumquat was included in the genus *Citrus* until about 1915, when Dr. Walter Swingle reclassified six species to the genus *Fortunella*. This new genus honored Robert Fortune, who journeyed extensively in China and introduced over 120 species of plants to western gardens (see bio for Fortune below). The kumquat was also described on a list of plants in Japan in 1712, noted in Europe and North America since the mid 19th century, and in Hawai'i before the 1880s. It is also cultivated in Central and South America, South Africa, South India, and Australia.

Botanical description

Genus *Fortunella* (Swingle)
Family Rutaceae
Subfamily Aurantoideae

Preferred scientific names/varietal names

F. hindsii (Swingle)

'Hong Kong Wild', 'Golden Orange', 'Golden Bean', chin chu (Mandarin), shan chin can, chin tou, kam quat (Cantonese)

'Hong Kong' grows wild in Hong Kong, Kwantung, and Chekiang provinces of China, fruiting during the winter months. The small fruits are the size of a pea, 2 cm (½–¾ in), bright or scarlet orange, nearly round, with pulp in 3–4 segments. The flowers are white, short and broad, and do not open as widely as others in the genus. The tree has oval leaves with winged petioles, and the profuse thorns on the branches are longer than the fruit itself.

Flowers of *F. crassifolia*, variety 'Meiwa'. PHOTO: D. WARD

F. japonica (Thunb.) Swingle (syn. *Citrus japonica* Thunb., *C. madurensis* Lour.)

'Marumi'

'Marumi' is a round, golden-yellow fruit about 2.5 cm (1 in) in diameter, with thin waxy skin, aromatic and spicy, with large oil glands. The fruits have acid-sweet, juicy flesh, with pulp in 4–7 segments, and 1–3 seeds. The trees are slightly thorny and cold-tolerant.

F. crassifolia (Lour.) Swingle (syn. *Citrus margarita* Lour.)

'Meiwa'

'Meiwa' has the largest and sweetest fruits of the kumquats. Oblong to round, 3.2 cm (1.75 in) long, the fruits are sometimes seedless or with few seeds, and little juice, while the peel is orange-yellow, sweet, tender, fleshy, and edible. Some have postulated that 'Meiwa' is a cross between *F. margarita* and *F. japonica.*

F. margarita (Swingle)

'Nagami'

'Nagami' is widely grown as an ornamental tree. The prolific fruit are 4 cm (1.6 in) long and 2 cm (0.8 in) in diameter, with an orange-colored rind when ripe, slightly sweet peel with a bitter aftertaste, and juicy acid pulp.

F. polyandra **(Ridl.) Tanaka**

limau pagar, hedge lime grown in Malaysia

Limau pagar is native to tropical Malaysia and southern China, is larger than other kumquats, and may in fact be a limequat. It has a deep golden-orange peel, which is extremely sour, and flame-colored, seedy flesh.

Description

Kumquats are slow-growing, shrubby, compact evergreen trees, 2.5–4.5 m (8–15 ft) tall, and rarely exceeding 3 m (10 ft) in height. The kumquat scion wood is grafted to rootstock such as *Poncirus trifoliata*, citrange C-35, or citrange 'Carrizo'; the ultimate size of the tree is largely dependent on the rootstock selected. The flowers are white, fragrant, five-parted, and borne one to five in leaf axils. The branches are light-green, angled, thorny, thornless or with a few spines, depending on cultivar. Leaves are simple, alternate, lanceolate, pointed at tips, 3.3–8.6 cm (1.3–3.4 in) long, finely toothed from the apex to the middle, dark green above, lighter green below, petioles sometimes winged.

The fruit is round or oval-oblong, 1.6–4 cm (0.6–1.6 in) wide, and ripens slowly on the tree, changing from green

Left: 'Meiwa' fruit and tree. Right: 'Nagami' fruit and tree. PHOTOS: D. WARD to brilliant orange, yellow, or scarlet, depending on the cultivar. The peel is golden-yellow to reddish-orange, with large, conspicuous oil glands; rinds are thin to thick, waxy, edible, and acid to sweet in taste. The pulp is acid to subacid with three to eight segments and up to eight seeds and is more tart than the skin.

Climate

The kumquat is the most cold-resistant of the citruses and becomes dormant when temperatures fall below freezing, remaining dormant without shoots or blossoms for some time after warmer weather returns. Many cultivars are hardy to –7°C (20°F), but all grow faster and bear more fruit in warm climates. 'Nagami' requires a hot summer, (27–38°C [80–100°F]), but can withstand frost down to –8––6°C (18–21°F) without injury. In warm climates, trees may produce several crops during the year, but most fruiting occurs from fall to spring.

Propagation

Rootstock

The trees are rarely grown from seed. In China, Japan, northern Florida and California ~~are~~ they are grafted onto the trifoliate orange (*Poncirus trifoliata*). In southern Florida, scion is grafted onto sour orange and grapefruit. In Hawai'i, kumquats are grafted onto 'Carrizo' (a Washington navel × trifoliate orange hybrid) or onto citrange hybrid C–35 (Ruby orange × trifoliate orange) because of their resistance to citrus nematode, *Phytophthora* spp. and the tristeza virus.

Culture

Set out 2.4–3.6 m (8–12 ft) apart, or spaced at 1.5 m (5 ft) in hedged rows 3.6 m (12 ft) apart. The tree is frequently grown in a container, such as a 15-gallon pot, as a specimen plant. In colder climates, the container is brought indoors when temperatures drop below freezing.

Harvesting

Fruits are harvested when they reach full color (either orange or green-orange, depending on the variety) with two or three leaves attached to the stem to enhance keeping quality.

Pests and diseases

Kumquat is highly resistant to citrus canker, but several diseases have been observed, such as scab, algal leaf spot, greasy spot, anthracnose, fruit rot, stem-end rot and gummosis. Insect pests include fruit fly, citrus swallowtail larvae, aphid, and mealybug. Because the trees are susceptible to tristeza virus, they are grown on virus-resistant rootstock.

Food uses

The fruit is eaten out-of-hand whole when ripe (especially 'Meiwa'), preserved whole in sugar syrup, canned, candied, or sugared. The fruit is also made into marmalade by itself or mixed half-and-half with calamondins, and it is pickled or incorporated into sauces.

Urban and community forestry

Kumquat cultivars have long been a favorite in the urban environment. They are small, compact trees without competitive roots systems and are tolerant of hot, humid summers and cold winters. Full sun is best for growth and vigor, but they can tolerate semi-shade. They can be pruned into a hedge, and the brightly colored fruits are highly attractive in the landscape. They also can do very well when grown in pots. If not harvested, fruits will drop and require removal to reduce infestation by fruit fly. Cultivars 'Nagami' and 'Meiwa' are preferred, as they are the most ornamental in the landscape.

ROBERT FORTUNE

Robert Fortune (1812–1880) was a Scotsman sent by the British Horticultural Society to collect an assortment of curiosities in China. He became proficient in the Mandarin language and managed to disguise himself as peasant "Sing Wah" so well that he was able to travel to forbidden places unchallenged. Master of industrial espionage, Fortune made four trips to China and one to Japan and smuggled China's highly coveted tea cultivars and growing techniques to the Indian Himalayas, thereby diminishing China's lucrative monopoly. He kept careful journals of his collections and observations and is credited with introducing the art of bonsai to the Western world. His successful use of terraria led to the successful introduction of 120 species, including kumquat, to England in 1846. Introduced to Florida in 1855, the genus of thin, edible-rinded fruits was named *Fortunella* by Dr. Walter Swingle in 1915, to recognize the exploits and contributions of the intrepid plant explorer.

PUBLIC ASSISTANCE AND AGROFORESTRY EXTENSION

College of Tropical Agriculture and Human Resources
University of Hawai'i at Mānoa
Cooperative Extension Service
3050 Maile Way, Gilmore 203
Honolulu, Hawaii 96822
Tel: 808-956-8139; Fax: 808-956-9105
E-mail: extension@ctahr.hawaii.edu
Web: <http://www.ctahr.hawaii.edu/ctahr2001/Extension>.

University of Florida
Citrus Research and Education Center
700 Experiment Station Road
Lake Alfred FL, 33850
Tel: 863-956-1151; Fax: 863-956-4631

Extension offices for agroforestry and forestry in the Pacific: <http://www.traditionaltree.org/extension.html>.

GENETIC RESOURCES

Bureau of Citrus Budwood Registration
Division of Plant Industry
3027 Lake Alfred Road
Winter Haven, Florida 33881
Tel: 863-298-7712; Fax: 863-298-7738
Web: <http://www.doacs.state.fl.us/budwood>

USDA-ARS National Clonal Germplasm Repository for Citrus and Dates
1060 Martin Luther King Blvd.
Riverside, CA 92507
Tel: 951-827-4399; Fax: 951-827-4398
Web: <http://www.ars-grin.gov/ars/PacWest/Riverside/homepg1.htm>

INTERNET

Electronic Data Information Source of the University of Florida, Institute of Food and Agricultural Sciences (UF/IFAS) <http://edis.ifas.ufl.edu>.

Citrus Nutrition and Fertilization (University of Florida) <http://edis.ifas.ufl.edu/TOPIC_Citrus_Nutrition_and_Fertilization>.

Citrus Research & Education Center's Florida Citrus Pest Management Guide <http://www.crec.ifas.ufl.edu/CRECHOME/groweraids.htm>.

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Appendix A. Selected fruit and leaf characteristics of *Citrus* spp. (Castle and Gmitter 1999)

Fruit

Species	Size (diam)	Shape	Peel color and other	Pulp Color	Juice
C. aurantifolia (lime)	4–6 cm (1.6–2.4 in)	Globose to ovoid	Green, greenish yellow	Green	Very sour
C. aurantium (sour orange)	5 cm (2 in)	Subglobose, sl. oblate	Greenish yellow to scarlet red	Orange	Very sour
C. grandis (pummelo)	9–25 cm (3.5–10 in)	Subglobose, globose, oblate-globose to pyriform	Pale green to pale yellow	Pale green to pinkish	Scanty, mildly acid to mildly sweet or insipid
C. hystrix (Kaffir lime)	7 cm (2.8 in)	Subglobose to oblate-globose or ellipsoid	Green to yellow, very bumpy, glandular, bitter	Greenish	Acid, bitter
C. limon (lemon)	4–7 cm (1.6–2.8 in)	Ovoid, mammillate	Light to deeply yellow	Pale greenish to yellowish	Sour
C. macroptera (wild orange)	6–7 cm (2.4–2.8 in)	Subglobose, somewhat contracted at base	Pale dull yellow, fairly smooth, moderately thick pericarp	Greenish yellow, dry	Acid and bitter
C. medica (citron)	8–10 cm (3.1–4 in)	Ovoid to oblong	Yellow to green, rough tuberculate, thick	Pale, greenish	Acid to mildly acid
C. paradisi (grapefruit)	15 cm (5 in)	Globose or oblate	Yellow	Pale yellow green	Copious, acidic to faintly bitter
C. reticulata (mandarin)	6 cm (2.4 in)	Oblate-globose to depressed-subconcave globose	Orange, greenish orange, thin	Pale to rich orange	Mild to sweet
C. sinensis (sweet orange)	8–10 cm (3.1–4 in)	Subglobose to sl. oblate	Greenish yellow to bright orange	Orange	Mildly sweet to sweet

Leaf

Species	Size (length)	Shape	Petiole
C. aurantifolia (lime)	5–7.5 cm (2–3 in)	Elliptic to oblong ovate	Spatulate, narrowly winged
C. aurantium (sour orange)	10 cm (4 in)	Ovate, apex obtusely acute, base cuneaaate to rounded, margins sl. undulate to subcrenate	2–3 cm long, wing spathulate, 5–15 mm broad
C. grandis (pummelo)	11–13 cm (4.3–5.1 in)	Ovate to elliptic,	Broad, obcordately winged, with wings ¼ to ⅓ the length of the leaf
C. hystrix (Kaffir lime)	4–5 cm (1.6–2 in)	Broadly ovate to ovate-oblong	Broadly winged and the same size as the blade
C. limon (lemon)	7–9 cm (2.8–3.5 in)	Ovate , narrow, margin subserrate to serrate-crenulate	Narrowly winged to merely marginate
C. macroptera (wild orange)	10 cm (4 in)	Broadly ovate–lancelolate	Winged obovate to broadly subspathulate, as large as the blade
C. medica (citron)	6–7 cm (2.4–2.8 in)	Elliptic-ovate to ovate-lanceolate, obtuse to rounded, serrate-crenate margins	Short, wingless, not clearly articulated
C. paradisi (grapefruit)	9–18 cm (3.5–7 in)	Ovate to elliptic, smaller than *C. grandis*	Obovate-oblanceolate, narrower petiole wing
C. reticulata (mandarin)	8 cm (3.1 in)	Rhombic, acute, lanceolate to broadly lanceolate, margins irregularly crenate or crenulate	Short, wingless to sl. marginate.
C. sinensis (sweet orange)	10 cm (4 in)	Elliptic to ovate, margins undulate to crenate	Short, 1/5 the length of the leaf blade

APPENDIX B. Attributes of selected citrus scion cultivars and cultivar groups

(key: F–fresh fruit use, P–pulp use, E–early season, M–mid-season, L–late season)

Variety	Production areas	Use	Season	Advantages	Disadvantages
Sweet oranges					
Navel oranges Washington (Bahia), Bahianinha, Navelate, Navelina, Newhall, Leng, Lane Late, and others	Argentina, Australia, Morocco, South Africa, Spain, U.S. (California), Uruguay	F	E–L	Large fruit; seedless; fairly easy to peel; season of maturity of various clones ranges from early to late	Low yield; specific climatic conditions required for best quality; processed juice is bitter from limonin content
Common oranges					
Ambersweet	U.S. (Florida)	P, F	E	Excellent color; early maturity; easy to peel	Poor performance as young trees; demanding cultural requirements
Hamlin	U.S. (Florida), Brazil	P	E	Productive tree; early maturity; few seeds	Poor color; fair flavor
Jincheng	China	F, P	M	Good yield, color, and quality; stores well	Oval shape creates problems for mechanized grading
Natal	Brazil	P	L	The latest-maturing cultivar in Brazil	Freeze damage to fruit in colder regions
Pera	Brazil	P	M	Productive tree (in Brazil)	Fair quality; seedy; prone to set multiple crops
Pineapple	U.S. (Florida)	P	M	Productive tree; good color and flavor	Alternate bearing; seedy; cold-sensitive when heavily cropped
Shamouti	Israel, Cyprus, Turkey	F	M	Easy to peel; seedless; distinctive flavor; good storage capability	Thick rind of coarse appearance; low juice content; juice is bitter from limonin
Valencia	U.S. (California, Florida), Australia, Argentina, Brazil, Morocco, South Africa, Uruguay	P, F	L	Excellent color and juice quality; few seeds; late maturity	Lower yield potential; freeze damage to fruit in colder regions
Xuegan	China	F, P	M	Large fruit with good quality; stores well	Thick peel
Acidless oranges Succari, Lima, Anliucheng, and others	North Africa, Middle East, Brazil, China	F	E–M	Acceptable fruit for consumers intolerant of acid.	Unsuitable for processing
Blood oranges Doble Fina, Maltaise Sanguine, Sanguinelli, Moro, Tarocco, and others	Mediterranean region	F, P	M–L	Unique flavor and appearance	Specific climatic conditions required for optimum quality

Variety	Production areas	Use	Season	Advantages	Disadvantages
Grapefruit					
White grapefruit					
Duncan	U.S. (Florida)	P	M–L	Productive, vigorous tree; large fruit; excellent quality	Excessively seedy
Marsh	U.S. (Florida), Cuba, South Africa	F, P	E–L	Productive, vigorous tree; nearly seedless; good quality	Flavor less intense than that of Duncan
Oroblanco (Sweetie)	Israel, U.S. (California)	F	E–M	Seedless; high sugar content and low acidity allow production of good-quality fruit in cool areas and allow earlier harvest	Thick rind and open core, atypical of grapefruit; yields lower than yields of Marsh have been reported
Pigmented grapefruit					
Flame	U.S. (Florida)	F	E–M	Good flesh color in early and mid-season; good flavor and texture; nearly seedless	Color fades in late season; little commercial experience
Redblush (Ruby Red)	U.S. (Florida), Cuba, South Africa	F	E–M	Healthy, productive tree; nearly seedless; good quality; attractive peel blush	Less colorful flesh than more recently released cultivars
Rio Red	U.S. (Texas)	F	E–M	Good flesh color; healthy, productive tree; nearly seedless	Little commercial experience
Star Ruby	U.S. (Texas, Florida), South Africa	F	E–M	Most intensely pigmented flesh and rind; seedless; retains color late in the season; thin rind	Weak, unthrifty trees; great susceptibility to *Phytophthora*, herbicide injury, storage rots, and cold
Mandarins and their hybrids					
Clementine (Oroval, Fina, Nules, and many other clones)	Spain, Morocco	F	E–M	Easy to peel; seedless when grown in isolated blocks; good flavor	Small fruit, seedy with cross-pollination
Dancy	U.S. (Florida)	F	M	Vigorous tree; good color and flavor; easy to peel	Alternate bearing; seedy; difficult to harvest; susceptible to *Alternaria*
Ellendale	Australia, Argentina, Uruguay	F	M	Large fruit with good color and flavor; easy to peel; nearly seedless in solid blocks	Prone to splitting of fruit and tree; high acidity; seedy with cross-pollination
Fairchild	U.S. (California, Arizona)	F	E	Attractive appearance; adaptable to arid production areas	Small fruit; seedy; rind is oily and difficult to remove
Fortune	Spain	F	L	Productive tree; attractive fruit, with good color and flavor; later maturity than most mandarins	Rind prone to pitting; susceptible to *Alternaria*; seedy with cross-pollination; high acidity
Imperial	Australia	F	E	Very early maturity; easy to peel	Alternate bearing; fair flavor
Kinnow	Pakistan, India	F, P	L	Very high sugar content; juicy; vigorous tree	Seedy; alternate bearing
Mediterranean (Willowleaf, Baladi, Avana, and others)	Italy, Portugal	F	M–L	Easy to peel, unique flavor and aroma; cold-tolerant	Small fruit with seeds; poor storage and shipping capability; alternate bearing

Variety	Production areas	Use	Season	Advantages	Disadvantages
Minneola	U.S. (Florida), Israel, South Africa, Argentina	F	M	Large fruit with distinctive shape, excellent color, and rich flavor; vigorous, productive tree	Susceptible to *Alternaria*; seedy with cross-pollination
Murcott (Smith, Honey tangerine)	U.S. (Florida), Brazil, Israel, Australia	F, P	M–L	Excellent flavor and flesh color; productive, cold-hardy tree	Seedy; alternate bearing; susceptible to scab and *Alternaria*; terminal bearing habit
Orlando	U.S. (Florida)	F, P	M	Vigorous tree; cold-hardy	Difficult to peel; pale flesh and juice; low acidity; seedy
Ortanique	Jamaica, Israel, South Africa, Australia, Cyprus	F	L	Large, attractive fruit with good color and flavor; stores well; juicy; very late maturity; productive tree	Rind is oily and difficult to remove; seedy with cross-pollination
Ponkan (Nagpur suntara, Batangas, Warnurco)	China, India, Japan, Philippines, Brazil	F	M	Large fruit; very easy to peel; crisp flesh texture; productive tree	Rind becomes puffy; difficult to harvest, ship, and store; seedy; alternate bearing
Robinson	U.S. (Florida)	F	E	Very early maturity; good color; cold-hardy tree	Seedy; difficult to peel; susceptible to twig and limb dieback
Satsuma (Owari, Miyagawa, Okitsu, Clausellina, and many other clones)	China, Japan, Spain, Turkey, Korea, Argentina, Uruguay, U.S. (California), South Africa	F, P	E–M	The most cold-hardy tree among the edible citrus cultivars; easy to peel; seedless; tolerant of citrus canker	Poor fruit quality in humid subtropics; rind puffiness shortly after maturity
Sunburst	U.S. (Florida)	F	M	Very attractive fruit with excellent color	Susceptible to mite damage; seedy; difficult to peel
Temple	U.S. (Florida)	F, P	M–L	Unique flavor; attractive external color and appearance	Susceptible to cold and citrus scab; seedy; fruit acidity

APPENDIX C. Kumquat varieties and hybrids

Kumquat varieties

Botanical name	Variety	Other names	Locale	Fruit size	Ripe color	Skin/Peel
F. hindsii (Champ) Swingle	'Hong Kong Wild'	chin chu, shan chin can, chin tou (Mandarin), kam quat (Cantonese), Golden Bean, Golden Orange	Hong Kong, Kwantung, Chekiang Provinces	nearly round, 2 cm (0.8 in)	orange to scarlet	thin, not fleshy
F. japonica (Thunb.) Swingle (syn *Citrus japonica* Thunb., *C. madurensis*, Lour.)	'Marumi'		introduced to USA from Japan	round, 2.5 cm (1 in)	golden-yellow	smooth, large oil glands, thin, aromatic and spicy
F. crassifolia Swingle	'Meiwa'	ninpo, neiha kinkan, kinkit (Japan)	Chekiang province, China, and Fukuoka province, Japan	short-oblong to round, 4 cm (1.6 in)	orange-yellow	very thick, sweet
F. margarita (Lour.) Swingle	'Nagami'	too kin kan (Japan)	China	4.5 cm (1.8 in) long and 3 cm (1.2 in) wide	yellow to bright orange	thin, slightly sweet
F. polyandra (Ridl.) Tanaka	'Limau pagar'	Malayan kumquat, hedge lime	southern China, tropical Malaysia	large compared to other kumquats	deep golden-orange	extremely sour
F. swinglei Tanaka	'Swingle's kumquat'					
F. obovata hort ex. Tanaka	'Chang Shou'	longevity kumquat				

Fortunella × (Kumquat hybrids)

Botanical name	Common name	Varietal name	Fruit size	Ripe color	Skin/Peel	Pulp
× *Citrofortunella* spp. or F × *Citrus aurantifolia* (Christm.) Swingle	limequat	Mexican lime × kumquat hybrids		light yellow	resembles lime when immature	sweet, juicy
× *C. floridana* J. Ingram & H.E. Moore	limequat	'Eustis'	oval or round 2.8–4 cm (1.1–1.6 in) wide	pale yellow	smooth, glossy, prominent oil glands, thin, edible	light green, tender, juicy, very acid
× *C. floridana* J. Ingram & H.E. Moore (different seed)	limequat	'Lakeland'	oval 4.5–7 cm (1.8–2.8 in) wide	bright yellow	smooth, thin	juicy, pleasantly acid
× *C.* Swinglei J. Ingram & H.E. Moore	limequat	'Tavares'	obovate to oval 3.2–4.75 cm 1.3–1.9 in) wide	pale orange-yellow	smooth, thin, tender edible	buff-yellow, juicy, very acid
× *C. reticulata* or *C. unshiu* (Mak.) Marc. × (*F. japonica* × *F. margarita* 'Meiwa')	orangequat		larger than kumquats	deep orange		juicy, deep orange
× *C. limon* (L.) Burm.	lemonquat					
Citrus × 'Meyer' × *F. margarita* 'Nagami'	lemonquat					
× citrange	citrangequat	'Thomasville'	resembles oval kumquat		edible	very juicy, acid
× *Poncirus trifoliata* (L.) Raf.	citrumquat					
Limequat × *F. hindsii* (Champ.) Swing.	procimequat					
× *Citrus reticulata*	kumandarin					
Citrus × yuzu × *F. margarita* 'Nagami'	yuzuquat				edible	very acid
F. margarita sic (*crassifolia*) 'Nagami' × *F. margarita* 'Meiwa'	nameiwa, ten-degree kumquat					

Pulp	Segments	Seed	Tree /Shrub	Thorns	Leaves	Climate	Comments
	3–4	plump seeds	tender shrub, grown in West as ornamental pot plant	very thorny		bring indoors below 0°C (32°F)	
scant, acid	4–7	1–3 small seeds	reaches 2.75 m (9 ft), very cold tolerant	slightly thorny	small leaves, upright open habit	more cold-tolerant than Nagami; if acclimated, hardy to –7°C (20°F)	
sweet or subacid	7	seedless or few seeds	dwarf or small tree, ornamental form has variegated fruits	frequently thornless or with short, stout spines	very thick, rigid, partly folded, pitted with oil glands	if acclimated, hardy to –7°C (20°F)	best for eating out of hand, introduced to USA from Japan, possibly a 'Nagami' and 'Marumi' cross
acidic, little juice, acidic aftertaste	4–5	2–5 seeds	vigorous tree, reaches 4.5 m (15 ft)		small dark green leaves, fine branches	cold tolerant; if acclimated, hardy to –7°C (20°F)	most popular variety in Florida
flame colored flesh		up to 8 seeds	tender shrub, resembles lime			resembles lime, more cold tolerant, indoors below 0°C (32°F)	could be a limequat
			tender shrub			bring indoors below 0°C (32°F)	
			shrub			cold tolerant; hardy to –7°C (20°F)	

Segments	Seed	Tree	Thorns	Leaves	Flowers	Climate
		small compact tree		single leaflets, petioles narrowly wingled		more cold tolerant than lime, but not as cold hardy as kumquat, very resistant to withertip
6–9	5–12 small	everbearing, fall to winter	small spines		pure white, prolific	cold tolerant; if acclimated, hardy to –7°C (20°F)
5–8	2–9 large		nearly spineless		white with pink streaks	
7–8	6–11 large	vigorous	short spines		pink flower buds	
						if acclimated, hardy to –12°C (10°F)
	seedy	shrub, vigorous, erect, very ornamental	thorny or thornless	trifoliate		highly cold-resistant, if acclimated hardy to –9°C (15°F)
		shrub				if acclimated, hardy to –12°C (10°F)
		shrub		dark, glossy leaves with undulating margin		extremely cold-hardy; if acclimated, hardy to –12°C (10°F)

APPENDIX C. **Major pacific island exports of citrus fruit and citrus products for 2003 (unless otherwise specified).**

	Fiji		French Polynesia		New Caledonia		Samoa		Vanuatu (1990)	
Commodity (UN Code)	**Value (1000)**	**Kg (1000)**	**Value (1000)**	**Kg (1000)**	**Value (1000)**	**Kg (1000)**	**Value (1000)**	**Kg (1000)**	**Value (1000)**	**Kg (1000)**
Citrus fruit, fresh or dried (0805)	$72	585	$1,187[6]	60[6]	$31,829	21,565	$320,313	132,235		
Oranges, fresh or dried (080510)	$2,491[4]	2,701[4]					$671	546		
Mandarin, clementine & citrus hybrids, fresh or dried (080520)	$10[6]	21[6]			$28	0				
Grapefruit, fresh or dried (080540)			$651[3]	109[3]	$18	1			$115[2]	40[2]
Lemons and limes, fresh or dried (080530)	$3	488			$31,783	21,534	$40[5]	109[5]		
Citrus fruits, otherwise prepared or preserved (200830)	$5	3								
Orange juice, frozen (200911)	$19,343	21,000					$1,010			
Orange juice (0591)									$137[1]	117[1]
Orange juice, not frozen, fermented, or spirited (2 00919)	$35,367	17,922	$38,100	21,316		20,919	$334	50		
Grapefruit juice, not fermented or spirited (200920)	$68	85	$12,061	6,772			$12,330[6]	9,812[6]		
Citrus juice nes (one fruit) not fermented or spirited (200930)	$19,840	3,792					$1,634,130	179,945		
Essential oils of bergamot (330111)	$587[4]	41[4]					$1,168	13		
Essential oils of citrus fruits (330119)	$2,474	425					$501	1		
Citrus based jams jellies marmalade, etc. (200791)	$580	56	$191	60	$1,243[6]	0[6]	$1,252	716		
Citrus fruits, otherwise prepared or preserved (200830)	$5	3					$4,209[6]	1,460[6]		

[1] Data for 1990; [2] Data for 1993; [3] Data for 1997; [4] Data for 2000; [5] Data for 2001; [6] Data for 2001.

Source: UN Commodity Trade Statistics Database (UN Comtrade). <http://unstats.un.org/unsd/comtrade/>.

Species Profiles for Pacific Island Agroforestry (www.traditionaltree.org)

Citrus species (citrus)

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Acknowledgments: The authors and publisher thank Dale Evans, Heidi Johansen, Ken Love, Ty McDonald, and Debbie Ward for their input. Photo contributions by Scot Nelson, Jeff Williamson, and the Citrus Research and Education Center are greatly appreciated.

Recommended citation: Manner, H.I., R.S. Buker, V. Easton Smith, and C.R. Elevitch. 2006. *Citrus* species (citrus), ver. 2.1. In: Elevitch, C.R. (ed.). Species Profiles for Pacific Island Agroforestry. Permanent Agriculture Resources (PAR), Hōlualoa, Hawai'i. <http://www.traditionaltree.org>.

Sponsors: Publication was made possible by generous support of the United States Department of Agriculture Western Region Sustainable Agriculture Research and Education (USDA-WSARE) Program; SPC/GTZ Pacific-German Regional Forestry Project; USDA Natural Resources Conservation Service (USDA NRCS); USDA Forest Service Forest Lands Enhancement Program; State of Hawai'i Department of Land & Natural Resources Division of Forestry & Wildlife; Kaulunani, an Urban Forestry Program of the DLNR Division of Forestry and Wildlife and the USDA Forest Service; and Muriel and Kent Lighter. This material is based upon work supported by the Cooperative State Research, Education, and Extension Service, U.S. Department of Agriculture, and Agricultural Experiment Station, Utah State University, under Cooperative Agreement 2002-47001-01327.

Series editor: Craig R. Elevitch

Publisher: Permanent Agriculture Resources (PAR), PO Box 428, Hōlualoa, Hawai'i 96725, USA; Tel: 808-324-4427; Fax: 808-324-4129; E-mail: par@agroforestry.net; Web: <http://www.agroforestry.net>. This institution is an equal opportunity provider.

April 2006
ver. 2.1

Cocos nucifera (coconut)

Arecaceae (palm family)

coconut, coconut palm (English); *ha'ari* (Societies); *iru* (Palau); *lu* (Yap, Kosrae); *ni* (Pohnpei, Marshalls); *niu* (Polynesia, Papua New Guinea, Fiji); *niyog* (Guam); *nizok* (N. Mariana Islands); *nu* (Chuuk, Cook Islands); *te ni* (Kiribati)

Edward Chan and Craig R. Elevitch

PHOTOS: C. ELEVITCH

With its many uses, coconut is often called the "tree of life."

IN BRIEF

Distribution All tropical and subtropical regions.

Size Height at 40 years typically 20–22 m (65–72 ft); canopy has a diameter of 8–9 m (26–30 ft).

Habitat Usually found sea level to 150 m (490 ft), but will grow at 0–600 m (0–1970 ft) near the equator; rainfall 1500–2500 mm (60–100 in).

Vegetation Associated with a wide range of coastal species as well as cultivated species inland.

Soils Remarkably adaptable to a wide range of soil types as long as waterlogging does not occur within 1 m (3.3 ft) of the surface.

Growth rate Moderate, 30–50 cm (12–20 in) in height annually during the first 40 years of growth.

Main agroforestry uses Coastal stabilization, windbreak, overstory, and many others.

Main uses Staple food, wood, handicrafts, etc.; thought by many to be the "world's most useful plant."

Yields 50–80 fruits per palm/year on mature tree; optimal annual yields of 2–2.5 mt copra/ha (0.9–1.1 t/acre) can be achieved.

Intercropping Compatible with many agricultural species, as well as animal grazing.

Invasive potential There is no danger of coconuts being invasive, as the spread inland from its natural habitat can only be affected by humans. The large size of the seed and low numbers produced per palm also make its spread easy to control.

INTRODUCTION

The coconut palm (*Cocos nucifera*) is found throughout the tropics, where it is interwoven into the lives of the local people. It is particularly important in the low islands of the Pacific where, in the absence of land-based natural resources, it provides almost all the necessities of life—food, drink, oil, medicine, fiber, timber, thatch, mats, fuel, and domestic utensils. For good reason, it has been called the "tree of heaven" and "tree of life." Today it remains an important economic and subsistence crop in many small Pacific island states.

Coconut is believed to have its origins in the Indo-Malayan region, from whence it spread throughout the tropics. Its natural habitat was the narrow sandy coast, but it is now found on soils ranging from pure sand to clays and from moderately acidic to alkaline. It is non-invasive, and people have been largely responsible for its spread, particularly inland from its natural habitat. It thrives under warm and humid conditions but will tolerate short periods of temperatures below 21°C (70°F). Its crown of feather-like fronds and bunches of large fruits carried atop long slender stems makes it easily recognizable.

The arrival of Europeans in the Pacific in the 19^{th} century signaled the commercialization of the plant, and coconut oil was the first vegetable oil to appear in world trade. Its demand triggered the establishment of large coconut plantations in the European colonies around the world, including in Papua New Guinea (PNG), the Solomon Islands, Fiji, Vanuatu, and Samoa. However, its importance declined after WWII with the emergence of alternative vegetable oils touted to have superior health benefits. These included soybean, groundnut, sunflower, and canola oils. More recently, competition has come from another palm, the oil palm (*Elaeis guineensis*), which produces a similar oil from its kernel. Today, coconut oil has been relegated mainly to non-food uses in the developed countries but retains its importance in producing countries for traditional uses. It continues to have an important role in subsistence agriculture in that it is well suited to mixed cropping and provides not only most of life's necessities but also, in many Pacific islands, food for livestock such as pigs and poultry. Coconut oil and other products are also making a comeback commercially in both natural foods and cosmetic industries.

DISTRIBUTION

Native range

Coconut is native to coastal areas (the littoral zone) of Southeast Asia (Malaysia, Indonesia, Philippines) and Melanesia. In prehistoric times wild forms (niu kafa) are believed to have been carried eastward on ocean currents to the tropical Pacific islands (Melanesia, Polynesia, and Micronesia) and westward to coastal India, Sri Lanka, East Africa, and tropical islands (e.g., Seychelles, Andaman, Mauritius) in the Indian Ocean. In these regions, the palms were able to establish themselves on sandy and coralline coasts. Coconut is either an introduction or possibly native to the Pacific coast of Central America.

Current distribution

The coconut palm has wide pantropical distribution. It is a ubiquitous sight in all tropical and subtropical regions 23° north and south of the equator. It is also found outside these latitudes, where it will flower, but fruits fail to develop normally. It is believed that Polynesians migrating into the Pacific 4500 years ago brought with them aboriginal selections (niu vai). At about the same time, people from Indo-Malaya were colonizing the islands of Micronesia. Malay and Arab traders spread improved coconut types west to India, Sri Lanka, and East Africa about 3000 years ago. Coconuts were introduced into West Africa and the Caribbean (including the Atlantic coast of Central

Coconut palms growing on the foreshore of a Pacific island beach. Floating nuts would have been deposited just above the high water mark by large waves, where they then became established. PHOTO: E. CHAN

America) during the 16th Century by European explorers. Through the involvement of people, the palm spread inland and is now grown over a wide variety of soil types and up to an altitude of 600 m (1970 ft) at the equator. It is an important plant in the lives and economies of people in the following countries:

Southeast Asia Burma, Indonesia, Malaysia, Philippines, Singapore, South China (Hainan), Thailand, Vietnam

Indian Subcontinent, Indian Ocean Bangladesh, South India, Sri Lanka, and islands of Andaman, Nicobar, Seychelles

Africa Cameroon. Ghana, Ivory Coast, Kenya, Madagascar, Mozambique, Nigeria, Tanzania

Central America/Caribbean Brazil, Ecuador, Jamaica, Mexico, Trinidad and Tobago, Venezuela

Melanesia Fiji, Papua New Guinea, Solomon Islands, Vanuatu

Polynesia Cook Islands, Hawai'i, Kiribati, Line Is, Nauru, Niue, Samoa, Tonga, Tuamotu Archipelago, Tuvalu, Society Is., Tokelau, Tuvalu

Micronesia Palau, Chuuk, Guam, Northern Mariana Islands, Pohnpei, Yap, Kiribati

Coconuts are found on the tropical coast of Australia but are more of a curiosity with ornamental value. Beyond 23° N and S, coconuts are grown as an ornamental in Florida and even as far south as Brisbane (26° S) Australia.

BOTANICAL DESCRIPTION

The following description applies to the Tall variety of coconuts, which is the dominant type grown the world over.

Preferred scientific name

Cocos nucifera L.

There are no other known species in the genus *Cocos*.

Family

Arecaceae (palm family)

Subfamily

Cocoideae

Non-preferred scientific names

Palma cocos Miller

Common names

coconut, coconut palm (English)
ha'ari (Society Islands)
iru (Palau)
lu (Yap, Kosrae)
ni (Pohnpei, Marshall Islands)
niu (Polynesia, Papua New Guinea, Fiji)
niyog (Guam)
nizok (N. Mariana Islands)
nu (Chuuk, Cook Islands)
te ni (Kiribati)

The local names for coconut (*niu* in Polynesia and Melanesia, *niyog* in the Philippines and Guam) are derived from the Malay word *nyiur* or *nyior*. This is often cited as proof that the species originated in the Malay-Indonesian region.

Other regions

coco da Bahia, *coco da India*, *coqueiro de Bahia* (Portuguese)
coco, *coco de agua*, *cocotero*, *palma de coco*, *palmera de coco* (Spanish)
coco, *cocos*, *cocospalm*, *klapperboom* (Dutch)
coco, *cocotier*, *cocoyer*, *coq au lait*, *noix de coco* (French)
Kokospalme (German)
kelapa, nyior (Malaysia/Indonesia)
niyog (Philippines, Tagalog)

Size

A crown of fronds is borne on a single unbranched stem with aerial growth from a single growing point. A 40-year-old palm typically attains a height of 20–22 m (66–72 ft), and an 80-year-old palm may attain a height of 35–40 m (115–130 ft). The canopy has a diameter of 8–9 m (26–30 ft).

Form

The fronds in a mature healthy palm describe a sphere and are evenly distributed in all directions from the growing tip. In heavily bearing palms, the weight of nuts may push down on the horizontal fronds, resulting in an X-shaped canopy in which no fronds are held in a near-horizontal position.

Flowers

Description of flower

The coconut palm is monoecious, i.e., with male and female flowers on the same inflorescence, called a spadix, that develops within a woody sheathe or spathe. At flowering, the spathe splits lengthwise to expose the spadix. Each spadix consists of a main axis 1–1.5 m (3.3–5 ft) in length with 40–60 branches or spikelets bearing the flowers. Each spikelet carries from zero to three female flowers ("buttons") at its base and several hundred male flowers above. Thus a spadix will have several thousand male flowers but only

40–60 buttons. The male flower has six perianth segments surrounding six stamens. The larger female flowers are globose and consist of six perianth segments in two whorls, a tricarpellate ovary and trifid stigma. Following pollination, only one carpel develops into the seed, the other two aborting. The perianth persists at the base of the mature fruit.

Anthesis is usually completed before the female flowers are receptive, encouraging cross-pollination. However, pollination can occur between flowers of successive spadices on the same palm. Under favorable growing conditions, first flowering occurs about 4–5 years after planting.

Seasonality

Once a palm reaches maturity, a spadix (flower spike) is produced in every leaf axil. Between 12 and 15 spadices are produced throughout the year at fairly regular intervals, although drought conditions can delay the emergence of the spadix or cause it to abort. The number of female flowers per spadix varies. Since the floral primordia are initiated 12 months before the spadix emerges, the number is correlated to the growing conditions (weather, nutrition) 12 months prior to emergence.

Leaves

Until about an age of 1 year, leaves remain entire. Thereafter the leaves (called "fronds") are progressively more pinnate. The widely recognized coconut leaves are peripinnate (even-pinnate) with 200–250 linear-lanceolate leaflets arranged in a single plane on either side of the rachis. Fronds are 4.5–5.5 m (15–18 ft) in length, with the petiole making up a quarter of its length. Leaflets are 1.5–5 cm (0.6–2 in) wide and 50–150 cm (20–60 in) long. The expanded base of the petiole provides firm attachment for the frond to the stem. The petiole and rachis may be green or bronze, which is indicative of the fruit color. Talls in their prime produce about 12–18 leaves per year, and Dwarfs produce 20–22 leaves per year. As leaves senesce about 2.5 years after unfolding, this means Talls have 30–35 leaves in their crown at any given time.

Top: Inflorescence showing spikelets, some bearing developing fruits at their base and all bearing or having borne hundreds of male flowers. Bottom: Fruit in different stages of development. PHOTOS: C. ELEVITCH

Fruit

Fruit description

The fruit is a fibrous drupe. It consists of, from the outside in, a thin hard skin (exocarp), a thicker layer of fibrous mesocarp (husk), the hard endocarp (shell), the white endosperm (kernel), and a large cavity filled with liquid ("water"). When immature, the exocarp is usually green, sometimes bronze. Wide variation in fruit shape and size exist within types and populations. Fruit shapes vary from elongated to almost spherical and weigh between 850 and 3700 g (1.9–8.1 lb) when mature.

Time to bearing

It is not unusual for the first one or two inflorescences to carry only male flowers, with the number of female flowers increasing with age. From pollination, it takes about 12 months for the fruit to mature. The first mature fruits can be produced 5–6 years from planting. Fruits are produced throughout the year but where rainfall is seasonal, more fruits are produced in some months than others.

Seeds

The seed comprises the dark brown shell and kernel. The surrounding husk, which is brown and dry at maturity, always remains intact. Fruits harvested for planting are usually referred to as seednuts to differentiate them from those for non-propagation uses such as drinking, consumption, and copra. Seednuts are similar in shape to the fruit but are correspondingly smaller and weigh less due to the drying out of the husk and partial loss of water from the cavity. The nut has three micropyles or "eyes," one of which is soft and indicates the position of the viable embryo embedded in the kernel. A nut may have more than one viable embryo, but this is rare. About 50–80 fruits per year are produced on a bearing palm.

Modes of dissemination

The seeds are spread by water and people. The ability of some nuts to survive up to 120 days afloat in the sea and germinate when they make landfall is the natural means by which the species could spread far from its origin without the assistance of man. However, its spread in this way is limited to the coasts. Although minor compared to water and people, by bouncing and rolling after a fall of 10 to 20 m (33–66 ft), seeds can move as much as 10 m (33 ft) from the mother tree, often inland. The coconut, however, primarily owes its spread inland and pantropical distribution to people.

Hawaiian names for stages of coconut fruit development (after Handy and Handy 1972)

Name	Meaning
ʻōʻio	unripe nut with jelly-like translucent flesh
hao hao	maturing nut with shell still white and flesh soft and white
ʻili kole	half-ripe nut, not good for extraction of cream, meat eaten raw with red salt and poi
niu oʻo	nut mature but husk not dried
niu maloʻo	nut mature, husk dry, water still present, best stage for planting
niu ō kaʻa	old nut with no water and flesh separated from shell, oil is extracted at this stage

Rooting habit

As a monocot, the palm has no taproot but instead produces adventitious roots from the base of the stem. There are 2000–4000 adventitious roots about 1 cm (0.4 in) in diameter per palm. The depth of rooting depends much on the physical characteristics of the soil and the depth of the water table. While roots can grow as deep as 5 m (16 ft) in well drained sandy soils, most of the roots are to be found within the top 1.5 m (5 ft) of soil. Laterally, They normally spread 6 m (20 ft) but can grow as far as 30 m (100 ft) from the base in optimal conditions. Decayed roots are regularly replaced by new roots that emerge from the basal stem.

GENETICS

Known varieties

There are two distinct types according to size and stature of the palm—Talls and Dwarfs. Talls are by far the more commonly grown variety around the world. Talls are cross-pollinated and are thus highly variable, as seen in the wide variation in characteristics such as size, shape, and color of the fruit as well as fruit composition (thickness of husk, weight of endosperm), and yield. Dwarfs, on the other hand, are largely self-pollinated and thus are genetically more homogeneous. This is reflected in the more uniform appearance of the different dwarf types.

Talls

Talls fall into two main types. The first is niu kafa, thought to be the wild type and characterized by elongated, triangular-shaped fruits with very small elongated nuts and a high husk-to-nut ratio. Niu kafa was much valued by the early Polynesians for its long fibers used in making braided cordage known as "sennit." Not presently grown, niu kafa has been displaced by the second type of Talls, the domesticated, large-fruited niu vai. Characteristics of the wild type can still be found in natural stands of coconuts. A whole range of nut sizes and shapes exist between the two extremes of niu kafa and niu vai.

Of the Tall varieties, those that have evolved in isolation from a narrow introduction base are more homogeneous and have become important in breeding programs to produce improved planting materials. Talls are named after the locality, island, or country in which they are found, including homogeneous types such as 'West African', 'Rennel' from the Solomon Islands, and 'Tagnanan' from the Philippines. Characteristics that have been used to classify tall varieties include the floral biology, nut physiology, and germination time.

Dwarfs

Dwarfs are smaller in stature and produce smaller nuts but in greater numbers. Their small stature makes them popular for homegardens, parks, and roadsides. Dwarf varieties are characterized by the immature fruit color and named after their country of origin, e.g., 'Red', 'Yellow', and 'Green Malayan', 'Cameroon Red', and 'New Guinea Brown'. As the name suggests, Dwarf palms are smaller in size and stature than the Talls. The stems are slender and, unlike the Talls, do not form boles at the base. They flower and bear significantly earlier than the Talls and produce a higher number of smaller nuts. Dwarfs come into bearing at 3 years compared to 5 years for the Talls. Because of their smaller stature, homogeneity, and precocity, they are used in hybridization with Talls. Their smaller size allows for higher-density plantings, but dwarfs do not adapt to varying conditions as well as the Talls.

Distinct from the above dwarf varieties is the 'Niu Leka Dwarf' from Fiji, also known as 'Samoan Dwarf' in Hawai'i. Its stem is thicker and shorter, but unlike the other dwarf varieties, forms a bole at its base. It has short stiff fronds and large nuts.

It is interesting to note that early germinators (Talls) are found in the Indo-Malayan region where coconuts are thought to have originated. Whether coconuts were disseminated naturally on ocean currents or by man, slow-germinating nuts would have had a better chance at sur-

COCONUT DIVERSITY

The illustration on the opposite page shows the wide range found in fruit size, color, shape, and husk thickness as well as variation in kernel and cavity size. Varieties shown are as follows, from left to right. The country where each photograph was taken is noted in parentheses, if not the country of origin. ILLUSTRATION COURTESY R. BOURDEIX © 2005 EDITIONS DIVERSIFLORA AND CIRAD

Top row

1. 'Papua Yellow Dwarf', PNG
2. 'Tahiti Red Dwarf', French Polynesia (Côte d'Ivoire)
3. 'Madang Brown Dwarf', PNG (Côte d'Ivoire)
4. 'Cameroon Red Dwarf', Cameroon (Côte d'Ivoire)
5. 'Spicata Tall', Samoa
6. 'Rotuman Tall', Fiji (Côte d'Ivoire)
7. 'Rennell Tall', Solomon Islands (Côte d'Ivoire)

Middle row

1. 'Niu Afa Tall', Samoa
2. 'Comoro Moheli Tall', Comoro Island (Côte d'Ivoire)
3. 'Sri Lanka Tall', Ambakelle, Sri Lanka (Côte d'Ivoire)
4. 'West African Tall', Akabo, Côte d'Ivoire
5. 'Tuvalu Tall', Fuafatu, Tuvalu
6. 'West African Tall', Mensah, Côte d'Ivoire
7. 'Miccro Laccadives Tall', India (Côte d'Ivoire)

Bottom row

1. 'Vanuatu Tall', Vanuatu (Vanuatu)
2. 'Malayan Yellow Dwarf', Malaysia (Côte d'Ivoire)
3. 'Malayan Tall', Malaysia (Côte d'Ivoire)
4. 'Tagnanan Tall', Philippines (Côte d'Ivoire)
5. 'Tampakan Tall', Philippines (the Philippines)
6. 'Kappadam Tall', India (Côte d'Ivoire)

A simplified classification of coconut varieties

Variety	Main Characteristics	Germination	Examples
Talls	Thick stem with swollen base (bole). Late flowering (5–6 yr from outplanting). Little or no overlapping of male and female phases of an inflorescence encouraging outcrossing.	**Early**	'Malayan Tall', 'Bali Tall', 'Tagnanan Tall', 'San Ramon Tall'
		Late	'West African Tall', 'Rennel Tall', 'Samoan Tall', 'Polynesian Tall', 'Solomon Tall', 'Vanuatu Tall', 'Gazelle (PNG) Tall', 'Jamaica Tall', 'Panama Tall'.
Dwarfs	Slender stem with short internodes. Bole slight or absent. Early flowering (3 yr from outplanting). Considerable overlapping of male and female phases of an inflorescence resulting in self-pollination.	**Intermediate**	'Malayan Red', 'Yellow' and 'Green' Dwarfs, 'Cameroon Red' Dwarf, 'Nias Green' and 'Nias Yellow' Dwarfs, 'PNG Brown' Dwarf, 'Samoan Yellow' Dwarf.
	Thick stem with bole, internodes shorter than normal dwarfs, outcrossing	**Intermediate**	'Niu Leka', also known as 'Fiji Dwarf' ,and 'Samoan Dwarf'


20 cm
R. Bourdeix, 2005

viving those long journeys. Early-germinating coconuts meant that in Malaysia, Indonesia, and the Philippines, ripe nuts were picked off the palms frequently, about once a month. Germination would mean both a loss of kernel (hence copra) as well as a loss of quality. In areas with slow germinating nuts such as PNG, the Solomon Islands, and Samoa (and probably other Polynesian islands), nuts are allowed to fall naturally and picked off the ground about once every 2 months throughout the year.

ASSOCIATED PLANT SPECIES

The sandy coast is a hostile environment for plant life and does not support populations of many large plants (except coconuts). The native vegetation on sandy shores are comprised mainly of vines, grasses, and sedges is of salt spray and occasional flooding by seawater.

Associated native species commonly found

The most common associated plant are ground creepers, beach morning glory (*Ipomoea pes-caprae*) and beach pea (*Vigna marina*), both of which are found throughout the tropics and often dominate the sandy shores. Less common morning glory species include *Ipomoea littoralis* and *I. macrantha*. Commonly found in association with the creepers are the grasses *Lepturus repens* and *Paspalum vaginatum* and sedges such as *Fimbrystylis cymosa*.

Species commonly associated as aboriginal introduction in Pacific islands

The best-known introductions by the Polynesians and Micronesians, in addition to coconuts, are the breadfruit (*Artocarpus altilis*), banana (*Musa* spp.), yam (*Dioscorea* spp.), taro (*Colocasia esculenta*), and sugarcane (*Saccharum officinarum*). These were presumably grown together further inshore, as they are today. Other useful plants introduced by the Polynesians into the Pacific include candlenut (*Aleurites moluccana*), bamboo (*Schizostachyum glacuifolium*), wild ginger (*Zingiber zerumbet*), ti (*Cordyline fruticosa*), and paper mulberry (*Broussonetia papyrifera*).

Left: Coconut growing with breadfruit, pandanus, and ti, Kona, Hawai'i. Right: Taro growing under coconuts, Tongatapu, Tonga. PHOTOS: C. ELEVITCH

Species commonly associated in modern times or as recent introduction

Recent introductions grown as an understory crop include the root crops giant taro (*Alocasia macrorrhiza*) and swamp taro (*Xanthosoma* spp.) and a host of other food crops and fruit trees. Cocoa (*Theobroma cacao*) and to a lesser extent robusta coffee (*Coffea canephora*) are grown as cash crops under old coconut palms in Melanesia and Samoa. Grazing cattle under coconuts is also an important Pacific island agroforestry practice.

ENVIRONMENTAL PREFERENCES AND TOLERANCES

Climate

A year-round warm and humid climate favors the growth of coconut. A mean annual temperature of 27°C (81°F), an evenly distributed rainfall of 1500–2500 mm (60–100 in) per annum, and relative humidity above 60% provide the ideal climatic conditions for the vigorous growth and yield of the palm. A permanent water table within easy reach of the coconut roots can offset inadequate rainfall, while amounts in excess of 2500 mm (100 in) could result in diseases of the fruit and leaves. Such conditions are normally found 20° north and south of the equator. Periods with mean daily temperatures below 21°C (70°F) adversely affect the growth and yield of the palms. Frost is fatal to seedlings and young palms when the growing point is still close to the ground. At the equator, coconut can grow and yield well up to an altitude of 600 m (1970 ft) but will only do so at sea level at latitude 23°. At the extremes of the latitudinal range, coconut only grows well on the coast of large land masses (e.g., east coast of Australia, Africa, South America, etc.) and on islands where the sea exerts a moderating influence on temperature and humidity.

Elevation range

0–600 m (0–1970 ft) (near the equator)

Mean annual rainfall

1500–2500 mm (60–100 in)

Rainfall pattern

Coconut grows in climates with summer, winter, bimodal, and uniform rainfall patterns.

Dry season duration (consecutive months with <40 mm [1.6 in] rainfall)

One month in sandy inland areas, and 3 months in clayey inland areas. Palms will survive longer droughts, but yields will be severely depressed.

Mean annual temperature

21–30°C (70–86°F)

Mean maximum temperature of hottest month

28–37°C (81–99°F)

Mean minimum temperature of coldest month

4–12°C (39–54°F)

Minimum temperature tolerated

0°C (32°F)

Soils

This palm has remarkable ability to adapt to a wide range of soil types. Although coarse sand is its natural habitat, best growth is obtained on deep soils with good physical and chemical properties. It is thus widely grown on loams as well as clays that are well drained.

Soil drainage

It requires free drainage.

Soil acidity

It tolerates alkaline soils up to pH 8 (on coralline atolls) and acid soils with pH 4.5 or higher. The ideal pH range is 5.5–7.

Soil texture

Coconut grows on a wide range of light, medium, and heavy soils.

Special soil tolerances

It tolerates saline and infertile soils. It grows on coralline atolls, but poorly, as these soils are shallow and infertile.

Tolerances

Drought

Coconut tolerates drought poorly. Symptoms include desiccation of older fronds, spears (emerging fronds) failing to open normally, and shedding of young nuts.

Full sun

It thrives in full sun.

Shade

Coconut grows under high levels of shade, but yields are severely affected; it does best when not shaded.

Fire

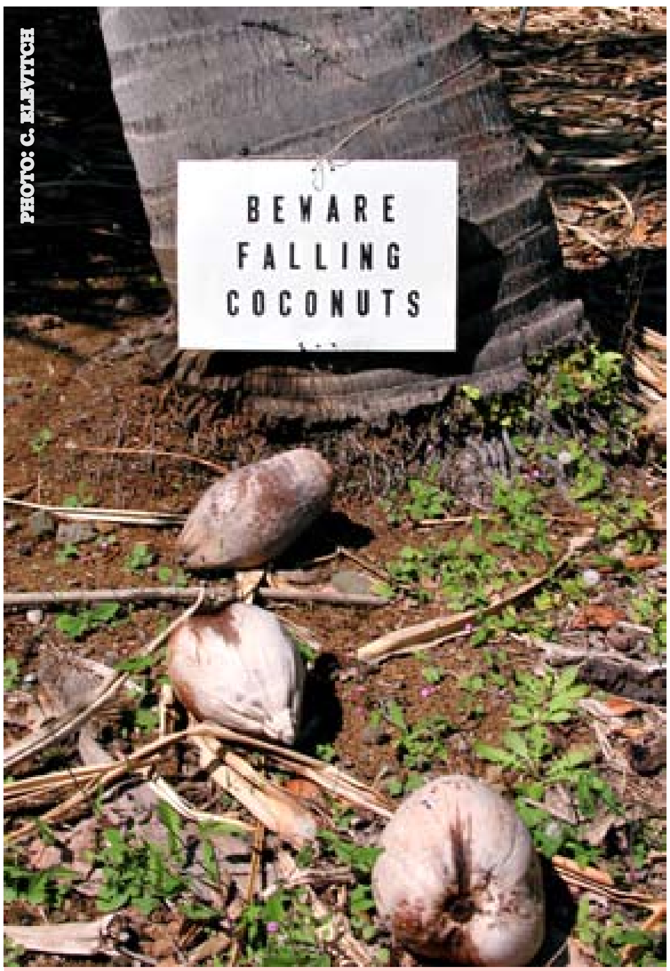
Young palms will succumb to fire, but mature palms will often survive if the canopy is far enough above the fire to escape the flames.

Frost

It has poor tolerance of frost. Severe frost is fatal to seedlings and young palms.

Waterlogging

Coconut does not like waterlogging within 1 m (3.3 ft) of surface, and will not survive more than 2 weeks of surface waterlogging.



WARNING

Falling coconuts are very hazardous and present a life-threatening danger, especially in homegardens, on beaches, and other places where people spend time. One way to reduce the danger is by regularly harvesting the nuts before they ripen and fall to the ground.

Cutting off the growing tip will kill the plant, such as here where a young seedling was cut off because it sprouted in an undesirable location. PHOTO: C. ELEVITCH

Salt spray

Coconut is able to withstand salt spray very well.

Wind

It is able to withstand cyclonic (hurricane) winds if roots are well anchored. Flexibility in the stem and fronds reduces the cross-sectional area presented by each tree and thus reduces the drag forces they must endure. In heavy storms, fronds facing or perpendicular to the direction of the wind tend to snap off close to the base. This reduces drag forces tremendously and helps coconuts survive storms. Most coconuts survive severe storms, although some are uprooted where there is not sufficient rooting depth. In some varieties a percentage of trees will snap off at the base of the root crown.

Abilities

Regenerate rapidly

In favorable conditions (full sun, plenty of moisture, etc.), sprouting nuts will revegetate an area relatively quickly.

Self-prune

Senescent fronds, the fruit stalk, and ripe nuts are shed.

Coppice

It will die if the growing tip is cut or damaged. However, it will regrow even if many fronds are damaged or cut and even after transplanting as long as much of the root system is preserved.

Other

Once established, it can grow on wave-washed beaches where most other plants would not survive.


A juvenile at the onset of bearing age, showing rapid vegetative growth. PHOTO: C. ELEVITCH

GROWTH AND DEVELOPMENT

The most rapid growth occurs between the second and fifth year in the life of a coconut palm. A stem appears under the crown after 3–4 years of growth, and stem elongation initially is 30–50 cm (12–20 in) annually but slows down in older palms (above 40 yr). Fruit production increases after the sixth year at the expense of vegetative growth. Thereafter, growth is fairly constant as yields are sustained for the next 40 years, and palm age can be roughly gauged from the length of the stem. Dry matter production in bearing palms has been estimated at 50–80 kg (110–176 lb) per year.

Flowering and fruiting

Under favorable conditions, Talls flower 4–5 years from outplanting, and it takes 11–12 months for the fruit to ripen. Usually only 30–40% of fruits set are carried to full term; most abort within 3 months of being pollinated. The palm produces 12–15 inflorescences (spadices) per year at fairly regular intervals, but the number of female flowers per spadix varies.

Yields

Yields vary a great deal from place to place. Generally, commercial monocrop plantings out-yield those in homegardens. Higher yields are obtained in commercial plantings because of the higher levels of inputs (management, maintenance, fertilizers, etc). Annual yields range from 15–20 kg (33–44 lb) copra/palm or, depending on the fruit size, from 50 to 80 fruits per palm.

Reaction to competition

Coconut competes well with most plants for nutrients and water, but aggressive grasses such as *Imperata cylindrica* retard growth and yield. Pasture grasses (including *Brachiara* spp. and *Ischaemum aristatum*) are commonly grown under old palms for cattle grazing. Coconuts grow poorly in shade. Depending on the amount of shade, seedlings planted under older palms or other trees can take up to 10 years to flower and will yield poorly.

PROPAGATION

Coconuts are propagated solely by seed. The seednut has no dormancy and requires no special treatment to germinate. However, germination speed of seednuts varies within and among ecotypes and varieties. Some Tall varieties (e.g., Malayan Talls) germinate while still on the palm, while others like the West African Tall and most Pacific populations take up to 6 weeks.

Clonal propagation of such a genetically variable species would have obvious advantages. Since the plant does not multiply vegetatively (only very rarely does it produce vegetative shoots), attempts at clonal propagation through tissue culture have so far met with limited success. Embryo culture is employed in country-to-country exchange of planting material for breeding purposes.

Seed collection

Seednuts may be collected throughout the year. The seeds are mature when the husk begins to lose moisture, the epicarp starts to turn brown and liquid is partially lost from the nut cavity, all of which begins to occur 11 months after pollination. Fruits fall to the ground when fully ripe after

12 months. Ripe fruits may be picked off the ground, but if it is important to know the identity of the female parent, as is the case in seed production, fruits are picked directly from the palm when the fruit is starting to turn brown. In addition to the browning of the epicarp, loss of liquid from the nut cavity when the fruit is ripe is indicated by a sloshing sound when the fruit is shaken.

Open-pollinated seednuts should be collected from healthy palms with particular attention given to heritable characters such as fruit size and amount of husk and kernel per fruit. High-yielding varieties are produced by crossing genetically disparate types with good fruit characteristics. Such hybrids may be crosses of Dwarf × Tall or Tall × Tall types. Production of such seednuts is quite involved and usually takes place in specially designed, isolated seed orchards.

Seed processing

Within a variety or population, the speed of germination indicates vigor, precocity (early sexual maturity, i.e., flowering), and high yield; in other words, the early germinators are the best performers, whereas the slowest germinators are usually poor and are discarded. In order to exploit the speed of germination as a selection criteria, it is important to ensure that seednuts sown together be of equal ripeness. If hybrids are used, off-types need to be culled. For practical purposes, germination is indicated by emergence of the shoot through the husk, although emergence through the eye of the endocarp would have occurred 4–6 weeks earlier. Because of the size of the seednut there is no danger of contamination with weed seeds.

Seed storage

Coconuts have no dormancy period and it is not advisable to store seednuts longer than necessary. With early-germinating types such as Malayan Talls, it is not advisable to store for any length of time. Slow germinators, such as the West African Talls and most Polynesian types, may be stored for up to a month with no ill effects as long as the water in the nut cavity does not dry out. If seednuts are to be stored for longer periods, they should be picked at 11 months of age when the epicarp is starting to turn brown and stored in a dry cool place. If fruits are picked half brown, they are stored under shade until the epicarp is completely brown before sowing.

Pre-planting treatments

No treatment is required. Some cultivars (e.g., 'Malayan Red') are susceptible to infection by the fungus *Marasmiellus* spp. during germination. Mixed results were obtained with fungicide treatments. Some pre-sowing treatments of seednuts include soaking in water and removing a slice of husk overlying the "eyes" of the nut. However, such refinements are unnecessary and only add to labor costs.

Growing area

If large quantities of seednuts are involved, a two-stage nursery is used to facilitate seedling selection. The first stage is the germination bed, which allows selection based on the speed of germination. The second stage is the nursery where the seedlings are grown to an acceptable size for outplanting and where plants with vegetative abnormalities are culled. The germination bed should be partially shaded (up to 50%) to prevent the nut water from evaporating before germination occurs, particularly with slow-germinating types. The nursery should be in full sun where seedlings may be raised in planting bags or in-ground. Sites used for germination beds and nurseries should be well drained. Seedlings in the nursery are spaced out at 60 by 60 cm (24 by 24 in).

Germination

Seednuts are laid flat in rows with 2/3 of the nut buried in coarse sand or soil to reduce the loss of nut water through evaporation (especially important for slow germinating varieties). The seednuts are sown right next to each other. A path every four rows will facilitate removal of germinating seednuts at weekly or fortnightly intervals. Depending on the type, germination can occur 4–6 weeks after sowing and continue over an 8-week period, by which time 75–80% of the seednuts should have germinated. Regular watering every other day during this period is important to prevent loss of water from the nut cavity through evaporation.

Germinating nuts are removed at regular intervals (weekly

Germinating seednut ready for transplanting. PHOTO: C. ELEVITCH or fortnightly) and transferred to the nursery. A good time to do this is when the first compound leaf (which resembles a rabbit's ears) is fully developed and judged to be normal. Discards include those with twisted, multiple, and diseased shoots. Germinating nuts are pried out, trimmed of exposed roots, and then planted in the nursery (in-ground or container) with the soil covering two-thirds of the nut.

Media

Germination beds Coarse sand to well drained friable soils are best to ease the lifting of germinating seednuts.

Nursery Well drained and friable soils are suitable particularly where seedlings are raised in-ground. Raised beds are recommended for in-ground nurseries if soil drainage is impeded. Black polyethylene planting bags 45 x 45 cm (18 x 18 in) (flat dimensions) hold about 30 liters (9 gal) of potting medium when filled and are suitable for holding seedlings for up to 10 months. While advantageous, (ability to provide optimal growth medium, minimize transplant shock, flexibility in time of planting out, and earlier higher yields), use of planting bags is an added cost (of bag, filling, and transport of seedlings) and smallholders sometimes prefer to raise seedlings in-ground.

Time to outplanting

The rate of growth depends on whether seedlings are raised in planting bags or in-ground (field nursery). If raised in-ground, seedlings should be outplanted not later than 6 months old; if raised in planting bags, at 8–10 months. Roots that have developed outside the planting bags are trimmed. In the case of seedlings that are raised in-ground, seedlings are carefully lifted and the exposed roots trimmed. However, the greater the amount of roots pruned off, the greater the transplanting shock.

Approximate size at time of outplanting

Six-month-old seedlings have 7–8 leaves and a height of about 80 cm (31.5 in) while 10-month-old seedlings will have 10–11 leaves and a height of 1.5 m (5 ft).

Guidelines for outplanting

Nursery operations are planned so that outplanting coincides with the onset of the rainy season. Under favorable conditions, planting shock is minimized and survival rate is close to 100%.

POTENTIAL DRAWBACKS

As a commercial crop, the long period from planting to full bearing has discouraged planting. The price of the primary product, copra (dried coconut kernel), is subject to world commodity markets, and the present price for copra has been depressed in the face of competition from other vegetable oils.

Symptoms of coconut heart rot. PHOTO: S. C. NELSON

Potential for invasiveness

There is no danger of coconuts being invasive since its spread inland from its natural habitat can only be effected by humans. The large size of the seed and low numbers produced per palm also make its spread easy to control.

Pests and diseases

Coconuts are affected by a wide range of pests and diseases, but none are more potentially damaging than those caused by viruses, viroids, and mycoplasmas. The best known is lethal yellowing disease. First identified in Jamaica, it is caused by a mycoplasma. The disease has spread to other countries in the Caribbean and Central America as well as Florida. Similar diseases have been found in palms in West Africa, Tanzania (East Africa), part of southern India, and some islands off the coast of Indonesian Kalimantan.

Cadang-cadang in the Philippines (tinangaja in Guam) is a lethal disease caused by a viroid (CCCvd), while foliar decay in Vanuatu is caused by a virus. Strict quarantine regulations governing the movement of planting material between countries have largely contained these diseases.

Fungal diseases of the frond are common, and while some varieties may be more susceptible to infection, its incidence is usually indicative of poor plant health and/or favorable conditions for the disease. Bud rot caused by the fungus *Phytopthora palmivora* is a concern, as it is usually fatal to the palm. While common, its incidence is usually low, although serious outbreaks of the disease have been reported from time to time. Cool, humid conditions favor its spread. The fungus has a pantropical distribution and besides the coconut palm also infects other palms such as oil palm (*Elaeis guineensis*) and betel nut (*Areca catechu*) as well as crops such as cocoa (fruit and stem), breadfruit (fruit), papaya (fruit), and black pepper (roots). In Hawai'i, a related fungus (*Phytophthora katsurae*) causes coconut heart rot. This disease has been reported to have killed up to 15% of the coconut palms in certain regions of Hawai'i.

Varietal differences in reaction to diseases and pests do occur. While the introduced Malayan Red Dwarf is more resistant to lethal yellowing than the local Talls in Jamaica, introduced varieties in Vanuatu were decimated by the foliar decay disease to which the local coconuts were resistant. A good example of a local variety becoming tolerant of a pest is to be found in PNG, where introduced Talls and hybrids were constantly attacked by rhinoceros beetles (*Oryctes rhinoceros* and *Scapanes australis*), but the local variety was left untouched.

Improving farm productivity by underplanting 40-year-old coconut palms with cocoa (*Theobroma cacao*) in Samoa. The cocoa is 18 months old and when mature will shade out the grasses and lay down a thick layer of leaf litter. Note the increased light penetration through the canopies of the old palms. PHOTO: E. CHAN

Taro and bananas growing under an old stand of coconuts, Tutuila, Samoa. PHOTO: C. ELEVITCH

Host to crop pests/pathogens

Pests and pathogens of coconuts may also affect other palms, and vice versa, but not other crops. Economic palms such as the nipa (*Nypa fruticans*) and rattan (*Calamus* spp.) occupy different ecological zones and are thus unlikely to exchange pests and pathogens with coconut. In countries such as Malaysia, Indonesia, and PNG where oil palms have been grown in proximity to coconuts, some coconut pests (rhinoceros beetle and palm weevil) and diseases (*Ganoderma* root disease) have crossed over. Betel nut (*Areca catechu*) and some ornamental palms are open to attacks by the pests and pathogens of coconuts grown nearby.

Top: Coconut husks make long lasting mulch for many plants and work especially well for epiphytes such as orchids. Middle: Cattle grazing on pasture under mature coconuts. Bottom: Residue left after extracting coconut cream makes excellent feed for pigs and chickens. PHOTOS: C. ELEVITCH

Other considerations in agroforestry

Its relative intolerance of shade limits its usefulness in agroforestry. However, the increased light penetration in old stands (above 40 years old) allows a host of other crops to be grown under coconuts, including fuelwood species such as *Leucaena leucocephala* and *Acacia* spp. to be grown as understory trees.

AGROFORESTRY/ ENVIRONMENTAL PRACTICES

Mulch/organic matter

Coconut husks can be used as mulch. They are slow to decompose but are a good source of potassium. In low-rainfall areas in some countries (e.g., India and Sri Lanka), husks are buried in trenches to serve as water reservoirs during drought. Decomposed husk is placed in holes when planting coconut seedlings on sandy soils. Placed on the ground convex surface up, husks are commonly used as mulch around coconut seedlings and other plants to control weeds (Malaysia, PNG, Samoa). Fresh or dried leaves are also used for mulch. Shredded husk can also be used as mulch or in nursery potting mix.

Soil stabilization

With its dense and widespread roots, coconut is used to protect sandy coasts against wave erosion.

Crop shade/overstory

Coconut provides excellent overhead shade for crops requiring it. Its fixed canopy size provides a fairly constant level of shading, although this decreases with age. Besides food crops and fruit trees in homegardens, it has been successfully intercropped with cocoa and coffee (Malaysia, Indonesia, Samoa, PNG, Fiji). It may be grown at wider spacing to allow for greater light penetration, albeit at the expense of coconut yield.

Homegardens

The coconut palm has a multitude of products, food and non-food, that are useful to the household. Its importance to residents in many small Pacific islands, especially atolls, cannot be overstated.

Windbreaks

Coconut is one of the most wind-tolerant plants in the world. It makes an excellent windbreak tree. Because it has foliage only at the top, it should always be grown in a multi-row windbreak with other species that can protect from the wind below the coconut canopy.

Silvopasture

Cattle are grazed under old coconuts in Philippines, Samoa, PNG, Vanuatu, and the Solomon Islands where the natural grasses have been replaced with improved species such as Batiki blue grass (*Ischaemum aristatum*) and Koroniva grass (*Brachiara humidicola*).

Animal fodder

Mature nuts are split and pigs allowed to feed on the kernels, while shredded kernels are fed to pigs and poultry after the cream has been extracted for cooking. Expelled copra cake from oil mills, which has a protein content of 20% and residual oil content of 6–7%, is used in animal feeds.

Woodlot

Shells, husks, spathes, empty bunch stalks, and petioles provide a ready and continuous source of fuel for the household.

Host plant trellising

Pepper has been gown up trunks but not with much success. In Samoa, passion fruit vines were successfully grown on wires strung between coconut palms.

Coastal protection

Coconuts can be used to stabilize sandy coastal areas, although its slow growth means it is 3–4 years before they are effective.

Ornamental

The palm is a very popular ornamental, especially to give a place or locality a "tropical look." Its drawback is that falling nuts pose a danger to humans and "de-fruiting" of palms is necessary to protect the public. Shorter and more colorful Dwarfs are also popular as ornamentals.

USES AND PRODUCTS

The Indonesians have a saying that there is a use for the coconut palm for every day of the year. The mature kernel is eaten as food and fed to pigs and chickens. Shredded kernel is used in sweets and desserts in Indonesia and Malaysia and in chutneys in Sri Lanka and India. The cream extracted from the shredded kernel is used in curries and sweets and in the Pacific islands for the flavoring of local dishes. The oil from the kernel is used in cooking, in oil lamps, in torches for illumination, to prepare ointments, and as hair oil. The water from immature nuts is drunk as a beverage throughout the tropics, and the jelly-like kernel is eaten. Husk fibers are made into ropes, and the whole husks and shells are used for fuel. Shells are also used as containers and drinking vessels. Sap obtained by tapping

COCONUT WATER—AN IDEAL DRINK

The clear liquid in the interior of a coconut is commonly referred to as "coconut water." It is a refreshing and cool, acclaimed by many to be the "perfect drink." In a healthy, undamaged coconut, the water is sterile. Its sodium and potassium content makes it an ideal drink for rehydration. During WWII, coconut water was used intravenously to treat patients suffering from blood loss when blood plasma was not available. It is a ready source of clean drinking water, especially after a natural disaster (cyclones, flooding). Characteristics of the water change as the coconut ages. A very young coconut (about 3–5 months, before the endosperm begins to form) has tasteless water that is somewhat astringent. Water from a mature coconut is slightly salty to the taste, although for coconuts grown well inland, the salty taste disappears. The best time to harvest a coconut for drinking is at age 6–7 months, just as the jelly-like endosperm begins to form. At this stage the water has maximum sweetness and low acidity. Nuts harvested at this age can be stored only 2–3 days before the water begins to sour.

A vendor prepares drinking coconuts for sale at market, Apia, Samoa. PHOTO: C. ELEVITCH the unopened spathe may be made into palm sugar or allowed to ferment into an alcoholic drink (toddy).

Mature green fronds are woven into baskets and mats, used as thatching for dwellings, and used to decorate houses. The midribs of leaflets are bundled together into brooms. Dried fronds, spathes, and empty bunch stalks are used for fuel.

Staple food

Coconut cream is obtained by squeezing the grated kernel. It is used in cooking with taro, bananas, fish, etc., in the Pacific islands and with rice in Indonesia and Malaysia.

Fruit

Jellylike young kernel of the immature nut is especially tasty, and a good food for babies. The sweet water from the nut is a popular and refreshing drink. The mature kernel is eaten fresh, or dried and grated for myriad dishes, cakes, and confections, but it is usually extracted for coconut cream in the Pacific. In Micronesia and atoll Polynesia, the young husk of some cultivars is eaten. In India and Sri Lanka, mature kernel is shredded and used in making chutneys. In Malaysia and Indonesia, shredded kernel is

HAWAIIAN COCONUT RIDDLES

(Neal 1965)

◊ Three walls and you reach water.

◊ A man with three eyes; he can cry out of only one.

◊ Something goes up brown and comes down white.

◊ My sweet water spring suspended in air.

Clockwise from left: Tava Taupu fashions a section of a coconut trunk into a drum at Pu'uhonua O Honaunau, Kona, Hawai'i. Lo'i Pepe Letoga quickly weaves fronds into a carrying basket, Uafato, Samoa. Sennit rope woven from coconut fiber. PHOTOS: C. ELEVITCH used in a variety of local desserts. The haustorium (often called the "apple") in the germinating seed is sweet and somewhat spongy and is a valued foodstuff in Polynesia and Micronesia.

Leaf vegetable

The heart of the palm comprising the young tender shoots surrounding the bud ("coconut cabbage") is a delicacy used in salads. Since harvesting it kills the palm, it is only available when palms are being felled.

Beverage/drink/tea

Nut water from immature nuts (7–8 months) makes a refreshing drink. The 'King' coconut in Sri Lanka is prized for its extra sweet nut water, while a dwarf green variety in Thailand has nut water that is aromatic.

Obtained by tapping the unopened spadix, the sap is collected in a vessel and allowed to ferment into an intoxicating drink ("toddy" or "tuba"). The unfermented and fermented toddy and syrup are of considerable importance in Micronesia and on atolls; these are popular in India, Sri Lanka, Malaysia, Philippines, Tuvalu, and Micronesia. The toddy can be distilled to produce a strongly alcoholic drink ("arrack"). Freshly fermented toddy is used in place of yeast for making local bread.

Honey

Bees are the main pollinators for coconuts, which produce copious quantities of flowers nearly continually. Coconut honey is of exceptional quality.

Medicinal

The young leaves are chewed to a paste and applied to cuts to stop bleeding. Water from a young nut contains sugar and other nutrients and is sterile fresh out of a nut. This water is fed to infants with diarrhea and, in emergencies, used intravenously as a saline drip (Solomon Islands).

Male flowers with ever-present attending bees. PHOTO: C. ELEVITCH

DEFINITIONS

Copra The dried coconut meat (endosperm) from which oil is expelled. In ripe nuts, the endosperm contains about 50% water and 35–40% oil.

Desiccated coconut Finely shredded, bleached and dried coconut meat (endosperm). As it is directly consumed in confections (e.g., candy bars), stringent hygiene standards are maintained in its production.

Coconut milk White emulsion obtained by squeezing freshly shredded meat (endosperm) mixed with water.

Coconut cream Obtained by centrifuging coconut milk whereby the cream separates from rest of the milk ("skim milk").

Sweetener

Fresh sap from the inflorescence obtained in the same way as for toddy is boiled down to produce palm sugar ("jaggery") that is popular in India, Sri Lanka, Vietnam, Indonesia, and Malaysia but not in the Pacific islands.

Timber

The old stems are used for fence posts, poles, sawn timber, roofing shingles, and furniture. Treatment with chromated copper arsenate is necessary to prolong life, especially if used outdoors. It has become a specialty wood especially for furniture and flooring, but it is economically viable only if large scale plantings are available to provide an adequate source of old stems, e.g., in the Philippines, Solomon Islands, Samoa, and Vanuatu.

Fuelwood

The shell is used dried or converted to shell charcoal for cooking or drying of kernels. Husks, spathes, empty bunch stalks and petioles—virtually all plant parts—can also be burned.

Craft wood/tools

The trunk and shells are fashioned into carvings, kitchen utensils, and axe handles. In Hawai'i, the base of the trunk has been used to make food containers and hula drums. In the Cook Islands, the hollowed-out trunk is used as a container in which "bush beer" is fermented.

Canoe/boat/raft making

The wood is used for small canoe hulls and paddles.

Fiber/weaving/clothing

Mature green fronds are woven into baskets, hats, mats, thatch, trays, fans, aquatic barriers, and all manner of plaited ware. The young leaves from a germinating nut are flexible and are used to make a foot harness tied between the feet for climbing coconuts. The unfurled immature leaves are used for making skirts, body ornamentation, and baskets.

Top: A palm carrying hundreds of very small nuts. Known in Malaysia as "palm with a thousand nuts" (kelapa beribu ribu), it occurs only rarely and has only a curiosity value. PHOTO: E. CHAN **Bottom: Branched coconuts are rare. This old coconut on Tongatapu, Tonga, has three branches with full tops loaded with coconuts.** PHOTO: C. ELEVITCH

Rope/cordage/string

Coir is the fiber obtained from the husk. The longest and finest fibers are spun into ropes, cordage, strings, and mats, while the thicker and shorter fibers are used in making brushes and as stuffing for seats and cushions.

Wrapping/parcelization

Green fronds are woven into all sizes of baskets for carrying food and other goods. In Indonesia and Malaysia, fronds are woven into little baskets in which rice is cooked.

Thatch/roofing/mats

Mature green fronds are commonly used as thatch for village dwellings in the Pacific islands. Coir is used for making door mats. Midribs are stripped from the lamina and bundled to form a broom.

Body ornamentation/garlands

The nut shells are fashioned into earrings, brooches, necklaces, and buttons.

Tannin/dye

When traditional colorants for tapa cloth are mixed with coconut oil, the colors are deeper and longer lasting. The charred husk is used to make a black dye in Tokelau.

Fragrance

In Hawai'i, the male flowers were heated in coconut oil to perfume tapa cloth. The bark is used to scent body oil.

Cosmetic/soap/perfume

Oil, often scented with blossoms of the Tahitian gardenia (*Gardenia taitensis*) or ylang-ylang (*Cananga odorata*), is used in body massages and for the hair. The oil is also used in making soap.

Oil/lubricant

Lauric oils, the dominant fatty acid (45–48%) in coconut oil, are obtained from kernels and used for cooking as well as in detergents, soaps, cosmetics, etc. The oily kernel is chewed and spat on the ocean to "calm" the water and see below the surface.

Left: Kava (*Piper methysticum*) and bananas grown as an understory crop, Tongatapu, Tonga. Right: Mixed garden with breadfruit, vi (*Spondias dulcis*), coffee, and many other crops, Kona, Hawai'i. PHOTOS: C. ELEVITCH

Illumination/torches

The seed oil is used in lamps and torches. Traditionally in Hawai'i and elsewhere, bits of dry husk were used as tinder in making fire by friction. The coconut midrib was used to string oil-rich nuts, such as candlenut (*Aleurites moluccana*), for torches.

Boundary marker

In Hawai'i, leaves were tied around coconuts as boundary markers, to ward off evil spirits, or as a sign of no trespassing (kapu). Specific trees or two trees planted together have served as boundary markers in Tuvalu.

Ceremonial/religious importance

Coconuts, bananas, and kava were traditional religious offerings in Hawai'i. The flowers are used in connection with religious rituals in Tahiti. The water of immature nuts is considered a sacred offering to visitors in Kiribati, and is used in divination in Hawai'i. To commemorate events, young coconut palms are bent to grow in odd shapes. Nuts are offered to deities in Hindu ceremonies.

Other

The burlap-like sheath at the base of each frond is used for a filter/strainer or to squeeze medicinal plants or coconut oil. It's also used to wrap bait for deep-sea fishing or to wrap the root-ball of transplanted seedlings.

URBAN AND COMMUNITY FORESTRY

The coconut palm is the most widely grown palm in tropical homegardens. Most of its parts find some use in the home. Its non-invasive nature, compact rooting habit, a non-branching stem and a crown limited in spread makes it very compatible with other plants in a park or street. More than any other plant, the coconut palm symbolizes the tropical coast. Falling nuts are a serious hazard, and fallen nuts and leaves (fronds) left on the ground are unsightly. The dwarf coconut with its variously colored fruits and smaller stature provides an attractive alternative to the tall types and is often more suitable for urban environments.

Size in an urban environment

Tall cultivars generally reach 20–30 m (65–100 ft) with a canopy spread of 8–9 m (26–30 ft). Dwarf cultivars grow up to 10–15 m (33–50 ft) in height, with a canopy spread of 4.5–6 m (15–20 ft).

Rate of growth in a landscape

Initially growth is rapid as new fronds progressively increase in length until they approach a maximum size for the palm. At an age of 3–4 years, plants may reach a height of 4.5–5.5 m (15–18 ft) to the tip of the tallest leaf, and a trunk begins to form at the base under the crown of leaves. Thereafter height is put on at the trunk at the moderate rate of 30–50 cm (12–20 in).

Root system

Coconuts have a very dense, fibrous root system that is mostly within 1.5 m (5 ft) of the soil surface. Coconut roots do not damage foundations and rarely raise sidewalks, although the roots often do overgrow the edges of surface objects such as pavement. The root system is compatible with many other plants as evidenced by the large number of species that are successfully intercropped with coconut.

Products commonly used in Pacific island households

One of the most useful plants, coconut provides numerous products commonly used in households. Perhaps the most common product in the Pacific is coconut milk (or cream) which is extracted from the freshly grated endosperm of the mature fruit. The water from the nut cavity of young nuts is a wonderful drink that is aseptic in healthy fruits. Eighteen to twenty-four coconut palms in their prime could provide one person with a daily supply of pure drinking water when consumed at a rate of three drinking nuts per day. The nut, shell and husk, fronds, and other

Left: Fish cooked in underground oven wrapped in coconut leaf. Right: Grating coconut for cream is a morning ritual in many Pacific islands. Both photos were taken in Alafua, Samoa. PHOTO: C. ELEVITCH palm parts are used to fashion household items, crafts, etc. The wood is durable and strong and can be used for building, furniture, and tools.

Light requirements

Young seedlings can be established in partial shade, but older palms require full sun to reach optimal productivity and vigor.

Water/soil requirements

Coconuts can grow in a wide variety of soils from coarse substrates to clay so long as the soil has good drainage and aeration. It tolerates a wide range of pH. Although the palm prefers environments with uniform rainfall (1000–2000 mm [40–80 in] annually) and high relative humidity, it can survive in arid areas given adequate soil moisture. In arid areas, irrigation, run-off from structures such as roofs and pavement, or even household graywater can be employed to keep soil moisture above minimum levels. Graywater from showers, laundries, and sinks is ideal, as these sources contain some nutrients, although harmful chemicals such as lye, solvents, bleach, etc., should not be used for irrigation. Also, proper health precautions and local regulations for graywater should be observed.

Life span

Tall coconut varieties can reach an age of 100 years, although productivity declines after age 40. Dwarf varieties have a shorter lifespan of about 70 years.

Varieties favored for use in homegardens or public areas

In urban areas, Dwarf varieties are often more practical due to their compact size. Their dense crowns give them an appearance in the landscape that is often considered more attractive than Tall varieties. Because of the smaller crown size, a few Dwarfs can be planted in the same area as one or two Talls.

Seasonality of leaf flush, flowering, fruiting

In optimal conditions with uniform soil moisture, high humidity, and favorable temperatures, coconuts grow continually throughout the year.

Top: Larry Kunitake shows a 'Niu Leka' dwarf coconut growing in his mixed homegarden. Bottom: Landscaping with coconuts in Apia, Samoa.
PHOTOS: C. ELEVITCH

Exceptional ornamental values

The sight of a coconut palm is a universal icon of tropical environments, appreciated by all. Living close to coconuts gives the added pleasure of the soft tapping noise produced by fronds gently blowing in the breeze.

Use as living fence, hedge, or visual/noise barrier

Because of the denser crown, dwarfs can be used as a living fence, if shorter plants are underplanted once trunks form.

Birds/wildlife

The palms attract a wide range of insect pollinators, including large numbers of honeybees.

Maintenance requirements

In its prime, a coconut produces about 12–15 leaves and 50–80 fruits per year, which means about that many leaves and fruits will drop from each palm annually. From an esthetic perspective, fallen leaves and fruit may need to be removed regularly to keep a tidy appearance. This material can be used as mulch where it is not an eyesore, if not used for other purposes.

In many private and public urban areas falling fruit and fronds present a life-threatening danger to people and animals. This requires regular maintenance to remove larger fruits and browning (senescent) fronds before they fall. As to the frequency for removing immature nuts to ensure that no one is injured or killed by a falling nut, consider the following: although nuts may fall at any stage of development, most fall during the first 3 months (no damage from these) or after reaching maturity. Unusually strong winds and storms can knock off fruits at any stage of development. Fronds do not fall off before browning, except in the worst of storms.

To ensure safety, nuts should be removed well before they reach maturity, and fronds should be removed before they brown and fall off. Nut pruning, however regular or severe, will not adversely affect palm growth (although it affects the appearance of the palm). Removing nuts older that 8 months old will substantially reduce the hazard of falling nuts.

In private urban environments, where drinking nuts are desired, nuts aged 6–8 months could be picked every 3–4 months by someone in a cherry picker, with a knife attached to a pole, or by climbing the palm. This results in palms having nuts always younger than 8 months, still well before nut maturity. This method leaves the remote possibility that someone can be hit by a falling nut that is less than 8 months old but large enough to cause harm.

In public urban environments such as parks, along streets, and in landscaping, a much more cautious pruning regime is required. Here fruit stalks are removed before they reach an age of 3–4 months, ensuring that no fruit develops beyond a size that would fall harmlessly to the ground. In addition to the open fruit stalks, the unopened spathes at the top of the crown should be nicked open if possible, which will cause it to decay and not bear fruit.

Fronds are less of a problem, and pruning fronds that are browning along with two or three younger ones substantially reduces risk without any appreciable effect on growth.

Special considerations regarding leaf, branch, and fruit drop

Generally, coconut palms can withstand high winds and floods. In storms, some fronds may snap off, which tends to lower wind drag and helps the plants survive.

Nuisance issues

None.

Hazards

Falling nuts present a very serious danger to people and animals, which is of special concern in urban and public environments. This often necessitates the regular removal of immature fruits well before they mature and fall naturally (see "Maintenance requirements" above).

Common pest problems

A variety of serious diseases affect coconut (see "Pests and

Composition of selected vegetable oils (adapted from Enig 2000).

	Coconut	Palm kernel*	Palm*	Soy	Olive	Canola	Cocoa
Fatty Acid							
Caprylic C_8**	8	4					
Capric C_{10}	7	4					
Lauric C_{12}	49	50					
Myristic C_{14}	18	16					
Palmitic C_{16}	8	8	45	11	14	4	24
Stearic C_{18}	2	2	5	4	2	2	35
Oleic $C_{18:1}$	6	14	39	23	71	59	38
Linoleic $C_{18:2}$	2	2	9	53	10	23	2
α-linoleic $C_{18:3}$				8	1	10	

* from the oil palm *E. guineensis*.
** # of carbon atoms:# of double bonds per molecule. The first five fatty acids are saturated and the last three are unsaturated.

A heavy-bearing palm resulting from a cross between the 'Malayan Yellow' Dwarf and the 'West African' Tall. Yields up to 32 kg (70 lb) copra per palm per year have been recorded. PHOTO: E. CHAN

diseases" above). Generally, these are not treatable or preventable. Mulching with organic materials such as grass and plant clippings or compost will help conserve soil moisture while providing a steady source of organic nutrients, thereby encouraging plant health.

COMMERCIAL PRODUCTS

The primary coconut products traded internationally are derived from the fruit: copra and desiccated coconut, coconut cream and protein, whole mature nuts, coir, and activated carbon from shells. Young drinking nuts, coconut water (fresh, canned or frozen), and palm sugar are important in local economies and have a ready market in developed countries with large Asian populations. The other primary products in local economies include shell charcoal, mature nuts for cooking and food uses, brooms, ropes, and coconut shell products, some of which may find niche markets overseas. For many Pacific island states, copra and its by-product, copra press cake, are the only important exports.

Spacing

As a monocrop, it is planted 9 m (30 ft) apart in a triangular pattern. If intercropping is planned, wider spacings and planting patterns are adopted. However, less attention is paid to spacing and planting patterns on small family farms. Commercial plantations can cover several hundred hectares, but 90% of the world's copra production comes from small family farms. As processing of copra is a simple operation, there is no minimum plantation size for commercial production, but 5 ha (12 ac) would usefully occupy a household.

Management objectives and design considerations

Site selection for commercial production should be stringent concerning soil and climate. Optimal growing conditions shorten the non-productive phase and ensure high yields. Vigorous growth reduces weed competition and pest attacks. Fertilizer may be necessary although the cost-effectiveness of fertilizers should be taken into account in view of the low commodity price. Intercropping with suitable cash crops should be considered to increase economic returns.

Design considerations

Use of slow-germinating types (which includes most Pacific island varieties) ensures that nuts may be harvested after falling to the ground at wider time intervals. Mature nuts and copra are bulky, so easy access (good roads, available transport) to markets are important.

Advantages and disadvantages of growing in polycultures

Coconut does not thrive if shaded, even if the shade is only from the side. Underplanting old palms (above 40 years old) with crops such as cocoa, coffee, and taro not only suppresses weeds but also increases returns from the land.

Estimated yield

Optimal annual yields of 2–2.5 mt copra/ha (0.9–1.1 t/ac) are attained in the fourth or fifth year of bearing.

On-farm processing methods

Copra production is a simple process in which a farmer is able to add value to the product. Larger farms have specially-built dryers which in their simplest form consist of a raised drying platform beneath which a fire (usually of coconut shells and husks) is lit. Desiccated coconut, cream, and protein products are not suited to farm-level processing.

Copra is produced in one of two ways. The Indo-Malayan region produces mainly cup copra while the Pacific islands produce finger copra as well as cup copra. Cup copra production requires the removal of the husk from the nuts, which are then split into two halves. The half nuts are then sun dried over 10–12 days or more. In a forced hot-air dryer it takes about 4 days. The partially dried kernel separates easily from the shell and the kernel is dried to less than 7% moisture. In finger copra, the fruit (husk and all) is split into halves with an axe and the kernel sliced into narrow strips and pried away from the shell. The finger cuts are then dried the same way, but drying time is less. Because the husk is not separated from the shell in the finger cut method, shell charcoal production is not possible.

Markets

The market for copra and coconut oil is worldwide. All large and medium-sized producers including PNG, Solomon Islands, and Samoa have oil mills and export mainly the oil. World exports of coconut oil in 2002 was 1822 million mt (2 million t) compared to only 0.160 mt (0.176 t) of copra exported. Desiccated coconut production is dominated by the Philippines, Sri Lanka, and Indonesia, which together exported 239,000 mt (263,500 t) in 2002. Pacific island states suffer the disadvantage of being small, isolated producers far from the major markets in Europe and the USA. However, organizations such as the EU provide assistance in the form preferential tariffs to imports from the Pacific islands as well as price support.

INTERPLANTING/FARM APPLICATIONS

Example system

Location

Papua New Guinea, Samoa, Malaysia, and Indonesia.

Description

There is a long-established practice (40–50 years) of planting cocoa trees under old coconut palms. Cocoa dry bean yields vary from 400 kg/ha (356 lb/ac) for village farms to 1 mt/ha (0.45 t/ac) for commercial plantations. Associated copra yields are 1–1.5 mt/ha (0.45–0.67 t/ac).

Crop/tree interactions

The coconut provides shade for the cocoa and protection from wind, and the coconuts benefit by default as the cocoa shades out weeds, builds up leaf litter, and shares fertilizers not usually applied to coconuts.

Spacing/density

Cocoa planted at 3 x 3 m (10 x 10 ft) intervals.

PUBLIC ASSISTANCE AND AGROFORESTRY EXTENSION

Extension offices for agroforestry and forestry in the Pacific: http://www.traditionaltree.org/extension.html

GENETIC RESOURCES

Important collections are located at:

PRAP's Production and Dissemination of Improved Coconut Cultivars is based in Saraoutou Research Station, Vanuatu.

International Coconut Genebank (ICG) for the South Pacific is located at PNG Cocoa and Coconut Research Institute, Rabaul, East New Britain, Papua New Guinea.

The Coconut Genetic Resources Network (COGENT), under the auspices of the IPGRI (formerly IBPRI), coordinates activities on genetic resources from exploration to enhancement of germplasm.

INTERNET

Asian & Pacific Coconut Community: <http://www.apcc-sec.org>.

Traditional Pacific Island Crops Coconut (*Cocos nucifera*) Internet Resources: <http://libweb.hawaii.edu/libdept/scitech/agnic/coconut.html>.

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Cocos nucifera (coconut)

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Acknowledgments: The authors and publisher thank Dale Evans, John Francis, Heidi Johansen, Tom McCarthy, Manuel Monic, Diane Ragone, Art Whistler, and Kim Wilkinson for their input. Photographs contributed by Scot C. Nelson are gratefully acknowledged. Thank you also to Roland Bourdeix of the French Agricultural Research Centre for International Development (CIRAD) for providing the photo of coconut diversity.

Recommended citation: Chan, E., and C.R. Elevitch. 2006. *Cocos nucifera* (coconut), ver. 2.1. In: Elevitch, C.R. (ed.). Species Profiles for Pacific Island Agroforestry. Permanent Agriculture Resources (PAR), Hōlualoa, Hawai'i. <http://www.traditionaltree.org>.

Sponsors: Publication was made possible by generous support of the United States Department of Agriculture Western Region Sustainable Agriculture Research and Education (USDA-WSARE) Program; SPC/GTZ Pacific-German Regional Forestry Project; USDA Natural Resources Conservation Service (USDA NRCS); Kaulunani, an Urban Forestry Program of the DLNR Division of Forestry and Wildlife and the USDA Forest Service; State of Hawai'i Department of Land & Natural Resources Division of Forestry & Wildlife; USDA Forest Service Forest Lands Enhancement Program; and Muriel and Kent Lighter. This material is based upon work supported by the Cooperative State Research, Education, and Extension Service, U.S. Department of Agriculture, and Agricultural Experiment Station, Utah State University, under Cooperative Agreement 2002-47001-01327.

Series editor: Craig R. Elevitch

Publisher: Permanent Agriculture Resources (PAR), PO Box 428, Hōlualoa, Hawai'i 96725, USA; Tel: 808-324-4427; Fax: 808-324-4129; E-mail: par@agroforestry.net; Web: <http://www.agroforestry.net>. This institution is an equal opportunity provider.

April 2006
ver. 3.1

Cordia subcordata (kou)

Boraginaceae (borage family)

anau **(Chuuk), beach cordia, sea trumpet (English), cordia, island walnut, kerosene wood (Papua New Guinea),** ***galu*** **(Yap),** ***ikoak*** **(Kosrae),** ***ikoik*** **(Pohnpei), ironwood (Australia),** ***kalau*** **(Palau),** ***koa*** **(Guam),** ***kanava*** **(‘Uvea, Futuna, Tokelau, Tuvalu),** ***kou*** **(Hawai‘i),** ***motou*** **(Niue),** ***nawanawa*** **(Fiji),** ***niyoron*** **(Guam, Northern Marianas),** ***puataukanave*** **(Tonga),** ***tauanave*** **(Samoa),** ***te kanawa*** **(Kiribati),** ***tou*** **(Societies, Cooks, Marquesas, Tuamotus),** ***vaua asi*** **(Solomon Islands)**

J. B. Friday and Dana Okano

PHOTO: J. B. FRIDAY

Mature kou tree at Lahaina, Maui, Hawai‘i.

IN BRIEF

Distribution Native throughout the Pacific as well as parts of the Indian Ocean and East Africa.

Size Reaches 7–15 m (23–49 ft), although typically seen smaller at about 5–7 m (16–23 ft).

Habitat Generally sea level to 30 m (100 ft), can grow at elevations up to 150 m (500 ft); rainfall 1000–4000 mm (40–160 in).

Vegetation Associated with species of coastal forests.

Soils Sandy and clay soils, rocky limestone or lava headlands; prefers neutral to alkaline soils.

Growth rate Early growth can be rapid on favorable sites, over 1 m/yr (3.3 ft/yr) for the first few years.

Main agroforestry uses Coastal protection, windbreak, homegardens.

Main uses Wood for crafts, ornamental, ceremonial.

Yields No data available.

Intercropping Compatible with many coastal species, although requires full sun.

Invasive potential Has potential to spread easily by seeds, but rarely does so; since it is native to Pacific islands, the tree is not considered invasive.

INTRODUCTION

Kou (*Cordia subcordata*) is an attractive small to medium-size tree that averages 7–10 m (23–33 ft) in height at maturity but may grow up to 15 m (49 ft). It prefers warm coastal areas on the leeward side of islands, and plentiful sunlight, but it can tolerate semi-moist inland forests. Kou has a native range including the Pacific, tropical Asia, and east Africa. While it is native to Hawai'i, seeds were probably also carried to some Pacific islands by the early Polynesian settlers as part of their indigenous agroforestry systems.

There are many traditional uses of kou, including as a shade tree around homesteads, because it provides a broad, dense crown. The large, beautiful orange flowers are used to make leis. Leaves were used to dye tapa or combined to make medicinal products. The main product of the tree is its wood, which is lightweight, soft, easily workable, little-shrinking, long-lasting, and durable. In the past, kou would occasionally be used to make canoes (especially on atolls, "plank canoes"), but it was more often used for food vessels and utensils, as it has no strong flavor that would impart taste to food. Other objects such as paddles, boxes, small furniture, and carved figures were also often made from the wood. Today the wood is prized for handicrafts and carving of traditional figures by traditional artisans from Papua New Guinea through the Solomon Islands to the Cook Islands, and it provides a significant source of income in those places.

Environmentally, the tree is very useful in Pacific islands for shade and windbreaks. Kou prefers coastal areas and direct sunlight while easily withstanding frequent salt spray. Kou's shallow and extensive root system makes it useful for the conservation of eroding coastal areas. Unfortunately, kou's susceptibly to the kou leaf worm (*Ethmia nigroapicella*) has caused many horticulturists and ornamental growers in Hawai'i to replace it with the non-native Geiger tree (*Cordia sebestena*). Losing the kou tree would mean losing part of the native culture in Hawai'i.

DISTRIBUTION

Native range

Kou is native throughout Pacific, from tropical Asia through Melanesia, Micronesia, and Polynesia to the Marquesas and northward to Hawai'i. Its native range includes the islands of the Indian Ocean and the eastern coast of Africa (Mueller-Dombois and Fosberg 1998).

Current distribution

Kou was probably one of the trees brought to Hawai'i by the original Polynesian settlers, although it had naturalized in Hawai'i previously (Wagner et al. 1999). It is now naturalized on all main Hawaiian islands except Moloka'i and Kaho'olawe. Throughout the Pacific, kou is increasingly rare, both from over-exploitation for carving and attacks from exotic pests. It is reported as disappearing in parts of its range (Clarke and Thaman 1993).

ORIGIN OF KOU IN HAWAI'I

Kou had been thought for years to have been introduced to Hawai'i by the early Polynesian navigators, along with candlenut (*Aleurites moluccana,* kukui), milo (*Thespesia populnea*), and kamani (*Calophyllum inophyllum*). However, in 1997 scientists excavating a sinkhole on Kaua'i found abundant fossilized kou seed in sediment layers dating 5,000 years before present, millennia before the first people arrived in Kaua'i. Kou is clearly a native plant to Hawai'i (Burney et al. 2001).

BOTANICAL DESCRIPTION

Preferred scientific name

Cordia subcordata Lam.

Family

Boraginaceae (borage family)

Non-preferred scientific names

Cordia orientalis R.Br.
Cordia moluccana Roxb.
Cordia rumphii Blume

Common names

anau (Chuuk)
beach cordia, sea trumpet (English)
cordia, island walnut, kerosene wood (Papua New Guinea)
galu (Yap)
ikoak (Kosrae)
ikoik (Pohnpei)
ironwood (Australia)
kalau (Palau)
koa (Guam)
kanava ('Uvea, Futuna, Tokelau, Tuvalu)
kou (Hawai'i)
motou (Niue)
nawanawa (Fiji)
niyoron (Guam, Northern Marianas)

puataukanave (Tonga)
tauanave (Samoa)
te kanawa (Kiribati)
tou (Societies, Cooks, Marquesas, Tuamotus)
vaua asi (Solomon Islands)

Size

Kou is a small evergreen tree with a broad, dense, wide crown that typically reaches 7–10 m (23–33 ft) in height. The canopy may spread 8 m (25 ft) across, often as wide as the tree is tall. The bark is pale gray and furrowed or flaky. The trunk is usually less than 40 cm (16 in) in diameter but may be larger in very old trees. The boles of the trees are often crooked and shaped by the wind. Through the 19th century in Hawai'i trees grew up to 15 m (50 ft) in height with stems 1 m (3.3 ft) across, and such giants may still be seen in remote areas in the Marshall Islands and perhaps elsewhere in the Pacific (McClatchey, pers. comm.), but today growth in Hawai'i is much reduced by defoliation caused by the kou leaf worm (Rock 1974).

Flowers

Kou bears clusters of orange flowers at the terminal ends of its branches and in leaf axils. The large, funnel-shaped flowers are 2.5–4 cm (1–1.5 in) long and broad, with five to seven slightly wrinkled lobes. The short-lived flowers are scentless.

Leaves

Kou leaves are alternate and broadly egg-shaped to elliptical with blunt-pointed ends. They are light green, shiny above and dull below, 8–20 cm (3–8 in) long and 5–13 cm (2–5 in) wide.

Fruit

Kou fruits are round or egg-shaped balls 2–3 cm (0.75–1.25 in) long, hard and woody when mature. They grow in clusters and turn brown and fall from the tree as they ripen. Kou fruits all year long; green and ripe fruits are often found on trees at the same time the trees are flowering.

Seeds

Each fruit contains four or fewer delicate, white, narrow seeds 10–13 mm (0.4–0.5 in) long. Kou fruits float easily and are carried from island to island on the ocean.

Similar or look-a-like species

Kou-haole or Geiger tree, *Cordia sebestena* L. is another ornamental tree that looks similar to kou. *Cordia sebestena* is smaller in size than kou with smaller, rough-textured

Top: Leaves, flowers, and ripe fruits. Bottom: Fruits (penknife for scale). PHOTOS: J. B. FRIDAY

leaves, darker orange flowers, and fleshy white fruit. Other ornamental species of *Cordia* include *C. dichotoma, C. alba, C. glabra,* and *C. superba.* Only *C. dichotoma* has naturalized in Hawai'i. *C. alliodora* is a much taller, straighter plantation timber tree. *C. aspera* is a forest tree in Samoa, and *C. speciosa* occurs in New Caledonia. There are about 250 species in the genus *Cordia*; most grow in the New World tropics.

Species variability

Variation is little known aside from minor variations such as in flower color. Kou has been identified as a priority species on several different Pacific islands for further genetic research by the South Pacific Regional Initiative on Forest Genetic Resources (SPRIG 1999).

Known varieties

No established varieties are known, although sometimes a sport with variegated leaves occurs.

ASSOCIATED PLANT SPECIES

Kou trees grow in coastal habitats, both in shrubby beach forests and lowland forests. The trees also occur on the inland edges of mangroves, although they are not a mangrove species. Kou is a frequent component of secondary forests and former habitations.

In native habitat

Kou trees are found in beach forests along with small trees and shrubs such as beach hibiscus (*Hibiscus tiliaceus*, hau), naupaka (*Scaevola sericea*), beach heliotrope (*Tournefortia argentea*), screwpine (*Pandanus* spp., hala), and Indian mulberry (*Morinda citrifolia*, noni), and in tall coastal forests along with milo (*Thespesia populnea*), kamani (*Calophyllum inophyllum*), *Pisonia grandis*, tropical almond (*Terminalia catappa*), beach she-oak (*Casuarina equisetifolia*), and fish poison tree (*Barringtonia asiatica*). Native herbaceous plants commonly include *Canavalia* spp., beach morning glory (*Ipomoea pes-caprae*), and beach pea (*Vigna marina*) (Mueller-Dombois and Fosberg 1998).

As aboriginal introduction in Pacific islands

Kou may be found growing alongside or mixed into coconut and breadfruit plantations, especially on atolls in Micronesia (Mueller-Dombois and Fosberg 1998). Kou trees frequently occur along with introduced coastal stands of *Casuarina* spp., tropical almond, beach heliotrope, and milo in Hawai‘i.

ENVIRONMENTAL PREFERENCES AND TOLERANCES

Climate

Kou most frequently grows in coastal forests and stands, but it may also occur along the margins of mangroves and mixed in with coconut and breadfruit plantations. It occasionally forms small pure stands or thickets. It is a tropical tree and does not grow at higher elevations.

Elevation range

Generally sea level to 30 m (100 ft); it may grow at elevations up to 150 m (500 ft).

Mean annual rainfall

1000–4000 mm (40–160 in)

Rainfall pattern

Grows in climates with summer, winter, or uniform rainfall patterns.

Dry season duration (consecutive months with <40 mm [0.16 in] rainfall)

3–4 months

Mean annual temperature

24–28°C (75–82°F)

Mean maximum temperature of hottest month

28–36°C (82–97°F)

Mean minimum temperature of coldest month

17–25°C (63–77°F)

Minimum temperature tolerated

12°C (54°F)

Soils

Kou grows in sandy and clay soils, and on rocky limestone or lava headlands. It prefers neutral to alkaline soils. Experience in Hawai‘i suggests that kou may not be suitable for use on acid soils, particularly former sugarcane lands.

Soil texture

The tree tolerates light to heavy soils (sands, sandy loams, loams, sandy clay loams, sandy clays, clay loams, and clays).

Soil drainage

Freely draining soils are required.

Soil acidity

Kou prefers neutral soils with pH 6.1–7.4.

Special soil tolerances

It can grow in saline soils.

Tolerances

Drought
Kou is moderately drought tolerant.

Full sun
The tree prefers full sun but can tolerate slight shade.

Frost
It does not tolerate frost.

Waterlogging
Kou grows in coastal areas and along the edges of mangroves where it is subject to occasional waterlogging.

Salt spray
Kou grows in exposed coastal areas where it tolerates steady winds and regular ocean spray.

Wind
Tolerates wind, although constant wind produces leaning and crooked trees (flagging).

Abilities

Regenerate rapidly
Kou is a prolific seeder and may naturally regenerate from seed.

Although tolerant of light salt spray, heavy spray can badly injure leaves. PHOTO: C. ELEVITCH

GROWTH AND DEVELOPMENT

Kou is moderately fast growing when young, if established on a good site, in full sun, near the coast but sheltered from the wind, in rich neutral loamy or sandy soil, with sufficient water. Once the trees reach mature size, 7–10 m (23–33 ft) in height, growth is slow.

Growth rate
On good sites, trees may reach 1–1.5 m (3–5 ft) in height 1 year after planting, 4–5 m (13–16 ft) in 2-year-old plantations, and 7 m (23 ft) after 4 years. Growth is significantly slower in drier or more exposed sites, or if trees are attacked by the leaf worm.

Alley cropping system with kou (foreground) and kamani (*Calophyllum inophyllum*, background) on Moloka'i, Hawai'i. The lean is caused by persistent winds. PHOTO: J. B. FRIDAY

Flowering and fruiting
Flowering may begin when the trees are 3–5

years old. Kou fruits all year long; green and ripe fruits are often found on trees at the same time the trees are flowering.

Yields

No data is available for wood yields.

Rooting habit

Kou has an extensive, shallow root system. It is adapted to shallow and sandy soils and drought.

Reaction to competition

Kou grows poorly in stands of dense, tall grasses.

PROPAGATION

Kou is propagated only by seed. Ripe fruits with viable seeds may be collected under mature trees or picked from the tree. Whole fruits may be sown directly into seedbeds or pots, or they may be soaked overnight. Clipping the ends of the fruits may hasten germination. Fresh seeds are usually used, but they may be stored for up to a year.

Seed collection

Kou seeds all year (most abundantly in the spring), and ripe fruits may be collected at any time. Seedlings may also be found growing under mother trees and may be transplanted if desired.

Seed characteristics

There are 560–700 fruits/kg (250–320 fruits/lb), each containing one to four seeds.

Seed storage

Kou seed is orthodox, meaning that the seed may be dried and stored for a long time. Whole fruits may be dried and stored in cool, dry conditions for up to a year, but viability decreases over time. Fresh seeds picked from trees may have 100% germination; seed picked off the ground may be less viable.

Pre-planting treatments

The woody fruits may be soaked overnight or for up to 2 days to hasten germination. The end of the capsule may be clipped off prior to soaking in water, which is also thought to hasten germination. Seeds are usually not removed from the fruits because it is difficult to do so without damaging them. Whole fruits are sown one to a pot; if multiple seedlings germinate, the extras must be transplanted or rogued out.

Left: Ripe seed capsule (fruit) soaked overnight in water. Above right: The capsule end is clipped off, and one of the delicate seeds is exposed as it begins to germinate. Below right: The outer part of the capsule adjacent to germinating seeds comes loose. PHOTO: C. ELEVITCH

Growing area

Seedlings may be grown in partial shade, and some cover of the growing area is desirable to protect young seedlings from hard rains, but if shaded, seedlings must be hardened off in full sunlight for 4–6 weeks. Germinating seeds must be protected from rats.

Germination

Seeds will take 3–4 weeks to begin germinating, and most will germinate within 6 weeks. Whole fruits may be sown in a germination bed, and the newly-germinated seedlings may be transplanted to pots. Transplants of the seedlings may be made at the cotyledon stage.

Media

A well drained medium is best. A soilless mix of peat moss, perlite, and vermiculite is better drained and less apt to contain diseases than a potting mix containing garden soil. Potting media should be amended with slow-release fertilizers and compost.

Time to outplanting

Kou seedlings may stay in the nursery 6–8 months. Seedlings usually grow slowly for the first 6–10 weeks, then grow more rapidly. The rapid growth phase in the nursery may last 4–6 months, including hardening off in full sun during the last 4–6 weeks before planting.

Approximate size at time of outplanting

Seedlings ready for outplanting are approximately 40–50 cm (16–20 in) in height.


Left: Pregerminated seedlings in flats, showing one ready to outplant grown in a container measuring 6 x 6 x 13.3 cm (2.4 x 2.4 x 5.25 in). Right: Nursery-grown seedlings showing symptoms of fungal disease. PHOTOS: C. ELEVITCH

Guidelines for outplanting

Survival is typically high, although transplanted seedlings grow slowly at first and need to be protected from weeds until the tree canopies are well above the weeds.

Other comments on propagation

Seedlings may be susceptible to fungal diseases, especially if over-watered or grown in wet, cool areas. Watering in the early morning allows leaves to dry out during the day. Spacing seedlings widely in the nursery allows more light penetration into the canopy and better air circulation. Establishing the nursery in a coastal area may also help prevent diseases. Seedlings should be hardened off in full sun with infrequent watering before outplanting, and they should be kept in their containers until outplanting.

DISADVANTAGES

Kou is a hardy tree in coastal environments but unsuitable for uplands and acid soils. It is occasionally attacked and sometimes killed by the kou leaf worm. The heartwood is valuable, but the tree does not grow rapidly. Boles are small and often crooked. Kou trees seed prolifically, and the round, hard fruits may be a hazard for pedestrians when the tree is planted in urban areas.

Potential for invasiveness

Kou seeds prolifically and could become a weedy pest in new areas. It is native to almost the entire Pacific, though, and as such would not be considered an alien weed.

Diseases and pests

Kou is highly susceptible to damage from the kou leaf worm (*Ethmia nigroapicella*). The small moth has pinkish forewings with black spots and yellowish hind wings. Isolated trees in exposed areas may be killed by this pest. The tree was once more common in Hawai‘i before the introduction of the moth, which was first recorded there in 1883 (Swezey 1943). The wood is very termite resistant (Grace and Tome 1995). Large trees may develop heart rot.

Other disadvantages or design considerations

Kou has failed to survive or grow well in plantation trials in Hawai‘i on deep, acid soils at 380 m (1250 ft) elevation with 2000 mm (80 in) rainfall at ‘Ōpae‘ula, O‘ahu; on deep, acid soils with 2000 mm (80 in) rainfall at 150 m (500 ft) elevation at Maunawili, O‘ahu; on thin, acid soil derived from organic matter over ‘a‘ā lava rock, at elevation 180 m (600 ft) and rainfall 4000 mm (160 in) at Waiākea, Hawai‘i; and on deep, acid soils at 125 m (415 ft) elevation with 1100 mm

Natural regeneration of kou under a mother tree. PHOTO: J. B. FRIDAY

(43 in) rainfall in Kīpū, Kaua'i. All trials were fertilized and planted in single-species blocks.

AGROFORESTRY/ENVIRONMENTAL PRACTICES

Homegardens

Kou is frequently planted around homes, particularly for shade on the hot, leeward sides of islands.

Living fences

Kou trees are used for living fences and to mark boundaries and former settlement areas.

Boundary markers

In former times, kou trees marked settlements.

Windbreaks

Kou trees are fairly resistant to coastal winds and salt spray and are used for windbreaks. Because the crown on exposed trees may be sparse, other species should be combined with kou if good protection is needed. Naupaka (*Scaevola sericea*) would make a good, thick, low barrier if planted between kou trees while beach she-oak (*Casuarina equisetifolia*), where native, and milo (*Thespesia populnea*) would work well to create a denser windbreak.

Coastal protection

Kou's tolerance of wind and salt spray, preference for sandy soils, and drought tolerance make it an excellent species for coastal protection. The abundant natural regeneration can form dense stands protecting coastal areas.

Ornamental

Kou is a favored ornamental tree in coastal areas in the Pacific because of its relatively small size, its salt and wind tolerance, and its beautiful flowers. The tree's cultural importance also is another reason to plant it, even if it will never be harvested for wood.

USES AND PRODUCTS

Nut/seed

The seeds, carefully removed from the woody fruit, have been eaten in times of famine (Clarke and Thaman 1993).

Medicinal

The leaves have been reported to have medicinal properties.

Beautiful/fragrant flowers

The beautiful orange kou flowers have been used for leis, although they only last a short time.

Kou makes a very attractive ornamental in public areas and shopping centers. PHOTO: C. ELEVITCH


Left: Kou flower. Right: A kou bowl by Ed Pavao, Hawai'i, showing creamy sapwood and dark heartwood. PHOTOS: J. B. FRIDAY

Animal fodder

Kou leaves have been used as fodder for pigs in Kiribati and elsewhere.

Fuelwood

Kou burns readily, and wood that is left over after the best pieces have been used for carving or other purposes may be used for fuelwood. The flammability of the wood has earned it the nickname "kerosene wood" in Papua New Guinea.

Craft wood/tools

Kou wood is light to moderately dense, ranging in specific gravity from 0.45 to 0.65. The sapwood is light tan colored, occasionally pinkish, while the heartwood is brown with dark brown to black streaks, sometimes with purple tones, often nicely figured. The wood is finely textured, moderately durable, shrinks little, and takes a fine polish. In ancient times the wood was used for cups, bowls, and calabashes. Small pieces were made into small storage boxes, containers, and lids for calabashes. Kou wood was favored because it was easily worked and did not impart a taste to the food. Ancient Hawaiians made large calabashes, called 'umeke lā'au, from kou for storing and fermenting poi. These could hold 8–16 liters (2–4 gal) of food (Abbott 1992). Today the wood is used for ornamental carving, turning, storage containers, small furniture, and carved figurines. In the Cook Islands the wood is used for carving traditional figures and making musical instruments.

Canoe/boat/raft making

Kou is sometimes used for canoes or paddles if large enough trees are found.

Body ornamentation/garlands

The bright orange flowers are traditionally favored for leis. The flowers have a wide floral tube that makes for easy stringing with the materials available to the ancients, such as beach hibiscus (*Hibiscus tiliaceus*, hau) fiber. It is easy to see how this lei was made in days of old without metal lei needles.

Tannin/dye

In old Hawai'i, the leaves were used to dye *kapa* (bark) cloth tan and for coloring fishing lines to make them less visible (Abbott 1992).

Ceremonial/religious importance

The tree is significant culturally and in traditional religions in the Pacific. Kou groves were often planted around sacred places, and kou figures in Pacific island mythology.

URBAN AND COMMUNITY FORESTRY

In old Hawai'i and other Pacific islands, kou trees were planted around houses and living areas to give shade in the hot coastal areas and provide wood for carving and flowers for leis. An introduced insect pest, the kou leaf worm, decimated kou populations in Hawai'i a century ago, and the tree has become much less common. Overharvesting elsewhere in the Pacific has also contributed to the tree's scarcity. Growing kou trees brings a native Pacific island tree back into the urban landscape and may in time create a supply of wood to perpetuate local wood carving traditions.

Size

In a landscape or homegarden setting, kou trees usually reach only about 7–10 m (23–33 ft) in height and are often smaller in exposed environments. Canopy spread may be as wide as the tree is tall.

Rate of growth in a landscape

Kou trees may grow up to 1.5 m (5 ft) in height per year in the first few years, but height growth is more typically 1 m (3.3 ft) per year with stem diameter growth of 1.5–3 cm/yr (0.6–1.2 in/yr). The tree's canopy may be sparse for the first few years.

Roots

Kou has an extensive, shallow root system. Its root system is probably very competitive with other plants nearby.

Products commonly used in a Pacific island household

The rich brown wood is easily worked and was traditionally used for carving calabashes and other food vessels. Unlike koa (*Acacia koa*), another prime Hawaiian timber used in woodcarving, and some other woods, kou wood does not impart a taste to food. Today kou wood is sought after by bowl turners and carvers. In areas where kou is abundant it makes excellent firewood. The bright orange, tubular flowers are strung into beautiful but short-lived leis.

Light requirements

Kou prefers full sun but will tolerate light shade.

Water/soil requirements

The tree grows in rocky or sandy soils along shorelines. It generally does not do well in heavy acid clay soils. Kou is tolerant of salt spray and is moderately wind tolerant.

Top: Densely planted kou hedge around a home, Hōnaunau, Hawai'i. PHOTO: C. ELEVITCH **Bottom: Kou leaf worm and the typical damage it does to leaves.** PHOTO: J. B. FRIDAY

Expected life span in a homegarden

Huge old kou trees are seldom seen in Hawai'i and most Pacific islands today, but the trunk can grow to over a meter (3.3 ft) in diameter. Such giants must be over a century old.

Varieties favored for use in a homegardens or for street trees

Trees with green and white variegated leaves have been known to occur.

Seasonality of leaf flush, flowering, fruiting

Kou flowers and fruits year round.

Exceptional ornamental values

It is an attractive tree with smooth gray bark and dense foliage interspersed with bright orange flowers.

Use as living fence, hedge, or visual/noise barrier

Kou trees, planted densely, make an effective barrier or windbreak in coastal areas.

Maintenance requirements

Kou trees require care when transplanting. Root injuries or excessive wetness in transplanting sites can lead to diseases. Holes for transplanting should be dug twice as wide as the root ball but no deeper. Seedlings should not be root-bound; any roots curving along the bottom of the container should be gently unwound before planting. Seedlings grown in dibble tubes or specialized tree-growing containers are best for windbreaks or forestry projects. Larger trees up to 1.5 m (5 ft) tall grown in large containers may be planted for landscaping purposes. Trees benefit from initial applications of fertilizer or compost. Mulch helps retain water in dry areas and keeps down weeds. Young trees should be watered until they are well established, especially if they are planted in sandy soils with low water-holding capacity. Mature trees are moderately drought tolerant.

Kou trees are usually crooked and may have multiple stems. Proper pruning is necessary to establish good form. Young seedlings may be spindly for the first couple of years until the full canopy develops. Thickets of young trees may grow up from seeds around mature trees.

Special considerations regarding leaf, branch, and fruit drop

Kou trees can sometimes be difficult to establish and generally do not do well away from the coast. They grow best below about 30 m (100 ft) in elevation. The prolific regeneration under the trees may also pose a problem if other groundcovers are desired.

Nuisance issues

None.

Hazards

The trees seed prolifically and drop large quantities of hard, marble-sized fruits. People walking on streets or sidewalks with these fruits underfoot could easily slip—a very real hazard.

Common pest problems

The kou leaf worm (*Ethmia nigroapicella*) attacks and defoliates kou, and severe infestations may kill trees. Kou was much more common in Hawai‘i before the introduction of the leaf worm in the late 1800s. Today attacks seem to be less severe, and most healthy trees recover from occasional attacks of the moth.

Kou seedlings are susceptible to attack by several pathogenic fungi, including *Pythium*, *Phytophthora*, and *Fusarium*. These fungi can be controlled by avoiding both overwatering in the nursery and injuring the roots when the trees are transplanted.

Other comments

In plantings in urban areas in Hawai‘i, the true kou, *Cordia subcordata*, has often been replaced by the Geiger tree, *Cordia sebestena*, mainly because the Geiger tree is not attacked by the kou leaf worm. The Geiger tree has similar foliage to the kou tree but red instead of orange flowers and soft white fruits. While it is an acceptable ornamental, Geiger tree is native to the West Indies and has no traditional uses in the Pacific.

KOU LORE

In Tuamotuan mythology kou is believed to be one of the first trees created. In a Tongan legend, the demigod Maui discovered fire and hid it in the kou tree, the breadfruit, and the coconut. The tree is a clan totem in Kiribati (Neal 1965).

In Hawai‘i kou was traditionally planted around houses and the flowers were used for leis. One story is told of a young chieftess who saw an old woman at the seashore in ‘Ewa on leeward O‘ahu stringing a lei of kou blossoms. The girl asked for the lei, whereupon the old woman angrily told her to make her own. The girl went and bathed in the sea and returned, again asking for the lei. The third time she asked for the lei, the old woman called for the sharks to come and eat her, and they heard the old woman and came and pulled the girl into the ocean and devoured her. The people of ‘Ewa since that time have refused to wear kou leis (Neal 1965).

A Hawaiian verse runs:

The cold wind of Kahaloa
Scattering the blossoms of the kou,
Stringing them into garlands and carried,
To wreath the sea of Kapua.
(Handy et al. 1991)

In Melanesia the wood is used for fuel and fires reportedly may be started by rubbing two pieces of kou wood together, hence the name “kerosene wood” in Papua New Guinea.

COMMERCIAL PRODUCTS

While kou wood is valuable, stands of kou trees have seldom been planted for wood production. Rather, wood has been harvested from ornamental trees or those planted in homegardens. Kou's value may be even more as a landscaping tree and cultural icon than for its wood.

Spacing for commercial production

When planting kou trees in a landscape setting, it should be kept in mind that the trees may grow to be broader than they are tall. Kou tends to be crooked, even when it grows in dense natural thickets, so close spacing of timber trees would be unlikely to produce straight boles. In a landscape setting, trees should be at least 6 m (20 ft) apart, while in a forestry setting they could be planted as close as 3 m (10 ft) apart.

Alley cropping system with kou, ornamental ginger, and kava in understory on Moloka'i, Hawai'i. PHOTO: J. B. FRIDAY

Management objectives

Kou trees are intolerant of shading, and seedlings need to be kept weeded when they are young.

Design considerations

When using kou as a landscape tree, it should be planted far enough away from sidewalks so that the seeds do not fall on the sidewalk and cause a hazard for pedestrians. Kou tolerates light shade and may be grown in mixed gardens with coastal agroforestry trees such as breadfruit and coconut.

Yields

No data available.

Market

The markets for kou wood are usually local carvers, bowl turners, and artisans. In Hawai'i the wood is often reserved for the most highly skilled carvers. A single large log could sell for thousands of dollars, but large logs are very rare.

INTERPLANTING/FARM APPLICATIONS

Example system 1

Location

Moloka'i, Hawai'i.

Description

An alley cropping demonstration was planted by the University of Hawai'i on former agricultural land on the island of Moloka'i in 1995 with kou, kamani (*Calophyllum inophyllum*), milo (*Thespesia populnea*), and kukui (*Aleurites moluccana*). The site is dry and windy, with only 460–530 mm (18–21 in) of rainfall annually, and is 150 m (500 ft) above sea level. The soil is classed as a typic Torrox in the USDA classification, with pH 6.5. Alfalfa for forage was grown between the trees until the canopies closed; after that a number of shade-tolerant crops were planted, including ornamental ginger, edible mushrooms, kava, and cacao.

Yields

Tree growth is satisfactory; kou trees averaged 7 m (23 ft) in height with the tallest growing 9 m (30 ft) in 7 years. The constantly high winds have caused the trees to lean over, however, and the effect of the stress on wood quality is unknown. Crop production is less than would be expected in full sun but is nonetheless significant.

Crop/tree interactions

Crop yield, even for the shade-tolerant crops (except for the edible mushrooms), is reduced because of shading. However, the trees also serve as windbreaks, without which fragile crops such as kava would not grow at all. The crops receive supplemental irrigation, which also benefits the trees.

Spacing/density of species

The trees were planted in wide rows 5 m (15 ft) apart with 3 m (10 ft) spacing within the rows.

Example system 2

Location

Aitutaki, Cook Islands.

Description

In an effort to conserve the increasingly rare trees, kou and milo have recently been planted along roadsides in coastal areas (Clarke and Thaman 1993).

Yields

Kou is used by local woodcarvers to make traditional figurines and musical instruments.

PUBLIC ASSISTANCE AND AGROFORESTRY EXTENSION

Extension offices for agroforestry and forestry in the Pacific: http://www.traditionaltree.org/extension.html

INTERNET

A description of the use of kou in old Hawai'i: Canoe Plants of Ancient Hawai'i: <http://www.canoeplants.com>.

A detailed description of kou propagation: Native Plants Network: <http://www.nativeplantnetwork.org>.

Photos of kou: Campus plants at the Mānoa Campus of the University of Hawai'i: <http://www.botany.hawaii.edu/faculty/carr/160webindex.htm>.

Examples of wood carving using kou in the Cook Islands: <http://www.atiutourism.com/carving.htm>.

University of Hawai'i College of Tropical Agriculture and Human Resources Landscape Series: <http://www2.ctahr.hawaii.edu/ctahr2001/PIO/FreePubs>.

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traditional tree initiative

Species Profiles for Pacific Island Agroforestry (www.traditionaltree.org)

Cordia subcordata (kou)

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Acknowledgments: The authors and publisher thank Heidi Bornhorst, Dietmar Braetigaum, Dale Evans, Heidi Johansen, Jim Hollyer, Art Whistler, and Ed Winkler for their input. The authors also thank the series editor for text suggestions and photographs and Rogerene Arce for contributing growth data.

Recommended citation: Friday, J.B., and D. Okano. 2006. *Cordia subcordata* (kou), ver. 3.1. In: C.R. Elevitch (ed.). Species Profiles for Pacific Island Agroforestry. Permanent Agriculture Resources (PAR), Hōlualoa, Hawai'i. <http://www.traditionaltree.org>.

Sponsors: Publication was made possible by generous support of the United States Department of Agriculture Western Region Sustainable Agriculture Research and Education (USDA-WSARE) Program; SPC/GTZ Pacific-German Regional Forestry Project; USDA Natural Resources Conservation Service (USDA NRCS); Kaulunani, an Urban Forestry Program of the DLNR Division of Forestry and Wildlife and the USDA Forest Service; State of Hawai'i Department of Land & Natural Resources Division of Forestry & Wildlife; USDA Forest Service Forest Lands Enhancement Program; and Muriel and Kent Lighter. This material is based upon work supported by the Cooperative State Research, Education, and Extension Service, U.S. Department of Agriculture, and Agricultural Experiment Station, Utah State University, under Cooperative Agreement 2002-47001-01327.

Series editor: Craig R. Elevitch

Publisher: Permanent Agriculture Resources (PAR), PO Box 428, Hōlualoa, Hawai'i 96725, USA; Tel: 808-324-4427; Fax: 808-324-4129; E-mail: par@agroforestry.net; Web: <http://www.agroforestry.net>. This institution is an equal opportunity provider.

April 2006
ver. 2.1

Endospermum medullosum (whitewood)

Euphorbiaceae (spurge family)

***a'asa*, *kakadikana* (Solomon Islands); *kumaro*, *napasa* (Vanuatu); PNG basswood (PNG); whitewood, whitewud (Vanuatu)**

Lex A. J. Thomson

IN BRIEF

Distribution The natural range extends from Indonesia (West Papua or Irian Jaya) through Papua New Guinea, the Solomon and Santa Cruz Islands, to Vanuatu.

Size Typically 20–40 m (66–132 ft) tall at maturity.

Habitat Lowland, humid tropics, 0–350 m (0–1150 ft), mean annual temperatures of 22–28°C (72–82°F), annual rainfall of 1500–5600 mm (60–220 in), uniformly distributed.

Vegetation Plays an important environmental role in revegetation of various types of disturbed sites.

Soils Wide range of soils, especially alluvials and seasonally inundated soils.

Growth rate Grows very rapidly in height, 2.5–3 m (8–10 ft) annually until an age of about 10 years, after which growth slows.

Main agroforestry uses Mixed-species woodlot, silvopasture.

Main products Timber.

Yields Wood yields of 20–30 m^3/ha/yr (286–429 ft^3/ac/yr) are expected to be obtainable on fertile sites.

Intercropping Short-term agricultural or timber crops can be grown.

Invasive potential Whitewood is potentially invasive outside its native range.

PHOTO: L. THOMSON

Tree at Khole, Santo, Vanuatu.

INTRODUCTION

Whitewood (*Endospermum medullosum*) is a useful timber species with excellent forestry plantation and agroforestry potential in the South Pacific region. It occurs naturally on the island of New Guinea, extending through the Solomon Islands to Vanuatu as far south as the island of Erromango. The species predominately occurs in lowland, humid tropical climates where rainfall is high, typically 2500–4500 mm (100–180 in) per annum, with no pronounced dry season. The tree has been reported growing on a wide range of soil types, especially alluvials.

Whitewood grows into a large, spreading tree 20–40 m (66–132 ft) tall. It is dioecious, i.e., there are separate male and female plants. It may be classified as an early secondary species with some pioneer characteristics. It is shade intolerant and can only regenerate and persist when sizeable gaps in the canopy are created and maintained. Natural regeneration after logging or extensive storm damage is often prolific, especially where this is accompanied by soil disturbance. Young trees may be shaded out by other faster-growing pioneers or smothered by climbers. Trees of all ages have good cyclone resistance, mainly losing leaves and lateral branches during strong winds.

Whitewood is the major commercial timber species in Vanuatu, and it is also milled and marketed extensively in Papua New Guinea (PNG) along with two related *Endospermum* species under the trade name PNG basswood. Traditionally the tree was used to a fairly limited extent for canoes, firewood, and medicines.

Whitewood has a rather soft, low-medium density timber in which both heartwood and sapwood have a light, whitish color. The texture is intermediate and even, and the grain is usually straight. It is readily kiln dried and not prone to surface checking. It is non-durable in ground contact but readily treatable with preservatives, including in the green condition. The timber is easy to saw and machine and produces an excellent finish that is readily stained. It is mainly used for light construction, furniture, and interior joinery.

In Vanuatu the species grows rapidly and its timber is in high demand, both locally and for export. The Department of Forests has encouraged planting of the species by smallholder farmers by providing seedlings and silvicultural information. These plantings may take the form of either agroforestry plantings or woodlots (Sam 1997). Whitewood is potentially invasive outside its native range.

DISTRIBUTION

Native range

Whitewood is distributed from Indonesia (West Papua or Irian Jaya) through Papua New Guinea, the Solomon and Santa Cruz Islands, to Vanuatu. In Indonesia it is recorded from several islands on the northern and western sides of Irian Jaya, namely Salawati, Biak, and Yapen Islands (Airy Shaw 1980a). The species is widespread in PNG, including New Guinea (West and East Sepik, Madang, and Morobe Provinces), Papua (Gulf, Northern, and Milne Bay Provinces), Bismark Archipelago (Manus and New Britain), and Bougainville (Smith 1947, Airy Shaw 1980a). The species is reported to be widespread in the Solomon and Santa Cruz Islands (Whitemore 1966). In Vanuatu whitewood is found on most islands north of Erromango, including Vanua Lava and Gaua (in the Banks group), Espiritu Santo, Malo, Maewo, Ambae, Pentecost, Malekula, Paama, Epi, the Shepherd Islands, Efate, and Erromango (Sam 1997, Wheatley 1992). The species is not presently being cultivated outside of its natural range.

BOTANICAL DESCRIPTION

Preferred scientific name

Endospermum medullosum L. S. Smith

Family

Euphorbiaceae (spurge family)

Common names

PNG Basswood (PNG)
Whitewood or whitewud (Vanuatu)

Local names

a'asa (Solomon Islands: Kwara'ae)
kakadikana (Solomon Islands: Roviana)
kumaro (South Maewo, Vanuatu: Baetora)
napasa (Espiritu Santo, Vanuatu: Matantas)

Size

The tree is typically 20–40 m (66–132 ft) tall, reaching a maximum height of 54 m (177 ft). The bole is typically long and fairly straight, although twisted and kinked, uneven, and/or leaning trees occur. The length of clear bole is generally 10–24 m (33–79 ft) (exceptionally to 36 m [118 ft]). The diameter above buttresses may reach more than 1 m (3.3 ft), but more usually the diameter of mature specimens is in the range 50–80 cm (20–31 in).

Typical form

Mature specimens have a distinctive appearance characterized by shallow, flat-topped, and umbrella-like crowns and massive horizontal branches in distinctive tiers. Young and pole-stage specimens exhibit a rather cylindrical bole: the crown is monopodial, with a single, straight leader and branches in whorls.

Flowers

The species is dioecious, i.e., male and female flowers are borne on different trees. The inflorescence consists of axillary panicles, 10–19 cm (4–7.5 in) long, with racemose branches to 4 cm (1.6 in) long, and a covering of stellate hairs. Bracts and bracteoles are 1.5–2 mm (0.06–0.08 in) long, triangular. Flowers are small, greenish white, and arranged in axillary spikes; bisexual flowers are rarely present; the calyx is indistinctly 4-lobed; petals are absent. Male flowers have a calyx ca. 1.5 mm (0.06 in) long; 5–7 stamens, spirally arranged, 4–valved anthers, and are fragrant. Female flowers have pedicels 3–4 mm (0.12–0.16 in) long, a calyx ca. 1 mm (0.04 in) long, and have a tomentose ovary, 1-locular, stigma sessile, discoid, lobed, ca. 1 mm (0.04 in) wide.

Branchlet showing growing tip. PHOTO: L. THOMSON

Leaves

Leaves are simple/entire, large 8–25 (–33) cm long by 5.5–20 (–25) cm across (3.1–7.9 [–13] in. long by 2.2–3.1 [–10] in. across) cordate or peltate, mid-dark green/sub-shiny and finely softly hairy above and light silvery-green and densely hairy below. The leaves are spirally arranged and bunched in clusters at branch ends (Whitmore 1966). The underside of the leaf and petiole has a distinct indumentum (hairs). Venation is reticulated, conspicuous raised. Small glands occur at major nerve junctions. Juvenile foliage is much larger, often several times the size of mature leaves, and with both surfaces covered in dense, soft hairs.

Fruit

Fruits are borne in panicles. At maturity each fruit consists of a small, firm/fleshy, ovoid capsule, 8–9 mm (0.31–0.35 in) long and 5–6 (–7) mm (0.2–0.24 [–0.28] in) diameter; light grayish green, ripening to light yellowish green.

Seeds

Fruits do not split, and they encase a single brown to black seed about 6 mm long by 4 mm across (0.24 x 0.16 in).

Similar or look-a-like species

Whitewood is most closely related to *E. myrmecophilum* L.S. Smith and *E. domatiophorum* Schaeffer (Schaeffer 1971, Airy Shaw 1980a).

E. myrmecophilum from Australia and Papua New Guinea is only reliably distinguishable from whitewood by the weaker indumentum (hairs) and less prominent venation on the leaf undersurfaces. As the name suggests, *E. myrmecophilum* has a close relationship with an ant, *Camponotus quadriceps*, and where this ant species occurs its branchlets are swollen, hollowed, and colonized by these ants. The leaves of young plants of *E. myrmecophilum* differ in having two large, swollen/flattened, sub-globose petiolar glands about 6 mm (0.24 in) across, whereas *E. medullosum* has two small petiolar glands, globose/rounded, about 1–1.5 mm (0.04–0.06) across and four to eight pairs of small glands, about 1 mm (0.04 in) across at major leaf junctions on the undersurface of the leaf blade. The upper stems of *E. myrmecophilum* are hairier (finely puberolous/tomentose) and the stipules, located at base of petiole, are shorter, 2–3 mm (0.08–0.12 in) long compared with 6–8 mm (0.24–0.3 in) long in *E. medullosum*.

E. domatiophorum from PNG has two domatia (pitted glands) instead of solid glands in the main nerve-axils and in the usually non-hairy leaf undersurface (Airy Shaw 1980a).

Top: Smaller petiolar gland on underside of whitewood leaf (top left) aids in distinguishing it from *E. myrmecophilum* (top right). Bottom: *E. myrmecophilum* (taller plants on left) and *E. medullosum* at 6 months of age, Santo, Vanuatu. PHOTOS: L. THOMSON

GENETICS

Variability of species

A high level of variation in growth and morphology is observed in Vanuatu populations. In SPRIG/Department of Forestry field trials at Shark Bay, Santo, the fastest growing sources in Vanuatu at age 4 years were from lowland parts of east and southeast Santo (Smith et al. 2003).

Known varieties

None.

ASSOCIATED PLANT SPECIES

In PNG it grows with *Homalium*, *Pterocymbium*, *Pometia*, and *Pterocarpus*. In Vanuatu it is the co-dominant or dominant species with *Antiaris toxicara*, *Elaeocarpus*, *Terminalia*, and others. It grows in two associations: at mid-elevation with *Calophyllum neo-ebudicum*, *Elaeocarpus* sp., *Syzygium* sp., and *Antiaris toxicaria*, and at low elevations with *Macaranga* spp., *Pangium edule*, *Antiaris toxicaria*, *Pterocarpus indicus*, and *Dysoxylum* spp. (Sam 1997). In the Solomon Islands, whitewood commonly occurs with *Campnosperma brevipetiolata* in previously disturbed areas (Marten 1980).

ENVIRONMENTAL PREFERENCES AND TOLERANCES

Climate

Whitewood predominately occurs in the lowland humid tropics.

Elevation range

0–350 (–1000) m (0–1150 [–3280] ft)

Mean annual rainfall

1500–5600 mm (60–220 in). Typical rainfall is 2500–4500 mm (100–180 in).

Rainfall pattern

Whitewood prefers climates with summer or uniform rainfall patterns.

Dry season duration (consecutive months with <40 mm [1.6 in] rainfall)

0 months

Mean annual temperature

22–28°C (72–82°F)

Mean maximum temperature of hottest month

29–32°C (84–90°F)

Mean minimum temperature of coldest month

15–24°C (59–75°F)

Minimum temperature tolerated

6–10°C (43–50°F)

Soils

In New Guinea the species has been reported growing on a very wide range of soil types, especially alluvials, including clays, gravelly alluvials, sandy clays, grey sandy loams of considerable depth, and seasonally inundated soils. In the Solomon Islands *E. medullosum* prefers drier inland lowland sites but is also found on damp alluvial soils. On Santo, Vanuatu, the species grows on ferralitic Cambisols, soils of good fertility formed over raised limestone.

Soil texture

The tree grows in light to heavy soils (sands, sandy loams, loams, and sandy clay loams, sandy clays, clay loams, and clays).

Soil drainage

Freely draining soils are preferred, but it tolerates soils that are seasonally waterlogged or shallowly inundated for short periods

Soil acidity

Neutral to acid soils (pH 7.4–4.0).

Tolerances

Drought

Because the tree grows in high-rainfall areas with no dry season, drought tolerance is expected to be limited.

Full sun

The tree prefers full sun but will tolerate 0–15% shade.

Fire

The tree's tolerance of fire is expected to be limited, as it has not evolved in fire-prone environments.

Frost

It does not grow in frost-prone regions, so it is unlikely to tolerate frost.

Waterlogging

Mature trees can tolerate up to a few weeks of shallow inundation less than 1 m (3.3 ft) in depth.

Salt spray

Expected to be limited, as it does not naturally occur in near-seaside situations.

Wind

With increasing wind speed the damage is usually leaf loss and then breakage of lateral branches. During cyclones some breakage of tops of smaller trees may occur.

Sapling after Cyclone Zuman, Santo, Vanuatu. PHOTO: L. THOMSON

Early findings on species susceptibility to cyclones showed whitewood as resistant to cyclones in Vanuatu (Neil 1987), although Marten (1980) has observed damage from strong winds in the Solomon Islands.

ABILITIES

Regenerate rapidly

It has good regeneration ability in gaps following logging and in garden areas. In open sites and large gaps it can be overtopped and shaded out by faster-growing pioneers, such as *Macaranga* or *Merremia* vines.

Self-prune

The tree has a very good self-pruning habit.

Coppice

Coppices well up to 3–4 years of age; thereafter coppicing ability is low and variable.

The author inspects coppice shoots. PHOTO: K. AKEN

Pollard

Pollarding ability is expected to be good even in older specimens.

GROWTH AND DEVELOPMENT

In fertile, sunny locations young plants grow very rapidly. In order to keep whitewood trees growing vigorously beyond the first 5–10 years, it is essential that they are provided with increased space to grow. This can readily be achieved in managed systems through timely, selective thinnings.

Growth rate

The tree is fast growing, with height growth in early years of 2.5–3 m (8–10 ft) per year. Height growth falls off considerably after about 7–10 years. Diameter increment also slows with age, e.g., 3–4-year-old trees have a diameter of about half that of trees 20–25 years old.

Flowering and fruiting

In plants grown under optimum conditions, flowering and fruiting first occur at about 3–4 years of age. However, plants need to attain 4–6 years of age before flowering is widespread and large quantities of fruit are produced.

Rooting habit

The major part of the root system consists of widely spreading, shallow lateral roots.

Reaction to competition

It dislikes overhead shading from neighboring plants.

PROPAGATION

Whitewood may be raised either from seedlings, small wildings (Marten 1980), or vegetative cuttings (Walker et al. 1996).

Propagation by seed

Seed collection

Collection times vary geographically: In PNG fruiting has been reported throughout the year, but the peak periods appear to be May–June and September–October. In the Solomon Islands fruits are mostly collected in January–March. In Vanuatu, fruiting occurs from February to May and August to October, with March–April being the best and most reliable months for collection.

Fruits are mature and ready for collection once some fruits in a bunch change from darker green to lighter green and turn soft. At this stage some fruits may fall and/or be consumed by birds.

The preferred collection method is to lob a rope over a large, fruit-bearing branch (e.g., by throwing or using a big-shot catapult with a weighted end), breaking off the branch, and hand picking the fruit bunches from the branch on the ground.

There are 9000–9600 fruits/kg (4090–4360 fruits/lb). A kilogram of fruit yields 30,000–35,000 freshly depulped seeds/kg (13,600–15,900 seeds/lb) (Ngoro 1988, Leslie 1994). Initial seed viability is highly variable and often very low due to damage by wasp larvae. Seeds appear to be intermediate or recalcitrant and should be collected when mature and sown as soon as possible after collection.

Propagule processing

Non-viable, wasp-infested fruits float in water, and these should be discarded at the time of collection. This flotation test should be done at the time of collection, as good fruits may float after a short period (e.g., less than 6–12 hours) of drying.

Ideally, seeds should be sown within a few days of collec-

Top: Fruit collection on Santo, Vanuatu. Bottom: Seedling/nursery, Shark Bay, Santo, Vanuatu. PHOTOS: L. THOMSON

tion, and they may be sown without removal of the outer pulpy fruit layer. If seeds are to be stored then it is recommended that the pulpy fruit layer be rubbed off on a wire mesh, washed, and the seeds air-dried under shade. The cleaned seed should be spread out in a thin layer to facilitate drying preferably on a well ventilated rack or absorbent surface. The period of air-drying varies depending on local conditions, but it is likely to take about 1 day under well ventilated conditions.

Seed storage

The most appropriate conditions for storage of seed are yet to be established. It is suggested that seed be stored moist in a well aerated medium, such as slightly moistened peat moss or sawdust in a plain cotton or open plastic bag, at a uniformly low–intermediate temperature of 10–15°C (50–59°F). Rigid, sealed storage containers should be used where there is the risk of seed loss from insect pests and vermin, such as rodents.

Pre-planting treatments

No scarification of seeds (or depulping of fruits) is required prior to sowing.

Growing area

Full sun is preferable, but seed may be germinated in partly shaded conditions (up to 25% shade).

Germination

Germination generally takes 2–5 weeks.

Media

A freely draining loam is preferred.

Time to outplanting

With good nursery practices, seedlings are ready to plant out in 14–16 weeks.

Approximate size

The optimal height for outplanting is considered to be about 25 cm (10 in).

Other comments on propagation

Given the often very low seed viability, it is advisable to sow the seed into open beds and prick out into containers as germinants emerge. Seedlings may be raised in rigid tapering plastic pots (12 cm deep, 250 cm^3 [5 in deep, 15 in^3]) and need to be given ample space, e.g., 50 seedlings per m^2 (4.5 seedlings/ft^2) to avoid crowding/shading and development of spindly seedlings (Walker et al. 1996). Root pruning and hardening off the seedlings in full sun prior to planting are important (Marten 1980).

Guidelines for outplanting

Good pre-planting weed control, especially elimination of the vine *Merremia peltata*, is essential: this can be achieved by a combination of cattle-grazing followed by glyphosate herbicide. Seedlings are best field-planted at the onset of the wet season, and growth is rapid in well hardened seedlings. Regular weed control must be done during the first 3 years on an as-needed basis. This may be as often as every 6 weeks during the wet season. However, young trees grow rapidly on favorable sites and cast heavy shade, so that minimal tending is required beyond 3 years.

Propagation by cutting

The species is readily propagated from cuttings taken from young hedges when set under mist. It is possible to grow plants suitable for field planting by directly setting 20–25 cm (8–10 in) long terminal cuttings directly into containers (Walker et al. 1996).

The potential benefits of using cuttings are:

- overcoming lack of availability of viable seed
- the capability to rapidly propagate superior populations, families, or individuals that have been identified in trials (Walker et al. 1996).

DISADVANTAGES

Potential for invasiveness

The species has several colonizing traits, including rapid early growth and production of heavy fruit crops that may be consumed and widely dispersed by certain bird species. In favorable environments it may constitute a minor environmental weed hazard. Whitewood is potentially invasive outside its native range (needs further evaluation).

Diseases and pests

In Vanuatu, relatively minor pests and diseases recorded in young plantations of whitewood include a defoliating black weevil, skeletonizing moth larvae (*Cyfura bifusciata* or *Urapteroides astueniata*), and a leaf fungus (*Phaeoseptoria* sp.) (Leslie 1994). Rat damage (eating tips of branches) and cattle damage (stripping of bark) have also been observed in commercial plantations in Santo. In the Solomon Islands the leaves of young trees are often skeletonized but the damage is not serious (Marten 1980). A wasp larva (*Syceurytoma* sp., family Eurytomidae) may cause considerable damage to developing seed crops, with over half of fruits being damaged (Leslie 1994). A study of brown root rot (caused by *Phellinus noxius*) established that whitewood was highly resistant to the disease (Ivory and Darubi 1993). In PNG, severe defoliation of juvenile leaves was recorded on a trial in Lae in September caused by an unidentified caterpillar.

Host to crop pests/pathogens

The tree is not reported to be a host for crop pests and pathogens.

Other disadvantages or design considerations

Cattle must be excluded from young plantings (at least for the first 4–5 years), as they may cause extensive damage and kill young trees by chewing the bark.

Hedge for production of cuttings for propagation. PHOTO: L. THOMSON

Obtaining sufficient seed for propagation is a potential limitation, as it is difficult to collect large quantities of viable seed from native stands due to damage from seed wasp larvae. Cleaned seed appears to lose viability in transit, as seed exchanged between different countries often has low viability.

AGROFORESTRY/ENVIRONMENTAL PRACTICES

Mulch/organic matter

The leaves break down moderately fast, and therefore the tree is expected to be useful for soil improvement and raising organic matter levels.

Soil stabilization

Whitewood is a very good soil stabilizer, having extensive lateral surface roots.

Crop shade/overstory

The tree provides moderately heavy shade that is only suitable for plants requiring moderate to high shade levels, such as cardamom, cocoa, and *Xanthosoma* taro (*X. sagittifolium*).

Alley cropping

The tree is good for alley cropping for about 3 years if planted at wide spacing, e.g., in rows 10–12 m (33–39 ft) apart, before shade levels become too great for most agricultural crops

Homegardens

It is suitable as an upper canopy component in mixed homegardens.

Improved fallows

The tree is ideal for improved fallows at lengths of 10–15 years.

Windbreaks

It can be a useful upper story component of windbreak plantings.

Silvopasture

The tree is highly suitable for older specimens in an open woodland/woodland with pasture configuration. Bark of young trees is readily chewed by cattle, causing severe damage and ring-barking.

Animal fodder

Leaves have been fed to pigs and cattle in Vanuatu (Siwatibau 1998).

Woodlot

Whitewood has excellent potential to grow in woodlots for timber production, especially if near to a sawmill and preservative treatment facilities (if wood is for local use).

Native animal/bird food

Fruits are a food source for pigeons.

Wildlife habitat

Older specimens provide useful wildlife habitat, often being emergent above other forest tree species.

Ornamental

Little-used as an ornamental, although the tree develops into an attractive, large, long-lived tree.

USES AND PRODUCTS

In Vanuatu, the wood of whitewood has been traditionally used for making canoes and for firewood. Other traditional uses include a leaf vegetable and medicinal. It is currently the major timber species cut in Vanuatu, together with *Antiaris toxicara* (with whitewood being preferred). The timber is used locally in Vanuatu, especially in preservative-treated form. It has an established export market in East Asia (principally Japan and Taiwan, with some export to other countries such as Australia). It is particularly useful for moldings, and the pale color of the wood lends itself to a variety of wood stains. Material from young, 3–4-year-old plantations has been successfully trial-milled and made into glue-laminated finger-jointed boards.

Leaf vegetable

In PNG the young leaves are sometimes used as a vegetable (Airy Shaw 1980a).

Medicinal

The bark is widely used in Vanuatu for custom medicine (Siwatibau et al. 1998), including treatment of rheumatism (Sam 1997). The bark or sap is used for treatment of stomachache on Santo (Curry 1995).

Timber

Whitewood has a rather soft, low–medium density timber in which both heartwood and sapwood have a straw color that lightens on exposure. The texture is intermediate and even. The grain is usually straight but sometimes slightly interlocked or wavy. Tension wood is sometimes present. It is very easy to kiln dry from the green condition and not prone to surface checking: the drying time from the green condition to a final moisture content of 12% is 2–3 days (Eddowes 1977). Mean air-dry density (12% moisture content) is about 440 kg/m^3 (27.5 lb/ft^3), and the timber has low strength properties (Forestry Division 1976). It is non-durable in ground contact but readily treatable with preservatives to prevent blue stain and attack from pinhole (ambrosia) borers. Its sapwood is susceptible to *Lyctus* and should be given an appropriate anti-*Lyctus* treatment before being sold. The timber is easy to saw and machine and produces an excellent finish (Pleydel 1970, Forestry Division 1976) using either machines or hand tools. It is used in Vanuatu for light construction, furniture, and interior joinery and has potential for veneer and plywood production. In PNG it is considered suitable for many purposes including molding, veneer, wide boards, lining, joinery, interior finish, match splints, match boxes, shuttering, turnery, dowels, pattern making, packing cases, furniture, cabinet work, weatherboards, shingles, and drawing-boards. In the Solomon Islands the species is used for light construction, weather boards, and boom-logs (Marten 1980).

Fuelwood

The wood is used locally for firewood, but whitewood is not a major fuelwood source.

Canoe/boat/raft making

The wood is used locally for canoes in Vanuatu.

Other

The wood is sometimes used as a food source and habitat for an edible worm in Vanuatu.

Lorum Plantation planted by Melcoffee Sawmills Ltd., Santo, Vanuatu. PHOTO: L. THOMSON

COMMERCIAL PRODUCTS

The primary commercial product from whitewood is timber.

Spacing in forestry

In monocultural plantings the spacing is rows 5–6 m (16–20 ft) apart with spacing within rows of 2.5 m (8 ft). However, the preferred silvicultural option is to plant in mixtures with a tree species that can be commercially thinned at about half the rotation age for whitewood. *Flueggea flexuosa* is ideal for this purpose, providing durable posts or small poles at 6–7 years of age. In the above system every alternate position is planted with *Flueggea*. The initial spacing of whitewood trees is 333–400 trees per ha (135–162 trees/ac). Thinning reduces the final density to 150–250 trees per ha (60–100 trees/ac), depending on the age of harvest and other factors.

On Santo, Vanuatu a final spacing of around 280–310 stems/ha (115–125 stems/ac) is considered to be optimal (Ken Robson, pers. comm.). To obtain this final stocking rate, an initial planting spacing of 6 x 3 m or 8 x 2 m (20 x 10 ft or 26 x 7 ft) is suitable, allowing the for thinning of poorer stems. The choice of 6 m or 8 m (20 ft or 26 ft) between rows depends on harvesting equipment to be used: 6-m spacing will accommodate portable sawmill operations while 8-m spacing is more adapted to the heavy machinery utilized by large logging companies.

Spacing in agroforestry

In mixed agroforestry systems, rows are planted 10–12 m (33–39 ft) apart with spacing within rows of 2.5 m (8 ft). It is preferable for every other planting spot to be planted with *Flueggea flexuosa*, which can be commercially thinned for durable posts and small poles at 6–7 years age. Initial spacing of whitewood trees is 166–200 trees/ha, and this would be the final spacing less any mortality and culling of poor stems.

Management objectives

The object is to produce tall, large-diameter, straight stems with knot-free wood. Some pruning to encourage clear wood is recommended, where the pruning regime aims to ensure a knotty core not exceeding 8–10 cm (3–4 in) in diameter and clear wood bole lengths of 4.5–6.0 m (15–20 ft). If breeding for improved wood quality, an additional objective is higher wood density. On less fertile sites it is recommended that trees be given 100–200 g (3.5–7 oz) of complete fertilizer during the first 2 years and/or intercropped with shrub legumes such as *Flemingia*.

Design considerations

Adequate initial spacing followed by timely thinning is needed to provide developing saplings with adequate sunlight, water, and nutrients for rapid growth. Growth in dense, even-spaced plantings can slow down and stall as trees begin competing for light, water, and nutrients (stagnate).

Yields

On fertile sites with optimum germplasm and silviculture, expected yields are high, about 20–30 m^3/ha/yr (286–429 ft^3/ac/yr). Yields in agroforestry systems at wider spacing will be lower, especially in early years, e.g., 15 m^3/ha/yr (215 ft^3/ac/yr).

Processing required

Wood needs to be preservative-treated for use in situations of moderate to high decay hazard. Finger-jointing or glue-lamination can be done to allow use of smaller dimension material.

Market

The wood is a good general-purpose timber for local markets, especially if treated with preservatives. It is a preferred timber in Japan, where it fetches high prices.

INTERPLANTING/FARM APPLICATIONS

Whitewood provides a useful low windbreak for crops in alley cropping systems. Intercropping is limited to the first 3–4 years depending on spacing, due to declining light levels in the area between tree rows. It can also be successfully used in silvopasture once the trees are older than about 10 years and resistant to bark-stripping by cattle.

The benefits of interplanting with crops include:

- substantial additional financial returns from timber in addition to the return from the agricultural crop
- trees act as planted fallow, restoring soil fertility more quickly after cropping, especially if the nitrogen-fixing shrub *Flemingia* is planted in alleys after the main cropping phase
- trees provide windbreak for crops in years 1–3
- the maintenance of crops between rows also serves as good weed control for trees.

Potential drawbacks of interplanting include:

- alley cropping phase ceases to be viable for most light-demanding crops after about 3 years
- wider spacing means lower growth rates on a per-unit area basis.

Example system

Location

Shark Bay, Santo, Vanuatu.

Description

This system has been developed in recent years by the Department of Forests and implemented by local villagers. It appears to have exceptional potential on Santo, as agricultural yields are maintained and farmers get substantial additional income from trees at two stages, after 6–7 years (from *Flueggea flexuosa* poles), and again at 15–20 years (from *Endospermum* timber).

Yields/benefits

Average growth increment of whitewood at age 5–8.5 years was about 17 m^3/ha/yr (243 ft^3/ac/yr), which is equivalent to a return of about US$240–600 per hectare per year

Whitewood-*Flueggea* agroforestry system at Santo, Vanuatu, at 4 years of age (left) and at 9 years after *Flueggea* was harvested (right). PHOTOS: L. THOMSON AND R. THAMAN

(US$100–240/ac/yr) to the grower. The amount received depends on stumpage: the low value is what is currently paid, whereas the higher value is reasonable for plantation-grown material where harvesting costs are much lower. Returns from poles from interplanted *Flueggea* trees are equivalent to about US$1500 per hectare (US$600/ac) after 6–7 years. Agricultural crop yields (from various root crops, vegetables, kava, etc.) during the first 3 years about the same as for non-intercropped systems.

Spacing

The spacing is 10 m between rows and 2.5 m within rows (33 x 8 ft). Within rows, every other tree is whitewood alternating with *Flueggea*.

PUBLIC ASSISTANCE AND AGROFORESTRY EXTENSION

Extension offices for agroforestry and forestry in the Pacific: http://www.traditionaltree.org/extension.html

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Traditional Tree Initiative—Species Profiles for Pacific Island Agroforestry (www.traditionaltree.org)

Endospermum medullosum (whitewood)

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Acknowledgments: The author and publisher thank Dale Evans, Brian Gunn, and Steve Walker for their input. Photo contributions from Kron Aken are greatly appreciated.

Recommended citation: Thomson, L.A.J. 2006. *Endospermum medullosum* (whitewood), ver. 2.1. In: Elevitch, C.R. (ed.). Species Profiles for Pacific Island Agroforestry. Permanent Agriculture Resources (PAR), Hōlualoa, Hawai'i. <http://www.traditionaltree.org>.

Sponsors: Publication was made possible by generous support of the United States Department of Agriculture Western Region Sustainable Agriculture Research and Education (USDA-WSARE) Program; SPC/GTZ Pacific-German Regional Forestry Project; USDA Natural Resources Conservation Service (USDA NRCS); State of Hawai'i Department of Land & Natural Resources Division of Forestry & Wildlife; and the USDA Forest Service Forest Lands Enhancement Program. This material is based upon work supported by the Cooperative State Research, Education, and Extension Service, U.S. Department of Agriculture, and Agricultural Experiment Station, Utah State University, under Cooperative Agreement 2002-47001-01327.

Series editor: Craig R. Elevitch

Publisher: Permanent Agriculture Resources (PAR), PO Box 428, Hōlualoa, Hawai'i 96725, USA; Tel: 808-324-4427; Fax: 808-324-4129; E-mail: par@agroforestry.net; Web: <http://www.agroforestry.net>. This institution is an equal opportunity provider.

April 2006
ver. 3.1

Erythrina variegata (coral tree)

Fabaceae (legume family)

'*atae* (Tahiti); coral tree, Indian coral tree, tiger's-claw (English); *drala* (Fiji); *gatae* (Samoa, Horne Islands, 'Uvea, Cook Islands); *gate* (Niue); *natae*, *netae* (Marquesas); *ngatae* (Tonga); *paar, weeku* (Chuuk); *paar, raar* (Yap); *parepein* (Pohnpei); *wiliwili haole* (Hawai'i)

W. Arthur Whistler and Craig R. Elevitch

IN BRIEF

Distribution Found throughout the tropics in cultivation.

Size Typically 10–15 m (33–50 ft), with a spreading crown, except for the commonly used cultivar 'Tropic Coral', which has a narrow, columnar form.

Habitat Grows best in the tropical lowlands with moderate rainfall 1000–1500 mm (40–60 in).

Vegetation Found with a wide variety of cultivated plants in farming and landscaping.

Soils Prefers sandy loams but does well in a wide range of soil textures and pH; it is a nitrogen-fixing tree so it can tolerate poor soils.

Growth rate Fast growing in favorable conditions with observed growth rates greater than 1.5 m (5 ft) per year.

Main agroforestry uses 'Tropic Coral': windbreak, living fence, trellis support. Regular form: ornamental, overstory shade.

Main products Fodder, medicinal.

Yields Primarily used for the services it provides, as commercial products are minimal.

Intercropping Interplanted as a shade tree in coffee and cacao plantations and as a trellis plant with betel nut (*Piper betel*), black pepper, vanilla, and yam (*Dioscorea* spp.).

Invasive potential Not considered an aggressive invasive, although it can naturalize along streams.

PHOTO: C. ELEVITCH

The columnar form of coral tree known as 'Tropic Coral', is often used for hedges, windbreaks, and living fence posts.

INTRODUCTION

The coral tree is cultivated throughout the tropics, particularly as an ornamental tree and as a shade and soil improvement tree (it fixes nitrogen) for other tree crops such as coffee and cacao. The large, spreading tree is tolerant of a wide range of soil textures and soil pH. It is also relatively tolerant of salty conditions, waterlogging, and seasonal drought. The most attractive type, var. *variegata*, is grown for its variegated leaves, as well as its seasonal showy red flowers. Another type that has ascending branches, cultivar 'Tropic Coral', is currently very popular as a boundary plant, living fence post, and windbreak. The tree is also often used as a shade tree planted among coffee or cacao trees (although *Erythrina subumbrans* is more commonly used for this purpose). The spiny stems can be a drawback in certain situations, and it cannot be planted too close to sidewalks, which will be lifted by its lateral root growth. In some places the tree is used for fuelwood and cattle fodder, especially when interplanted with other tree crops as a shade plant. It can easily be grown from either seed or cuttings. It has a low potential to be invasive, because the seeds are dispersed by dropping to the ground under the mother tree, but the tree can naturalize along stream courses below where it is planted.

DISTRIBUTION

Native range

Coral tree is indigenous to the Old World tropics, possibly originally from India to Malaysia, but is native or of ancient introduction westward to Zanzibar and eastward to eastern Polynesia (the Marquesas). It is typically found on sandy soil in littoral forest, and sometimes in coastal forest up to 250 m (800 ft) in elevation.

Current distribution

The tree is found throughout the tropics, in cultivation.

BOTANICAL DESCRIPTION

Preferred scientific name and author

Erythrina variegata L.

Family

Fabaceae (legume family)

Subfamily

Papilionoideae

Non-preferred scientific names

Erythrina corallodendrum var. *orientalis* L.
Erythrina indica Lam.
Erythrina orientalis (L.) Merrill
Tetradapa javanorum Osbeck

Common names

Pacific islands

'*atae* (Tahiti)
coral tree, Indian coral tree, tiger's-claw (English)
drala (Fiji)
gatae (Samoa, Horne Islands, 'Uvea, Cook Islands)
gate (Niue)
natae, *netae* (Marquesas)
ngatae (Tonga)
paar, weeku (Chuuk)
paar, raar (Yap)
parepein (Pohnpei)
wiliwili haole (Hawai'i)

Other regions

arbre au corail, *arbre immortel* (French)
dadap aykam (Java, Indonesia)
dadap blendung (Sunda, Indonesia)
galala itam (Moluccas, Indonesia)
chengkering (Malaysia)
andorogat (Bikol, Philippines)
bagbag (Ilocos, Philippines)
penglay-kathit (Burma)
rolouohs bay (Cambodia)
dok 'kho, *thong ban* (Laos)
thong lang lai, *thong phueak* (Thailand)

Size

The tree grows up to 20 m (66 ft in height) in height, but 10–15 m (33–48 ft) is more typical, with a spreading crown (except in the cultivar 'Tropic Coral'). The dense, oblong to rounded crown is low-branching with many ascending branches.

Flowers

Inflorescence of many-flowered fascicles occurs in terminal or axillary racemes up to 20 cm (8 in) or more long. Calyx is top-shaped, deeply split along one side, 1–1.8 cm (0.4–0.7 in) long, on a pedicel 2–5 mm (0.1–0.2 in) long. Corolla is papilionaceous; standard is short-clawed, ovate to subelliptic, 3–4 cm (1.2–1.6 in) long, red-orange with longitudinal white lines; wings are about half as long as the standard, greenish to pale red; keel is as long as the wings, greenish to pale red. Ovary is superior, stamens 10, diadelphous, with 9 fused together at the base, enclosed within the


Left: Coral tree inflorescence. Right: Seed pods can usually be found on trees nearly year-round. PHOTO: C. ELEVITCH

keel. Flowering is reported from July to November in the Southern Hemisphere and 6 months later in the Northern Hemisphere.

Leaves

Leaves are trifoliate, alternate; rachis is mostly 10–20 cm (4–8 in) long; blades are ovate to rhomboid, 8–18 cm (3.2–7.2 in) long; lateral ones are smaller than the terminal one, petiolules 6–13 mm long, with vegetative parts finely pubescent. They are deciduous just before and during the flowering season, except for 'Tropic Coral', which has been reported by some authors to not drop its leaves, while other sources have noted its deciduous habit. *E. variegata* retains its leaves better than other *Erythrina* species in Hawai'i. Low temperatures, powdery mildew, and/or drought combined with very windy conditions will accelerate leaf drop and retard the development of new leaves.

Fruit

Fruit a compressed, narrowly oblong pod 10–14 cm (4–5.6 in) long, sterile in the basal portion, and not constricted between the 5–10 dark brown seeds. The fruits are ripe from October to November in the Southern Hemisphere and March to April in the Northern Hemisphere, but they often remain on the tree for several months longer.

Seeds

Seeds are kidney-shaped, dark purple to red, and 1–1.5 cm (0.4–0.6 in) in length. These simply fall to the ground and may be washed away (they have been seawater-dispersed over their native range). There are 1450–5000 seeds/kg (660–2270 seeds/lb).

Similar species

The genus includes 110 species, many of which are cultivated as ornamentals. The only other related species common in the Pacific islands are *Erythrina crista-galli*, *E. fusca*, and *E. subumbrans*. Another species, *E. sandwicensis*, is endemic to Hawai'i and is uncommon in cultivation. These can be distinguished from *E. variegata* and each other as follows:

E. crista-galli—Easily distinguished from the other three by its flowering much of the year. Its leaves are leathery, dark green, and elliptic (widest toward the middle), and the flowers are rich, dark red.

E. fusca—This tree, unlike the others, occurs naturally in swampy areas. The leaves are oblong to oval in shape, like *E. crista-galli*, but the flowers are seasonal and dull purple-red.

E. subumbrans—The most distinguishable characteristic of this species is its seed pod, which is constricted at the base (the seeds are formed only in the upper part of the pod), unlike the other four species noted here, and the flowers are greenish to pale red.

E. variegata—This is the most commonly cultivated member of the genus. Its young stems and other parts are finely hairy, its leaves are mostly ovate (widest toward the base) and sometimes variegated with yellow (var. *variegata*). Its crimson to orange flowers are 5–8 cm (2–3.2 in) long, and its pod is 5–10 seeded.

E. sandwicensis—This is similar to *E. variegata* but has smaller flowers that are 3.5–4 cm (1.4–1.6 in) long and fewer seeds. one to three per pod. *E. sandwicensis* trunks and main branches have a characteristic orange hue, while *E. variegata* trunks and branches are whitish gray.

GENETICS

Variability of species

Variable because of its large range, and some varieties have been selected for propagation.

Known varieties

var. ***variegata*** (possibly the same as cv. 'Parcellii')—This one is easily recognized by its yellow and green variegated leaves and is favored as an ornamental throughout the Pacific.

var. ***orientalis*** (L.) Merr.—This is the "wild type."

var. ***alba*** (with white flowers)—This looks like the wild type, but has white flowers.

cv. 'Tropic Coral'—This is the cultivar used as fence posts and windbreaks because of its unique growth form (columnar, with branches all erect). 'Tropic Coral' probably originated under cultivation in New Caledonia, as a sport or mutant of the more typical open-branched form of *Erythrina variegata*. In cultivation it has spread to other tropical and warm-temperate areas, including Australia and southern Florida. This cultivar is not known to occur naturally anywhere in the wild.

Culturally important related species in the genus

The genus comprises 110 species, and many of these are cultivated for their showy flowers and/or variegated variation. Perhaps the most attractive of the species is *Erythrina variegata* var. *variegata*, with its variegated leaves. The other species of the genus most commonly cultivated are *Erythrina crista-galli* and *Erythrina fusca*.

Genetic resources where collections exist

Seed collections are stored in Costa Rica (the Centre for Tropical Agricultural Research and Training [CATIE]), and the seeds or the plants are often obtainable at local nurseries.

ASSOCIATED PLANT SPECIES

Its native habitat is littoral forest and coastal forest. In the former, it is associated with trees such as fish-poison tree (*Barringtonia asiatica*), tropical almond (*Terminalia catappa*), and many other littoral species. It also occurs inland in coastal forest, where it is mixed with numerous native lowland forest species.

Commonly associated in modern times

It is commonly associated with ornamental plants, and where it is a windbreak, often with crop plants such as vegetables, sugarcane, coffee, macadamia nuts, and many others.

Top: The variegated variety, var. *variegata*, is a favored ornamental in many parts of the Pacific. Bottom: *Erythrina crista-galli* is a popular ornamental, but is used little in agriculture. PHOTO: C. ELEVITCH

ENVIRONMENTAL PREFERENCES AND TOLERANCES

Climate

The tree is found in the humid tropics and subtropics and can tolerate a wide variety of climates within this zone. It does particularly well in monsoonal climates that have a wet summer and a dry winter, and it requires little water during the winter dry season, because it drops its leaves at that time. The rainfall in its natural environment ranges from 800 mm (32 in) to 1500 mm (60 in). It is usually found in the lowlands from near sea level to 250 m (800 ft), but it can be planted up to 1500 m (5000 ft) elevation.

The bark of coral tree is mostly smooth, with a small number of short thorns. PHOTO: C. ELEVITCH

Elevation range

lower: near sea level

upper: 250 m (800 ft) or more in nature, but can be grown at up to 1500 m (5000 ft) near the equator

Mean annual rainfall

lower: 800 mm (32 in), should be at least 1000 mm (40 in) for optimum growth

upper: 1500 mm (60 in) in native range, tolerates up to 3800 mm (150 in)

Rainfall pattern

In its native habitat the climate is monsoonal with a rainy summer and a dry winter of 5–6 months, but it can be cultivated in practically any rainfall pattern. The tree performs better in moderate than in heavy rainfall areas.

Dry season duration (consecutive months with <40 mm [1.6 in] rainfall)

5–6 months of dry season in its native range

Mean annual temperature

20–32°C (66–90°F)

Mean maximum temperature of hottest month

28–35°C (82–95°F)

Mean minimum temperature of coldest month

16–24°C (61–75°F)

Minimum temperature tolerated

0°C (it is intolerant of freezing)

Soils

It can be grown in a wide range of soil types. Although it prefers sandy loams, it will do well in clay and loam soils. It also is tolerant of a wide range of soil pH, ranging from 4.5 to 8.0. It can do well in nutrient-poor soil, as it fixes nitrogen.

Soil texture

Tolerates light to heavy texture soils (sands, sandy loams, loams, and sandy clay loams, sandy clays, clay loams, and clays).

Soil drainage

Grows in soils with free or impeded drainage and even tolerates seasonally waterlogged soils.

Soil acidity

pH 4.5–8.0

Special soil tolerances

It can grow in moderately saline and infertile soils.

Tolerances

Drought

It is drought tolerant, as it is native to monsoonal areas that have several months of dry season. It needs almost no water when it is leafless in the winter.

Left: Coral tree (cultivar 'Tropic Coral') and banana, both tolerant of salt spray, growing as a hedge along the coast of 'Upolu, Samoa. Right: Coral tree can be pollarded (pruned back severely to the branch in order to promote dense regrowth) on an annual basis. PHOTOS: C. ELEVITCH

Full sun

It prefers full sun.

Shade

It does not tolerate shade very well.

Fire

It is somewhat fire resistant.

Frost

It is intolerant of frost, which limits its natural distribution to the tropics.

Waterlogging

It is resistant to periodic waterlogging for up to 2 weeks, but it prefers well drained sandy loams.

Salt spray

It is moderately tolerant of salt spray, as it is a littoral tree.

Wind

It does well in windy situations and is often used as a windbreak.

Abilities

Fix nitrogen

It fixes nitrogen and thus can grow in and enrich areas of nutrient-poor soil.

Regenerate rapidly

It can regenerate rapidly, and saplings have been known to grow up to 3 m (10 ft) in height in a year.

Coppice

Coral tree responds well to pruning. Regrowth appears to be significantly faster when at least 15% of the foliage is left after cutting.

Pollard

The trees are regularly pollarded where they are used as shade trees and in landscaping.

GROWTH AND DEVELOPMENT

The tree is grown from cuttings or seed. Sapling growth is rapid, and a 1-year-old sapling can reach 3 m (10 ft) in height. Growth continues to be rapid during its young years. Trees as young as 3 or 4 years old can start flowering.

Growth rate

It typically reaches 3 m (10 ft) in height in a year, and 15–20 m (50–66 ft) in 20 to 25 years. On favorable sites, the stem can reach a diameter at breast height (dbh) of 50–60 cm (20–24 in) in 15 to 20 years.

Flowering and fruiting

Flowering and fruiting are seasonal. Flowering occurs when the tree is leafless in the summer, and fruiting soon follows. Its flowering time was used as a seasonal indicator in some places (e.g., in Samoa its flowering indicated that whales would soon be running in the adjacent ocean).

Yields

It is not usually used for fodder in the Pacific, but yields of 15–50 kg (33–110 lb) of fodder per tree per year have been recorded.

Rooting habit

It forms extensive vertical roots, but these may spread horizontally from the base of the trunk to make large surface roots, making the tree unsuitable for planting next to sidewalks.

Reaction to competition

The tree does not tolerate shade well, and the seedlings grow poorly in the shade of competition. For optimum growth, new plantings should be kept weed-free. Mature trees are tolerant of a grass cover, but it should be mowed to reduce competition.

PROPAGATION

Propagation is by two common methods, cuttings and seeds. Large branch cuttings can easily be planted to form new trees, as described below. Cuttings are the only way to propagate clonal varieties, as seeds are not true to type.

Propagation from cuttings

(after Wilkinson and Elevitch 2003a)

Cutting collection

This tree is most commonly propagated vegetatively for live fences, windbreaks, and establishment in areas where livestock is present (which could eat shoots from small seedlings). Large-size branch cuttings are used, usually 2–3 m (6.6–10 ft) in length and 5–10 cm (2–4 in) in diameter. Smaller cuttings may be used, a minimum of 30 cm (1 ft) in length and a diameter of 4–5 cm (1.8–2 in). However, larger cuttings at least 1.5 m (5 ft) long will establish more quickly, survive better against competition from weeds, and be less susceptible to damage or destruction from grazing animals. It is best to retain the terminal bud of branch cuttings to ensure fast new top growth. However, in many cases growers cut one long branch into several cuttings, and therefore this is not always feasible.

Cuttings can be taken any time of year, although the ideal time is when the new growth is appearing, usually at the onset of the rainy season. Growers traditionally favor taking cuttings with the waning moon and planting them in the ground with the waxing moon.

Storage of cuttings

Cuttings are stood upright in shady, dry, and cool conditions for a minimum of 24 hours and a maximum of 2 weeks. This standing time allows the cuttings to dry slightly and helps prevent rotting and fungal problems.

Outplanting

Whether planted directly in the field or in nursery containers, the cuttings should be grown in sunny conditions. After planting, soil moisture should be maintained, although overwatering can easily cause the buried part of the cutting to rot. For larger stakes 2–2.5 m (6.6–8.3 ft) tall, the lower portion of the cutting is buried 20–40 cm (8–16 in) deep. For smaller cuttings, generally about 20% of the cutting's length should be underground. Planters should make sure to plant cuttings correct side down! Some recommend dipping the top portion of the cutting in pruning wax to help keep moisture from rotting the wood. Another strategy for avoiding rot on the top portion of the cutting is to make sure the top is cut at an angle so that rainwater is shed. The planting holes may be sprinkled with VAM mycorrhizal fungi inoculant (an aid to establishment and growth in P-deficient soils) and rhizobia bacteria inoculant. The soil should be firmed around the base of the cutting. Incisions should be made in the bark of the part of the cutting that will be underground in order to improve rooting. It takes about a month for axillary shoots to appear.

Media

Usually cuttings are started directly in the ground. However, if using containers, any standard well drained potting media may be used.

Time to outplanting

Cuttings establish quickly, producing axillary shoots in 3–4 weeks, followed by rooting. Generally, 3–4 months in the nursery will yield a well rooted plant ready for outplanting.

Success rate

Under optimal conditions of soil moisture, 90–100% of coral tree cuttings will survive. Very wet conditions in the early stages of establishment can lead to rot in the underground portion of the cutting.

Propagation from seed

(after Wilkinson and Elevitch 2003b)

Seed collection

The seeds can be collected after the pods mature, which is usually late winter. In Hawai'i, it flowers in January and February and sets seed in February–April. The fruits are pods about 15–30 cm (6–12 in) long. Seeds are mature when the pod dries and turns brown and the seeds become hard with a shiny seed coat. Mature pods can be collected from the tree or from the ground.

Seed processing and storage

Seeds are easily cleaned by hand from dried pods. Seeds should be well dried in the sun. Prior to storage, seeds should be frozen for a minimum of 48 hours to kill any insect larvae harbored inside. Germination is commonly 90% or greater for recently harvested seed. Seeds maintain viability for several years when stored in an airtight container with desiccant in a cool location or in the refrigerator.

Pre-planting seed treatments

For best germination, scarification of the hard seed coat is recommended. Mechanical scarification (nicking with a large nail clippers) works very well; be sure not to damage the germ or the inner part of the seed. Soak the scarified seeds overnight in room-temperature water. If any seeds do not imbibe water, they may be nicked and soaked again. Hot-water scarification is an alternative to mechanical scarification and is appropriate for large seed lots. Seeds are soaked in hot water (80°C [176°F]) for 10 minutes and then in tepid water overnight.

Growing area

Seedlings should be grown in full sun in an uncovered growing area. Humidity and overwatering can lead to fungal diseases, so a hot and dry growing environment is ideal.

Germination

Scarified seeds will begin germinating in 5–10 days. Scarified seeds may be planted in containers or direct-seeded. Cover seeds shallowly with potting mix (about 0.6 cm [0.25 in] deep), followed by a thin mulch layer such as coarse poultry grit or sand. Water the seeds with a fine-headed sprayer. Keep moist but not overwatered. Overwatering can easily lead to damping off. After 1–2 weeks of growth, seedlings should be inoculated with rhizobia bacteria selected for this species.

Media

Any standard potting soil is suitable. As with other nitrogen-fixing plants, the medium should have low available N, which encourages active nodulation for nitrogen fixation, assuming rhizobia bacteria are present.

Time to outplanting

Well watered seedlings are normally ready for planting 10–16 weeks after germination. The size expected for outplanting is 30 cm (1 ft) tall, with a based diameter of 6 mm (0.25 in).

Other comments on propagation

Coral tree is not true to seed. Projects desiring the columnar variety 'Tropic Coral' (mainly for windbreaks and live fence posts) should propagate the tree from cuttings, not seed, to ensure the column-shaped form. Projects desiring thorny trees or more branching form (commonly desired for shade) should propagate vegetatively from trees with the desired form or from their seeds.

DISADVANTAGES

The tree is ideally planted by itself as a specimen or in rows; it needs to be kept away from sidewalks and lawn areas because large lateral roots can lift sidewalks and interfere with mowing. It is leafless during part of the year and so tends to produce a lot of leaf litter. The flowers, although spectacular, are seasonal and last on the tree only 1–2 months.

Potential for invasiveness

It is not very invasive, because it has an ineffective dispersal mechanism for its seeds (they just fall from the tree).

A serious pest identified in Hawai'i in 2005, the erythrina gall wasp causes severe defoliation and eventual death of trees. The presence of this pest effectively halts the planting of coral tree in Hawai'i until the problem is resolved. Left: New leaves with stems swollen by gall formation. PHOTO: C. ELEVITCH **Right: Completely defoliated hedge, Mānoa, Hawai'i.** PHOTO: D. EVANS

However, it can naturalize along streams where there are trees planted upstream.

Diseases and pests

The species is a host to the fruit-piercing moth *Othreis fullonia*, a serious pest in the Pacific islands. The tree itself is not particularly susceptible to diseases, but borers may infest weakened trees and some species of caterpillars can damage foliage. In Hawai'i, the leaves are susceptible to attack by powdery mildew (*Oidium* sp.), especially during the winter rainy season.

In 2005, a serious new pest was identified in Hawai'i, the erythrina gall wasp (*Quadrastichus erythrinae*) (Heu et. al 2006). This pest has also been reported in American Samoa and Guam, as well as parts of Southeast Asia. The wasp larvae develop inside the young leaf petioles and stems, and cause galls to form. Severe infestations have been reported throughout Hawai'i. These infestations can cause complete defoliation and death of trees. Treatments with certain pesticides have been effective at reducing infestations, although such treatments are impractical for most people. Until this problem is resolved, planting of coral tree in Hawai'i is not recommended.

Host to crop pests/pathogens

The species is a host to the fruit-piercing moth *Othreis fullonia*, a serious pest in the Pacific islands.

Other disadvantages

The wood is not very suitable for much other than light (and temporary) construction and for making light boxes.

AGROFORESTRY/ENVIRONMENTAL PRACTICES

Mulch/organic matter

Although not as prolific as some other nitrogen- fixing

Coral tree is deciduous in many environments. The loss of foliage could be a disadvantage if shade or wind protection is required during the dry season. PHOTO: C. ELEVITCH trees such as *Gliricidia sepium*, coral tree is often pruned annually when used for crop shade or living fence posts. The prunings make excellent mulch for crops.

Crop shade/overstory

The tree is sometimes used as a shade for coffee and cacao. For this purpose they are planted with a spacing of 8 x 10 m (27 x 33 ft). The trees are pollarded once a year to a height of 2–3 m (6.6–10 ft) to produce a spreading crown.

Alley cropping

Because of its relatively moderate growth rate after pruning, coral tree is usually not the best choice for a fast-growing nitrogen-fixing tree for organic matter production in alley cropping.

Homegardens

The tree is very well suited for homegardens as an ornamental.

Improved fallows

Since they fix nitrogen they are potentially useful trees for enriching the soil, as well as being a shade tree.

Living fences

Coral tree is excellent for living fences, as it can easily be grown from large cuttings. The type most suitable for this is 'Tropic Coral', which has a columnar shape and is evergreen. Farmers commonly establish fence posts from 3-year-old upright branches about 15 cm (6 in) in diameter and 2.5 m (8 ft) long. These are normally stacked in the shade in an upright position and left to cure for a week before planting.

Fence posts

The wood is not good for this, because it is not particularly resistant to rot. But if a living fence post is desired, it is excellent for this purpose.

Top: This densely planted row of 'Tropic Coral' is used to support hog wire, making a very strong enclosure for pigs. Bottom: A boundary hedge without attached fencing. PHOTOS: C. ELEVITCH

Boundary markers

It is commonly used for a boundary marker as a living fence.

Windbreaks

Commonly used as a windbreak, particularly the columnar variety ('Tropic Coral') and for soil and water conservation. The trees have a strong, vertical root system that does not seem to compete too severely with adjacent crops. Windbreaks are normally established from large cuttings planted in lines at a spacing of about 1 m (3.3 ft).

Silvopasture

Living fence posts can be used as support for fencing suitable for containing cattle or horses. The periodic pruning of these fence posts yields excellent fodder. Trees are also grown inside paddocks to provide some shade, wind protection, and as a potential source of off-season fodder.

Animal fodder

The foliage makes an excellent feed for most livestock, as the leaves normally contain 16–18% crude protein. A tree of average size, pruned three or four times a year, produces from 15 to 50 kg (33–110 lb) of green fodder annually depending on growing conditions. Trees maintained in coffee plantations benefit from associated cultivation practices and can produce up to 100 kg (220 lb) of fodder from one annual harvest. The leaves have no known toxicity to cattle.

Woodlot

The wood is not very suitable for use as timber, as it is soft, light, and not durable, but it can be used for fuelwood, especially when gathered in areas where it is used as a shade tree among other tree crops.

Native animal/bird food

Nectar-feeding birds are attracted to the copious nectar produced during the short flowering season.

Host plant trellising

Farmers in India use it to support climbing plants such as betel nut (*Piper betel*), black pepper (*Piper nigrum*), vanilla (*Vanilla planifolia*), and yam (*Dioscorea* spp.). Trees established to support vines are usually planted at a spacing of 2 x 2 m (6.6 x 6.6 ft) to 2 x 3 m (6.6 x 8 ft). Vines are planted 3–4 months after establishment of the tree seedlings or during the following rainy season. During the hottest months, foliage from the closely spaced trees shades the vines, and in the winter, the leaves fall to allow them to more receive more direct sunlight.

Coastal protection

The tree can be used in coastal areas, as it improves the soil and is native to littoral habitats.

Ornamental

It makes an attractive ornamental tree because of its large, showy red, seasonal flowers.

USES AND PRODUCTS

The coral tree is important for several reasons, but its distribution may be natural (seawater drift) rather than being carried through the islands as a useful tree. Although the light wood is of little use as timber, it was and still is commonly used to make the outrigger on traditional canoes and for floats on fishing nets. The flowering was used as a seasonal indicator on some islands (e.g., Samoa). The bark and leaves have been widely used to make traditional medicines, although there seems to be little commonality of usage in the Pacific islands. The nectar is an important seasonal food source for lories, honeyeaters, and flying foxes. Nowadays the tree is mainly used as an ornamental, especially the variety with variegated leaves (var. *variegata*), and as a living fence post, especially 'Tropic Coral'.

SAMOAN LORE

When the coral tree fruits are ripe, it is an indicator that whales are running and yams are in season in Samoa.

Medicinal

In Pohnpei the leaves are reportedly used to make a drink to cure curses, and the smoke from smoldering leaves, bark, or roots is inhaled for the same purpose. In Yap the leaves and bark are reportedly used as a potion to treat stomachache. In Tonga the bark is mixed with others and used to treat stomachache. In Samoa the leaves are occasionally used to treat eye ailments, and the bark is applied to swellings. In India, China, and Southeast Asia, the bark and leaves are used in many traditional medicines, including one said to destroy pathogenic parasites and relieve joint pain; the juice from the leaves is mixed with honey and ingested to treat tapeworm, roundworm, and threadworm in India; women take this juice to stimulate lactation and menstruation; it is commonly mixed with castor oil to treat dysentery; a warm poultice of the leaves is applied externally to relieve rheumatic joints; and the bark is used as a laxative, diuretic, and expectorant.

Coral trees in flower attract many nectar-feeding birds. PHOTO: C. ELEVITCH

Leaf vegetable

Boiled leaves can be eaten as a potherb.

Beautiful/fragrant flowers

These are sometimes used as decoration in vases, or in leis, but are seasonal.

Timber

The wood is not very suitable for use as timber since it requires careful seasoning, preferably kiln drying. It does not split on nailing, but holds nails poorly.

Fuelwood

It is a useful fuelwood tree. An average shade tree in a coffee plantation can yield 25–40 kg (55–88 lb) of wood from annual pollarding.

Craft wood/tools

The wood is used to construct outriggers and fishnet floats, packing boxes, picture frames, and toys, but other timbers are much for suitable for this purpose.

Canoe/boat/raft making

The light wood is favored for making outrigger floats.

Body ornamentation/garlands

Seeds and flowers may be used for making leis, but the seeds are prone to beetle infestation on the tree and the flowers are highly seasonal.

Top: 'Tropic Coral' makes a very good component in a hedge, visual barrier, or windbreak, and can be repeatedly pruned to maintain its size. Upolu, Samoa. Bottom: Hedge in commercial landscaping. Kaloko, island of Hawai'i, before arrival of the erythrina gall wasp. PHOTOS: C. ELEVITCH

URBAN AND COMMUNITY FORESTRY

Coral tree is an easy-to-grow, medium size tree with attractive foliage and flowers. It is well suited for coastal environments, where many people live, and can grow at elevations up to 1500 m (5000 ft) near the equator. It can be pruned to size and shape for many landscaping applications.

Size in an urban environment

The tree typically grows to 10–15 m (33–50 ft) in height, with a crown diameter of about half the height of the tree, except for the columnar cultivar 'Tropic Coral', which has a narrow crown diameter of 2–3 m (6.6–10 ft). However, in urban environments trees can be pruned periodically to maintain a desirable size and form.

Rate of growth in a landscape

As a nitrogen-fixing tree, it can grow rapidly, especially in cultivated landscapes with ample moisture. A tree can grow to 10 m (33 ft) in height in 8 years. After pruning, regrowth is also rapid, up to 3 m (10 ft) within the first year.

Root system

In younger trees, most roots are in the upper 30 cm (12 in) of soil. Older trees have deeper root systems. The extensive surface rooting may interfere to a limited degree with pavement, sidewalks, and other surface objects.

Products commonly used in a Pacific island household

Many parts of the tree have various uses, such as medicine, fodder, utility wood, and lei making, but the tree is probably best known as a shade, hedge, and living-fence tree.

Light requirements

Coral tree grows best in full sun. Seedlings as well as larger trees perform poorly if heavily shaded.

Water/soil requirements

It grows in a wide range of soil types. Because it is a nitrogen fixer, it tolerates infertile soils better than many landscaping plants.

Life span

Coral tree can live to be about 100 years old.

Varieties favored for use in homegardens or public areas

The yellow and green variegated var. *variegata* is a popular ornamental in the Pacific. 'Tropic Coral' has a narrow, columnar form and is also favored as an ornamental. Its compact canopy makes it suitable for tight landscapes and for narrow hedges and living fences. 'Tropic Coral' has only tiny prickles on the stems, which makes it easier to work with in a homegarden.

Seasonality of leaf flush, flowering, fruiting

Flowering takes place once a year (July–November in the Southern Hemisphere, and January–May in the Northern Hemisphere). Trees are deciduous just prior to and during flowering (except possibly for 'Tropic Coral', which may hold its leaves).

Exceptional ornamental values

The bright red, showy flowers last for several weeks. Flowering is particularly attractive because it occurs during a deciduous period when the grayish bark and framework of the tree are visible. The flowers have no scent.

Use as living fence, hedge or visual/noise barrier

When pruned to encourage leafy regrowth from the lower trunk, trees make an excellent hedge, particularly 'Tropic Coral'. This cultivar is also used very successfully as a living fence post on which to mount wire fencing. Thornier types may be used for a hedge or living fence where the added deterrent is desired.

Birds/wildlife

The flowers produce copious nectar and attract many small nectar-feeding birds that hop around and poke at the flowers.

Maintenance requirements

Small seedlings can usually hold their own with weed competition, but vines and tall grasses should be controlled for the first 2–3 years. Once established, the tree requires little maintenance. Fertilizer is rarely required, except in very infertile soils. Irrigation is also often unnecessary, as the tree handles drought well.

To control the size and form, pruning is required. Regrowth is rapid after pruning, so landscape hedges are typically

Recently rooted cuttings used for trellis to support bitter melon, vanilla, and beans. PHOTO: S. SKIPPER trimmed once or twice per year, depending on how much regrowth is visually acceptable. The prunings make excellent nutrient-rich mulch for other plants in the landscape, or are valuable fodder for most livestock.

The tree can also be pollarded to control the height and canopy diameter. In pollarding, a framework of several stems is formed at a desired height by pruning the tree during its early development. These stems are then pruned back heavily every 1–3 years, depending on the rate of regrowth.

Special considerations regarding leaf, branch, and fruit drop

Generally, regrowth after pruning is more susceptible to breakage in high winds than are branches on a tree that has never been pruned. Once pruned, regular follow-up pruning will reduce the risk of storm damage.

When using prunings for mulch, branches of any size may set root in wet environments. To avoid new plants emerging from mulch, newly rooted plants can be periodically pulled up using a hoe or other hand tool. Another option is to compost the prunings before using them as mulch.

Nuisance issues

None.

Hazards

Some trees are thornier than others. Thornier trees can present a hazard, especially in public places where people could be injured by stepping bare-footed on small fallen branches or even bumping up against the trunk of the tree. The seeds are poisonous if eaten without cooking.

Common pest problems

Powdery mildew (*Oidium* sp.), Chinese rose beetle (*Adoretus sinicus*), mealybugs (*Phenacoccus* spp.), and mites (*Tetranychus cinnabarinus* and *Polyphagotarsonemus latus*) are common pests that effect coral tree in the landscape. These are passing pest problems, however, and rarely require any treatment.

COMMERCIAL PRODUCTS

Coral tree is valued for its use as livestock fodder, windbreak, live fence, crop shade, organic matter production, ornamental uses, and uses in traditional handicrafts and medicines. The tree has little commercial use, although it is used commercially for paper pulp production in India.

INTERPLANTING/FARM APPLICATIONS

Some interplanting systems include:

Example system 1

Location

Throughout the Pacific, and other tropical regions.

Description

The tree is used for shade and soil enrichment in crops such as cacao or coffee. This is a new practice, as these crops were not traditionally cultivated in plantations (and are not native to the Pacific). In the Pacific, *Erythrina subumbrans* is probably more commonly used for this purpose.

Crop/tree interactions

It produces soil nitrogen from the roots, and a green mulch from the falling leaves. The tree can also be planted along the edges of the plantation as a living fence post and as a windbreak.

Spacing

When planted among other tree crops for shade, a spacing of 8 x 10 m (27 x 33 ft) is common. The trees can be planted very close together when making a living fence or hedge.

Example system 2

Location

India

Description

Farmers in India use it to support climbing plants such as betel nut (*Piper betle*), black pepper, vanilla, and yam (*Dioscorea* spp.). Vines are planted 3–4 months after establishment of the tree seedlings or during the following rainy season. During the hottest months, foliage from the closely spaced trees shades the vines, and in the winter, the leaves fall to allow more direct sunlight.

Crop/tree interactions

In this case, the young trees are used as trellises and for shade.

Spacing

The trees used to support vines are usually planted at a spacing of 2 x 2 m (6.6 x 6.6 ft) to 2 x 3 m (6.6 x 8 ft).

PUBLIC ASSISTANCE AND AGROFORESTRY EXTENSION

Extension offices for agroforestry and forestry in the Pacific: http://www.traditionaltree.org/extension.html

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traditional tree initiative

Species Profiles for Pacific Island Agroforestry (www.traditionaltree.org)

Erythrina variegata (coral tree)

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Acknowledgments: The authors and publisher thank Dale Evans, Robert Joy, Michael Robotham, Steven Skipper, and Kim Wilkinson for their input. A photo contribution from Dale Evans is greatly appreciated.

Recommended citation: Whistler, W.A., and C.R. Elevitch. 2006. *Erythrina variegata* (coral tree), ver. 3.1. In: Elevitch, C.R. (ed.). Species Profiles for Pacific Island Agroforestry. Permanent Agriculture Resources (PAR), Hōlualoa, Hawai'i. <http://www.traditionaltree.org>.

Sponsors: Publication was made possible by generous support of the United States Department of Agriculture Western Region Sustainable Agriculture Research and Education (USDA-WSARE) Program; SPC/GTZ Pacific-German Regional Forestry Project; USDA Natural Resources Conservation Service (USDA NRCS); Kaulunani, an Urban Forestry Program of the DLNR Division of Forestry and Wildlife and the USDA Forest Service; State of Hawai'i Department of Land & Natural Resources Division of Forestry & Wildlife; USDA Forest Service Forest Lands Enhancement Program; and Muriel and Kent Lighter. This material is based upon work supported by the Cooperative State Research, Education, and Extension Service, U.S. Department of Agriculture, and Agricultural Experiment Station, Utah State University, under Cooperative Agreement 2002-47001-01327.

Series editor: Craig R. Elevitch

Publisher: Permanent Agriculture Resources (PAR), PO Box 428, Hōlualoa, Hawai'i 96725, USA; Tel: 808-324-4427; Fax: 808-324-4129; E-mail: par@agroforestry.net; Web: <http://www.agroforestry.net>. This institution is an equal opportunity provider.

April 2006
ver. 3.2

Fagraea berteroana (pua kenikeni)

Gentianaceae (gentian family)

ksid **(Palau);** ***mbua*****,** ***mbua ndina*****,** ***mbua ni Viti*****,** ***mbua ni veikua*****,** ***kandisa*** **(Fiji);** ***peengas*****,** ***seewur peengas*** **(Chuuk);** ***pua*** **(Tonga, Horne Islands, 'Uvea, Niue, Cooks, Societies, Australs, Rapa, Marquesas);** ***pua Tonga*** **(Tonga);** ***pua kenikeni*** **(Hawai'i);** ***pualulu*** **(Samoa);** ***pwur*****,** ***seir pwur*** **(Pohnpei)**

W. Arthur Whistler and Craig R. Elevitch

IN BRIEF

Distribution Found on most of the high islands of the Pacific.

Size Typically a small shrub or tree to about 5 m (16 ft) but can reach 15 m (50 ft).

Habitat Wide range of cultivated environments, such as lava flows and cloud forests; humid and subhumid tropics and subtropics.

Vegetation Associated with many plants found in cultivation.

Soils Wide variety of soils, such as calcareous, fresh lava, weathered clay, and as an epiphyte without soil.

Growth rate Slow, 0.3–0.5 m/yr (12–20 in).

Main agroforestry uses Homegardens, wildlife habitat, ornamental.

Main products Flowers, wood.

Yields No data available.

Intercropping Grows well in mixed gardens.

Invasive potential Not considered invasive.

PHOTO: C. ELEVITCH

This specimen tree is about 4 m (13 ft) tall and has a typical shrubby form with many stems.

INTRODUCTION

Pua kenikeni is indigenous from Northern Australia and the Caroline Islands eastward to the Marquesas and is found on most of the high islands of this region. It is occasionally to commonly found in lowland to montane forests, particularly on lowland lava flows (as in Samoa), on narrow ridges (as on Rarotonga), and in montane and cloud forests (where it is often an epiphyte or strangler). Pua kenikeni ranges from near sea level to 1060 m (3500 ft) or higher elevations. In some places it is found mostly in cultivation, such as in Tonga, where it is probably native, and Hawai'i, where it is a modern introduction. It is grown commercially in nurseries in Hawai'i as a popular ornamental. Where it is native, it is spread by birds (typically starlings) and bats, which ingest the orange pulp that contains the tiny black seeds. It apparently does not become naturalized in places where it is introduced, and it is not considered to be invasive.

The tree is often more of a shrub, but it can reach 15 m (50 ft) in height. It is esteemed mostly for its fragrant, white flowers, as a garden ornamental, and for its timber. The long-tubed blossoms are widely worn, singly over the ear or strung into fragrant leis. They are also highly favored for making scented coconut oil. The durable, light brown, fine-grained wood is of good quality and can be smoothed into a high polish. The wood was much valued for making tool handles, tools, house posts, furniture, drums, and in modern times, handicrafts. Its relatively small size does not give it much potential for timber. Today it is mainly cultivated as a garden ornamental and for its fragrant flowers used in personal adornment.

DISTRIBUTION

Indigenous from New Guinea and northern Australia north to the Marianas, eastward to the Marquesas, it is found on most of the high islands of this area. It is occasional to common in lowland to montane forests, particularly on lowland lava flows (as in Samoa) and on narrow ridges (as on Rarotonga). Pua kenikeni is cultivated in Hawai'i, but not naturalized.

BOTANICAL DESCRIPTION

Preferred scientific name

Fagraea berteroana A. Gray ex Benth.

Family

Gentianaceae (formerly Loganiaceae), (gentian family)

Subfamily

Potalieae (tribe)

Non-preferred scientific names

Fagraea berteriana (a common misspelling)
Fragraea berteroana (a common misspelling)
Fagraea galilai
Fagraea grandis
Fagraea kusaiana
Fagraea sair
Fagraea samoensis
Fagraea vitiensis

Common names

ksid (Palau)
mbua, *mbua ndina*, *mbua ni Viti*, *mbua ni veikua*, *kandisa* (Fiji)
peengas, *seewur peengas* (Chuuk)
pua (Tonga, Horne Islands, 'Uvea, Niue, Cooks, Tahiti, Australs, Rapa, Marquesas)
pua Tonga (Tonga)
pua kenikeni (Hawai'i)
pualulu (Samoa)
pwur, *seir pwur* (Pohnpei)

Size

Up to 15 m (50 ft) in height, but often much shorter, especially when growing in the open and as a strangler; trunk often many-branched at the base, with a spreading crown.

Flowers

Inflorescence a terminal, many-flowered (mostly 9–25 flowers) cyme usually branched at the base, on a rachis up to 11 cm (4.2 inches) long, with small, paired ovate bracts at the nodes; calyx urn-shaped, 9–16 mm (0.4–0.6 inches) long, divided about one third of its length into 5 ovate sepals, on a pedicel up to 1 cm long; corolla trumpet-shaped, white aging to yellow or pale orange, tube 4–11 cm (1.6–4.4 inches) long, limb divided into 5 oblong, contorted lobes 1.7–3.6 cm (0.7–1.4 inches) long; ovary superior, style as long as the tube, with a bifid stigma; stamens 5, epipetalous, with long anthers included at the top of the throat; flowering may occur anytime during the year, and sometimes continuously.

Leaves

Simple, opposite, blade fleshy, mostly elliptic to obovate, 8–22 cm (3.3–8.7 inches) long, acute to cuneate at the base, shortly acuminate at the tip; surfaces glabrous, veins indistinct, upper side darker; margins entire; petiole 1.5–5 cm (0.6–2 inches) long; stipules forming a fleshy, notched structure (ocrea) in the leaf axil.

Fruit and flowers. PHOTO: W. A. WHISTLER

Fruit
Orange, ellipsoid berry 3.5–5 cm (1.4–2 inches) long borne on a thickened stalk. The fruits may be collected throughout the year, and the seeds are mature when the fruit turns orange.

Seeds
Many, tiny, black, irregularly angled, dispersed when the orange pulp in which they are imbedded is eaten by birds.

Rooting habit
No data available.

Similar species
It is a rather distinct tree. Similar to *Fagraea ksid* of Palau, which, however, may not be a separate species.

How to distinguish from similar species/look-a-likes
Distinguishable by its medium-sized tree habit, trunk often branching at the base or starting as an epiphyte, opposite leaves with a notched structure in the axil (the angle between the leaf and the stem), long, showy white, trumpet-shaped flowers that age to pale orange or yellow, and a large, orange, many-seeded berry.

GENETICS

Variability of species
Pua kenikeni is variable from island to island, mostly in the length of the flower "throat."

Known varieties
The Micronesian population of the species was divided into several varieties by Fosberg et al. (1979): var. *galilai* (Palau), var. *kusiana* (Kosrae), var. *ladronica* (Guam and the Northern Marianas), var. *pogas* (Chuuk), and var. *sair* (Pohnpei and Kosrae), but these are of questionable value. because this kind of separation, based mostly on minor and variable characteristics, has not been done elsewhere over the range of the species.

Large-flowered specimen, Ho'omaluhia Gardens, O'ahu, Hawai'i. PHOTO: C. ELEVITCH

ASSOCIATED PLANT SPECIES
It is associated with numerous species since it has such a wide ecological range. It dominates lowland lava flows on Savai'i, where only a few other species occur, such as *Glochidion ramiflorum*, *Rhus taitensis*, and *Wikstroemia foetida*.

Species commonly associated in modern times
The plant is found in a wide range of cultivated environments, such as lava flows and cloud forests in Samoa, and

ridge forests on Rarotonga. It is commonly cultivated in villages and around in houses in Tonga and especially Hawai'i.

ENVIRONMENTAL PREFERENCES AND TOLERANCES

Climate

It grows in the humid and subhumid tropics and subtropics. It would not do well in dry places or in cooler latitudes.

Elevation range

Lower: near sea level.
Upper: 1060 m (3475 ft).

Mean annual rainfall

Lower: 1500 mm (60 in) or less, but can be grown in drier areas with irrigation.
Upper: 6200 mm (244 in) or more.

Rainfall pattern

It prefers summer or uniform rainfall patterns.

Dry season duration (consecutive months with <40 [1.6 in] mm rainfall)

May survive 2–4 months of drought.

Mean annual temperature

15–31°C (60–90°F)

Minimum temperature tolerated

It is intolerant of frost.

Soils

It grows on a wide variety of soils, from calcareous to lava (as on Savai'i, Samoa), weathered clay (as on Rarotonga), and even as an epiphyte without soil.

Soil texture

It tolerates medium to heavy texture soils (loams, sandy clay loams, clays, clay loams, and sandy clays).

Soil drainage

The tree grows in soils with free drainage.

Soil acidity

pH 5.5–6.5

Special soil tolerances

Can grow in shallow and infertile soils and on lava flows.

Tolerances

The plant is adapted to sunny places with sufficient rainfall, and too much shade or too little water will deter its growth.

Drought

Seems to tolerate drought well. Too little water deters growth. However, water stress stimulates flowering.

Full sun

It prefers, and flowers best in, full sun.

Shade

It tolerates partial shade, although it will not grow as well as in full sun.

Frost

The plant does not tolerate frost.

Waterlogging

Probably does not tolerate waterlogging very well, because it is adapted to dry places such as lowland lava flows and epiphytic situations

Salt spray

It is moderately tolerant of salt spray.

Wind

Pua kenikeni is moderately tolerant of wind, although it can suffer leaf and flower damage.

Abilities

Coppice

Regrows well from pruning, which is a common method of keeping the tree low enough to pick the flowers.

GROWTH AND DEVELOPMENT

The plant is slow to start from seed, often taking several years to reach a height of 1 m (3.3 ft). Plants started from air-layers or cuttings are relatively fast growing.

Growth rate

It is common that a 0.5 m (1.5 ft) rooted cutting reaches 2 m (6.6 ft) in 3–5 years in optimal conditions.

Flowering and fruiting

Both occur throughout the year, but often with peaks (e.g., flowering in Samoa is reported to peak in May to September). Flowering for a vegetatively propagated plant usually begins within months of outplanting.

Yields

The tree is fairly easy to grow and produces many flowers, but flowering is sometimes sporadic.

PROPAGATION

The plant readily reproduces by seed, but seedlings usually take 5–7 years or longer to begin flowering. Air-layering is a common propagation method that yields plants capable of flowering within 9 months under optimum conditions. Cuttings are used commercially. Probably the best sources of seed for propagation are trees growing in a habitat that matches where they will be cultivated. Seedlings found in the forest in its native range are sometimes transplanted, typically into the trunk of a tree fern (*Cyathea* spp.).

Air-layering

Air-layering is best carried out on young branches 1–2 years old. Branches 1–2 cm (0.4–0.8 in) in diameter and 30–45 cm (12–18 in) long are ideal. Pick branches that are easy to access, and preferably with stems that are shaded by other branches. Air-layering works well any time of year, but the mother plant should be in good health and have adequate water and nutrition available.

Preparation

With a sharp knife, remove a ring of outer bark about 2–4 cm (0.8–1.6 in). This step is called girdling or wounding. Position this bark removal with at least 15 cm (6 in) below it to where it attaches to the main stem.

Treatments

A hormone treatment of the bark immediately above the wound can accelerate root formation. The rooting hormone IBA (indole butyric acid) is commonly used at 5000–10,000 ppm. Apply the rooting hormone to 2.5 cm (1 in) of the bark. It doesn't matter if some rooting hormone drips below this.

Rooting media

Once the girdle is made, the area is packed with a moist rooting medium and then wrapped with an impermeable moisture barrier. Many types of rooting media work well, including sphagnum moss, coir fiber, and wood shavings. The rooting medium should be light and hold together when placed in position. Use enough medium to allow for growth of sufficient amount of roots to sustain the new plant after separating the branch from the mother plant. Too much medium will make the wrapping ungainly. Usually one or two handfuls are enough. Moisten the rooting medium with water and squeeze it until no more water drips out. Place the rooting medium around the girdle and wrap it with clear polyethylene plastic (the same as in typical sandwich bags). Using a clear wrapper allows easy inspection of root growth. The wrapping should be taped snugly around the branch, sealing in the moisture and sealing out rainwater. Nursery grafting tape, twist ties, or vinyl flagging can be used. Be sure to tape well around the top edge of the plastic so that rainwater does not get funneled down the branch and inside the plastic.

If the rooting medium is not fully shaded by leaves and thus gets exposure to sun, an outer wrapping with aluminum foil can help reduce overheating.

Separation from mother plant

Begin inspecting the rooting medium 6–8 weeks after starting the air-layer. When a sufficient amount of roots to sustain the plant can be seen in the rooting medium, the air-layer is ready for separation. Remove the propagule by cutting the branch below the plastic wrap (on the side of the plastic closest to the main stem of the tree). The new roots are very fragile, and the severed branch should be transported very carefully to the potting area. Remove the wrapping around the rooting medium very carefully with minimal disturbance, and plant the air-layer in a pot large enough to establish it. A 4- or 8-liter (1- or 2-gal) container should work fine. The plant is then placed in semi-shade (approximately 50%) to acclimatize it during its beginning growth. After 2–3 months, the plant can be moved to a sunnier area, where it can become established in its container for about 6 months before being outplanted.

Size at outplanting

The size at outplanting depends upon the size of the original air-layer. A common size is 45 cm (18 in) tall and about 1–2 cm (0.4–0.8 in) diameter at the base.

Other comments on propagation

With good technique, a success rate of 80% or higher is possible. By first establishing air-layers in a container for up to a year, then transplanting into the field, survival is expected to be 100%. Pua kenikeni will grow as a container plant, with a minimum container size of 5 gallons or more recommended.

DISADVANTAGES

Potential for invasiveness

The plant seems to not be invasive. It has long been cultivated in Hawai'i but has not been reported to be naturalized there. It is unlikely to be an invasive pest outside its native range.

Susceptibility to pests/pathogens

Common diseases reported are leaf spots, fungal root rots, and root-knot nematode. Mealybugs, scales and thrips are also common pests.

Other disadvantages in agroforestry

For flower production, it is best to prune the trees to stimulate new growth for flowering and to keep the tree low enough for easy harvest. Since pua kenikeni requires full sun, other species planted together with it are limited to those that will not grow taller than the ideal height for picking the flowers.

AGROFORESTRY/ENVIRONMENTAL PRACTICES

Homegardens

It is planted in some places, such as Hawai'i and Tonga, as a garden ornamental.

Native animal/bird food

The fruits are commonly eaten by birds and fruit bats over its native range.

Wildlife habitat

It is an important component of some forests, particularly ridge forests (as on Rarotonga) and lava flows (Samoa).

Ornamental

It is a highly desirable ornamental because of its showy, fragrant flowers.

USES AND PRODUCTS

The tree is esteemed mostly for its showy flowers and its timber. The flowers are worn singly over the ear or strung

Here grown at a cemetery entrance on Tongatapu together with noni (*Morinda citrifolia*), screwpine (*Pandanus* sp.), and in the background, beach she-oak (*Casuarina* sp.). PHOTO: C. ELEVITCH into fragrant leis throughout Polynesia, Melanesia, and Micronesia and are also favored for making scented coconut oil. Leis of the flowers are sold commercially in Hawai‘i, Tonga, and elsewhere. Young plants are sold as an ornamental plant in Hawai‘i. Pua kenikeni has a durable, light brown, fine-grained but usually twisted timber that can be worked to a high polish. It was much valued for making tool handles, tools (such as one used for splitting breadfruit in Samoa), house posts (in Samoa and Fiji), and in modern times, handicrafts, but it probably has little potential value as a timber tree that could be grown on plantations. It was esteemed for making furniture, drums, and canoe parts in Tahiti. The flower is so esteemed in the Marquesas that it may well be called the "national flower" of those islands.

Medicinal

The inner bark is used to treat asthma and diabetes in Fiji (Smith 1998). An infusion of the bark is used to treat internal injuries in Tonga, usually in a potion comprising several species. The boiled leaves are reportedly used in New Caledonia for treating rashes and skin irritations.

Beautiful/fragrant flowers

The flowers are used to make leis, and single flowers are worn over the ear. The flowers are soaked in coconut oil to make scented oil. The tree makes an excellent fragrance tree.

Timber

The good quality wood is used for house posts.

Fuelwood

It can be used for firewood, especially where common.

Craft wood/tools

Used for tool handles, drums, handicrafts, and furniture.

Body ornamentation/garlands

It is very popular for making leis throughout its range, because of its attractive and fragrant flowers.

Ceremonial/religious importance

The tree was considered to be sacred in the Cook Islands, where its branches were regarded as paths for spirits of the dead descending to the underworld. In Tahiti, it was sacred to the god Tane, whose images were always made with its wood.

LORE

In Mangaian legend "the pua tree was the tree that guarded the entrance to the land of the spirits in the underworld." In Tahitian legend, "the first pua tree was brought from the tenth heaven by Tane, god of the forests. Hence the tree is sacred to him, and images of him were always made of pua wood." (Neal 1965)

URBAN AND COMMUNITY FORESTRY

Pua kenikeni's relatively compact size makes it ideal for use in both public and private urban areas. The tree is well known throughout the Pacific islands for its fragrant flowers that are used for leis, decoration, and to scent oil.

Size in an urban environment

Although the tree can grow up to 15 m (50 ft) in height, it typically reaches only half that height in landscape environments. When grown in the open, it usually has several co-dominant stems and a spreading canopy.

Rate of growth in a landscape

Growth is slow to moderate, up to about 0.5 m (1.5 ft) per year under optimal conditions.

Root system

It is unlikely that the root system is invasive or interferes with normal landscape operations.

Products commonly used in a Pacific island household

Use of the fragrant flowers in leis and other decoration is the most widespread use in Pacific islands. The wood is used for crafts and general construction. Parts have medicinal uses. In the Solomon Islands, the skin of the fruit is removed exposing the sticky interior and serving as a fly trap.

Light requirements

Pua kenikeni grows and produces flowers best in full sun. It will grow in partial shade (sometimes even as an epiphyte within the canopy of another plant), although not as vigorously as in full sun.

Water/soil requirements

The tree requires at least 1500 mm (60 in) in annual rainfall to grow well but will thrive in drier environments when provided with irrigation water to keep the soil moist. It

The tree does well in open areas on farms and in homegardens. Here it grows together with coffee, bananas, coconuts, and many other species in North Kona, Hawai'i. PHOTO: C. ELEVITCH

requires free soil drainage. Withholding irrigation water during periods of low rainfall stimulates flowering.

Life span

There is no data available; however, it is estimated to be many decades.

Varieties favored for use in homegardens or public areas

Local varieties have been described for Micronesia. Plants that perform well locally can be propagated by air-layering or cuttings to preserve desirable qualities.

Seasonality of leaf flush, flowering, fruiting

New vegetative growth and flowering take place year-round. Peaks in flowering occur at different times depending on the region (see "Flowering and fruiting" above).

Exceptional ornamental values

The nearly constant profusion of fragrant flowers is the hallmark of this tree.

Use as living fence, hedge, or visual/noise barrier

It is usually not used for these purposes. However, it is possible that if planted about 2 m (6.6 ft) apart, pua kenikeni trees could form a hedge. In this case, the trees could be pruned to size to encourage vegetative growth on lower branches.

Birds/wildlife

The fruits are eaten by birds and bats.

Maintenance requirements

In urban environments, regular pruning can be used to control the size of the tree, which also stimulates new growth, encourages flowering (which occurs on new growth), and keeps the flowers within picking height. Limited fertilizer use helps encourage new growth without suppressing flowering.

Special considerations regarding leaf, branch, and fruit drop

Pua kenikeni is moderately tolerant of wind. Usually the tree is kept short by pruning for flower production , which limits any damage from broken branches during high winds. Specimen trees that grow tall are more susceptible to wind damage.

Nuisance issues or hazards

None known.

Common pest problems

Several common landscape pests affect the tree (see "Susceptibility to pests/pathogens" above). Normally none of these are significant enough to require treatment.

COMMERCIAL PRODUCTS

The tree is well known as a minor ornamental and lei flower tree. Therein lies its two biggest commercial products: lei flowers and ornamental nursery plants. The flowers were once sold in Hawai'i for making leis. Each flower cost a dime, hence the Hawaiian name *pua kenikeni*, literally, "dime flower." Coconut oil scented with the flowers is made on locally on some Polynesian islands. Pua kenikeni has a modest commercial potential as an attractive ornamental plant and one planted for its flowers used in leis.

The creamy white, very fragrant flowers make wonderful lei flowers. PHOTO: C. ELEVITCH

Spacing for commercial production

The typical spread of a mature pua kenikeni is 4.6 m (15 ft). For flower production in monocultures, spacing of 4.6 x 4.6 m (15 x 15 ft) is recommended. In mixed plantings, spacing can be highly variable depending on the type of intercrops included.

Management objectives

Flowers are produced on new growth, so pruning is the best way to maintain flowering. Fertilizer use should be moderate, as overfertilizing will stimulate leaf growth rather than reproductive growth. Periodic water stress tends to increase flower production.

Harvest

Flowers are best harvested 2–3 times per week in the early morning. They are harvested by breaking the stem below the flower, leaving the green leafy base attached. Open white flowers can be stored at room temperature for up to 3 days, while flowers that have turned yellow or orange store for lesser periods of time.

Advantages and disadvantages of growing in polycultures

The plant grows very well in a mixed homegarden, but requires full sun in order to flower well.

Estimated yields, including monocultures to mixed agroforestry systems

No data available.

On-farm processing methods required to access market

Do not rinse the flowers in water. To remove thrips from flowers, wrap them in moist newspaper inside a sealed plastic container, and submerge in ice-cold water.

On-farm processing methods

Pua kenikeni flowers cannot be preserved by drying and must be used fresh in leis.

Markets

It has some value in the tourist market; tourists may buy leis of these flowers or coconut oil scented with their fragrance. Leis of the flowers were or are sold in Hawai'i and Tonga and probably elsewhere.

INTERPLANTING/FARM APPLICATIONS

Some interplanting systems include:

Example 1

Location

Kona, Hawai'i

Description

On a small family farm where the main crop is coffee, many plants are grown among the coffee for family use, including several pua kenikeni, bananas, kava, mountain apple, and citrus. Pua kenikeni is grown next to other short plants, such as coffee and dwarf bananas, which ensures full sun most of the day.

Spacing

Four pua kenikeni trees are growing with 2–3 m (6–10 ft) spacing.

Example 2 (Johansen 2004)

Location

South Kona, Hawai'i, at 1550 m (1800 ft) elevation

Description

Six 1-year-old seedlings were planted into an established ti (*Cordyline fruticosa*) grove. Minimum care was given during the first 3 years of growth, with three trees thriving, two surviving, and one dying, and none flowering.

Crop/tree interactions

Ti seems to be a good nurse crop in drought-prone areas. They keep the ground cool and funnel rain down their trunks to the ground.

Spacing

Six trees were planted with 2.5–3 m (8–10 ft) spacing.

Pua kenikeni growing well under ti (*Cordyline fruticosa*) plants in South Kona, Hawai'i. PHOTO: C. ELEVITCH

PUBLIC ASSISTANCE AND AGROFORESTRY EXTENSION

Extension offices for agroforestry and forestry in the Pacific: http://www.traditionaltree.org/extension.html

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Fagraea berteroana (pua kenikeni)

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Acknowledgments: The authors and publisher thank Dale Evans, Eileen Herring, Liz Huppman, and Heidi Johansen for their input.

Recommended citation: Whistler, W.A., and C.R. Elevitch. 2006. *Fagraea berteroana* (pua kenikeni), ver. 3.2. In: Elevitch, C.R. (ed.), Species Profiles for Pacific Island Agroforestry. Permanent Agriculture Resources (PAR), Hōlualoa, Hawai'i. <http://www.traditionaltree.org>.

Sponsors: Publication was made possible by generous support of the United States Department of Agriculture Western Region Sustainable Agriculture Research and Education (USDA-WSARE) Program; SPC/GTZ Pacific-German Regional Forestry Project; USDA Natural Resources Conservation Service (USDA NRCS); Kaulunani, an Urban Forestry Program of the DLNR Division of Forestry and Wildlife and the USDA Forest Service; State of Hawai'i Department of Land & Natural Resources Division of Forestry & Wildlife; USDA Forest Service Forest Lands Enhancement Program; and Muriel and Kent Lighter. This material is based upon work supported by the Cooperative State Research, Education, and Extension Service, U.S. Department of Agriculture, and Agricultural Experiment Station, Utah State University, under Cooperative Agreement 2002-47001-01327.

Series editor: Craig R. Elevitch

Publisher: Permanent Agriculture Resources (PAR), PO Box 428, Hōlualoa, Hawai'i 96725, USA; Tel: 808-324-4427; Fax: 808-324-4129; E-mail: par@agroforestry.net; <http://www.agroforestry.net>. This institution is an equal opportunity provider.

April 2006
ver. 2.1

Flueggea flexuosa (poumuli)

Euphorbiaceae (spurge family)

mamafua **(Solomon Islands);** ***namamau*** **(Vanuatu);** ***pou*** **(Rotuma, Fiji);** ***poumuli*** **(Samoa, Tonga, 'Uvea);** ***poutea*** **(Futuna)**

Lex A. J. Thomson

PHOTO: T. POULI

Stand of planted poumuli trees, Samoa.

IN BRIEF

Distribution The natural range extends from the Philippines to the Solomon Islands and Vanuatu; introduced into several Pacific islands, most notably Samoa.

Size Typically 10–16 m (33–52 ft) tall at maturity.

Habitat Lowland, humid tropics, 0–350 m (0–1150 ft), mean annual temperatures of 22–28°C (72–82°F), annual rainfall of 1500–5000 mm (60–200 in), uniform.

Vegetation Plays an important environmental role in revegetation of various types of disturbed sites.

Soils Wide range of soils including coralline, red clay, poorly drained, and coastal soils.

Growth rate On good sites, greater than 1.5 m/yr (5 ft/yr) for first 5–10 years, then less than 0.75 m/yr (2.5 ft/yr).

Main agroforestry uses Mixed-species woodlot, windbreak, homegarden.

Main products Timber, fuelwood, traditional medicine.

Yields Wood yields are estimated to be about 4–6 m^3/ha/yr (57–86 ft^3/ac/yr).

Intercropping Commonly planted with a wide variety of other species in fields and homegardens.

Invasive potential While it is potentially invasive outside of its natural range, it appears to have very limited potential to become abundant or a problem in little-disturbed native forest communities or on farmlands.

INTRODUCTION

Poumuli (*Flueggea flexuosa*) is a small to medium tree typically 10–16 m (33–52 ft) tall. It occurs naturally in the Philippines, eastern Indonesia, the Solomon Islands, and northern Vanuatu. It occurs in primary forest and dense shrublands at low altitudes, and it is often a pioneer species in river floodplains, fallow fields, and abandoned coconut plantations. In the Solomon Islands the tree has a restricted habitat in lowland coastal forests on coralline soils and beside rivers on poorly drained sites. It is considered a recent introduction in many parts of the South Pacific and is being increasingly planted in central/southern Vanuatu, New Caledonia, Fiji, Rotuma, Wallis and Futuna, Tonga, and Samoa. In these countries poumuli may infrequently and lightly colonize disturbed sites adjacent to where it is planted.

Poumuli is traditionally an important source of durable, round timber throughout its natural range. A major attraction for re-planting is its production of naturally durable logs on short rotations, e.g., 6–7 years for fenceposts and 12–15 years for construction poles. The species is well suited for planting in various agroforestry systems including boundary plantings for property demarcation, planted fallows, and in plantations mixed with other tree and food crops. In Vanuatu and the Solomon Islands, poumuli is considered by villagers to be a good candidate for agroforestry initiatives for small-scale plantations and community forestry. In the Solomon Islands, the tree has potential as a tree crop in a canarium nut/rattan (*Canarium indicum*/*Calamus* spp.) farming system. It is also being evaluated in agroforestry trials, together with kava and vanilla, in Tonga. The species may have a role as a nurse or intercrop for other valuable, long-rotation timber species, such as whitewood (*Endospermum medullosum*) and mahogany (*Swietenia macrophylla*), or as a shade tree for cacao (*Theobroma cacao*). As a locally common lowland pioneer species, the tree plays an important environmental role in revegetation of disturbed sites.

A possible disadvantage is that it has some potential to become an environmental weed. However, field observations suggest that the species appears to have only a very limited ability to invade undisturbed and more closed forest types and farmed lands, and these few trees are likely to be sought out and utilized for timber by local human populations.

Top: Poumuli is often planted along roads and farm boundaries in Samoa. Bottom: Seedlings (at lower left) are often planted in mixed-crop areas, as here, together with breadfruit, banana, taro, and coconut. PHOTOS: C. ELEVITCH

DISTRIBUTION

Native range

The natural range of poumuli extends from the Philippines through eastern Indonesia to the Solomon Islands and Vanuatu (absent from PNG). In Indonesia the species has been only rarely recorded, having been found on Mangole Island in the Sulu group and Vogelkop Peninsula in Irian Jaya. It is widespread in the Solomon Islands, including Shortlands, New Georgia group, Choiseul, Isabel, Guadalcanal, Malaita, Ulawa, San Cristobal, Santa Ana, and Santa Cruz group (Chaplin 1993). The precise southern limit of it natural range is unknown but is thought to be the southeast Solomons (Santa Cruz islands) or northern Vanuatu (Banks Group).

Current distribution

In Vanuatu the range has been extended by planting in recent times, and the tree now occurs from the Banks group, Espiritu Santo, Malo, Maewo, Pentecost, Epi, and Paama through to Erromango (Wheatley 1992, Siwatibau et al. 1998). Poumuli is considered to be either an ancient, usually Polynesian, or quite modern introduction in many parts of the South Pacific, including central/southern Vanuatu, New Caledonia, Fiji (Rotuma, Viti Levu, and Ovalau), Wallis and Futuna, Tonga, and Samoa (Airy Shaw 1980, Smith 1981). The origin of poumuli in Samoa has been the subject of speculation. This species was not recorded as being in Samoa in the late 1800s in old German lists of useful plants of Samoa. It is uncommonly found in indigenous Samoan forests, being restricted mostly to areas around human settlements. Poumuli is the most favored timber for posts used in traditional Samoan houses or meeting places (fale) and it is widely planted around homes and along boundary lines. Given that it is the most popular house post in Shortlands and Choiseul, together with the fact that Shortlands, Choiseul, and Samoa were under German administration during the past century, one can speculate that seeds from either Shortlands, Choiseul, or other former German territories near Shortlands (e.g., Bougainville and New Britain) were taken to Samoa and planted for production of durable round timber. The carriers of these seeds could possibly have been Samoan missionaries or colonial German agriculturalists or administrators.

BOTANICAL DESCRIPTION

Preferred scientific name

Flueggea flexuosa Muell.-Arg.

Family

Euphorbiaceae (spurge family)

Non-preferred scientific names

Securinega flexuosa (Muell. Arg.) Muell. Arg.
Securinega samoana Croizat.
Casearia disticha sensu Setchell, non A. Gray.

Common names

Solomon Islands

mamufu'a (Kwara'ae, Kwaio, To'oabita; Malaita)
mamafua (Kwaio, To'oabaita, Santa Ana, Kahua)
mamahuana (Shortlands)
mamahua (Ulawa; Kahua, San Cristobal)
mavua (Nginia, Guadalcanal; Bugotu, Santa Isabel)
mavuana (Roviana, Marovo, Kusage in New Georgia Group)
urama (Varisi, Choiseul)
uraka, vuraka (Choiseul)
nyia punabe (Ayiwo)
nganimau, nonimua (Santa Cruz group)
pomou (Vaiakau)

Vanuatu

namamau (Bislama language)
nemema (Loh, Torres Islands)
womomo (Vanua Lava, Banks Islands)
mamou (Gaua, Banks Islands)
mamava, momova (Maewo)
memewa, malaus, nvokor, nvakor, nvacur (Santo)
vumamau (Malo)
namalau (Malekula)
neinyelongi (Ipota, Erromango)

Polynesia (introduced)

poumuli (Samoa, Tonga, 'Uvea)
poutea (Futuna)
pou (Rotuma, Fiji)

Other regions

anislag (Philippines: Filipino)
katamangan (Philippines: Manobo)
malagau (Philippines: Butuan)

Size

Poumuli is a small to medium-sized tree, 10–16 m (33–52 ft) tall, very rarely attaining 25–30 m (82–98 ft). Mature specimens typically attain a diameter at breast height (dbh) of about 20–30 cm (8–12 in), up to a maximum of 50 cm (20 in).

Typical form

In younger specimens the crown is narrowly columnar to conical with many small straight, radiating, horizontal branches. Older trees typically have straight, clear boles for up to 6 m (20 ft), sometimes with indistinct buttresses. With age, branching develops a less regular appearance, and the canopy may exhibit an oblong or more spreading form.

Flowers

Male and female flowers are borne on separate trees (dioecious). The masses of small, light greenish-yellow flowers are arranged in short axillary clusters all along the twigs. Both male and female flowers have 5 sepals but no petals. Male flowers have 3–5 stamens, a disk composed of 5 glands, and a sterile pistillode, while female flowers have an annular, crenate disk and a globular, superior ovary.

Leaves

Leaves are simple, alternate, oblong-elliptic, with a rounded or tapered base and prominent, pointed, often recurved tip, shiny dark green above and light green below, 8–14 (–18) x 3–5 (–8) cm (3.1–5.5 [–7.1] x 1.2–2 [–3.1] in). Young leaves are light green. Venation consists of a midvein with 5–7 pairs of side veins, curving forward steeply and almost or just meeting well inside the margin. Petioles are 5–10 mm (0.2–0.4 in) long and may be either red or green (Wheatley 1992, Siwatibau 1998).

Fruit

Fruits are small, globose berries, 3–5 mm (0.12–0.2 in) in diameter, which ripen from light green, through reddish-green to dark purple-black at full maturity (Wheatley 1992, Foliga and Blaffart 1995, van Welzen 1998). There are 3000–8000 fruits per kg (1350–3600 fruits/lb). Poumuli plants commence fruiting from age 2–3 years onwards.

Seeds

There are 4–6 angular seeds about 1 mm (0.04 in) long in each fruit. There are about 300,000 seeds per kg (136,000 seeds/lb) (Chaplin 1993).

Rooting habit

Trees have a well developed, near-surface, lateral root system.

Similar or look-a-like species

Poumuli is a distinctive plant species at all stages of growth. It may be confused with *Glochidion*, e.g., in Vanuatu (red namamau), Fiji (molau), and Samoa (masame).

Key characteristics of poumuli include:

- straight trunk and narrow crown, with tiered layers of thin horizontal branches in young plantation specimens
- longitudinally shallowly, furrowed, light brown-gray bark

Top: Flowering twig (male plant). Bottom: Ripe fruits on twig (female plant). PHOTOS: T. POULI

- simple, elliptic light green leaves, with red petioles in seedlings
- small whitish flowers and fleshy reddish berries (in female trees) borne in axillary clusters all along the twigs.

It is distinguished from *Glochidion* species (which are also in the family Euphorbiaceae) by:

- the presence of a sterile pistillode (ovary, style, stigma) in male flowers
- its fleshy fruits (compared with capsular in *Glochidion*).

GENETICS

Variability of species

The species is expected to have considerable intra-specific variation given its extensive and disjunct natural distribution. In Vanuatu and the Solomon Islands, two morphological types can be distinguished based on the color of the petiole and the veins on the underside of the leaves (Chaplin 1993, Siwatibau et al. 1998).

ASSOCIATED PLANT SPECIES

The species occurs mainly in more open types of lowland tropical forest, including secondary forests and near-coastal thickets.

Macaranga spp. and whitewood (*Endospermum medullosum*) are frequently associated species in its native habitats. As an introduced species in Pacific islands, it is planted together with species such as coconut (*Cocos nucifera*), breadfruit (*Artocarpus altilis*), citrus (*Citrus* spp.), mahogany (*Swietenia macrophylla*), and tropical almond (*Terminalia* spp.).

ENVIRONMENTAL PREFERENCES AND TOLERANCES

Climate

This species is adapted to the lowland, humid tropics. The regions of its natural occurrence are uniformly warm to hot throughout the year.

Elevation range

0–350 (–900) m (0–1150 [–2950] ft); planted 600–900 m in Samoa

Mean annual rainfall

1800–4500 mm (70–175 in), reasonably uniformly distributed

Rainfall pattern

Poumuli prefers climates with summer, bimodal, or uniform rainfall patterns.

Dry season duration (consecutive months with <40 mm [1.6 in] rainfall)

0–3 months

Mean annual temperature

22–28°C (72–82°F)

Mean maximum temperature of hottest month

29–32°C (84–90°F)

Mean minimum temperature of coldest month

19–24°C (66–75°F)

Minimum temperature tolerated

12°C (54°F)

Soils

Poumuli naturally occurs on a wide range of soils including coralline, red clay, somewhat poorly drained soils, and various coastal soils. It exhibits excellent growth and stem form on fertile, bouldery, volcanic clay loams in Samoa.

Soil texture

Tolerates light to heavy soils (sands, sandy loams, loams, sandy clay loams, clay loams, sandy clays, and clays).

Soil drainage

It prefers freely draining soils but tolerates soils with impeded drainage.

Soil acidity

Neutral to acid soils (pH 4.0–7.4).

Special soil tolerances

It is not especially well adapted to shallow, infertile soils, and is intolerant of saline/brackish soils and soils that are waterlogged or shallowly inundated for more than a few weeks.

Tolerances

Drought

The species is recorded as being somewhat drought tolerant in Samoa, tolerating dry spells of 3–4 months once plants are well established.

Full sun

It prefers full sun.

Shade

It will grow satisfactorily with up to about 30% shade.

Fire

On Savai'i (Samoa) it has been reported to be intolerant of fire. Young plants (seedlings and saplings) are normally killed by severe fires, while mature trees usually survive low-intensity ground fires.

Frost

The tree is considered frost-sensitive; it does not naturally occur nor has it been planted in areas experiencing frost.

Waterlogging

It is likely to tolerate only short periods (measured in weeks) of waterlogging or shallow inundation in poorly-aerated soils, but it may grow satisfactorily in better-aerated, lighter-textured soils with somewhat impeded drainage.

Salt spray

It is tolerant of light salt spray but should not be planted in exposed seaside locations.

Wind

Poumuli has, overall, good resistance to steady winds and cyclones. On well drained soils, the tree is expected to resist storm damage mainly because of the strong bole, low stature, and evenly distributed crown with no large branches. In Samoa, the main damage from moderately intense cyclones is associated with defoliation and breakage of side branches, and trees recover well within 6–9 months. However, the tree is uprooted easily in the Solomon Islands (Chaplin 1993), and on Vava'u, Tonga, a high proportion of trees in trial plots were defoliated and died following cyclone Waka in 2002.

Abilities

Regenerate rapidly

The species is capable of regenerating rapidly, especially on cleared, fertile sites, and with human assistance (including weeding and re-transplanting wildings).

Self-prune

In Samoa self-pruning starts at about age 3–4 years. Poumuli has good self-pruning characteristics, with the lower branches progressively being shaded out, dying, and eventually being shed. They can be easily removed by knocking them off using the back of a cane knife. Cyclonic winds may also hasten the process of self-pruning, breaking branches from mid- and upper canopy positions.

Coppice

In Samoa, if stumps are cut very low (to allow for maximum utilization) then mature trees exhibit limited coppicing ability. If plants are cut at a height of more than 1 m (3.3 ft) above ground level, then even mature (10-year-old) trees may coppice very well. In the Solomon Islands, coppice shoots have been reported to develop from cut stumps.

Pollard

Canopies generally recover fairly well following cyclone damage, so trees would be expected to regrow after pollarding. Pollarding is not practiced, because trees have a fairly narrow canopy for many years and up to the time when they can be harvested for poles and posts.

GROWTH AND DEVELOPMENT

Poumuli can be characterized as a "sprinter," growing rapidly in the early years before slowing down from age 10–20 onward. Thereafter, growth, particularly in trunk diameter, is slow.

Growth rate

Height growth commonly exceeds 1.5 m per year (5 ft/yr) for the first 5–10 years, then falls away dramatically as plants reach near full height (about 17–20 m [56–66 ft]). On fertile sites in Samoa, trees averaged 3.0–3.3 m (10–11 ft) annual height growth and 2.7–4.7 cm (1.1–1.8 in) dbh increase per year in the first 3 years. In the Solomon Islands, it exhibits rapid diameter growth up to about 7–8 years; thereafter, diameter growth slows dramatically in more closely planted configurations.

Flowering and fruiting

Flowering and fruiting commence at about age 2–3 years, although flowering may commence within 18 months of field planting. In Samoa, female plants may often be found bearing flowers and fruits in the same umbel, and flowering/fruiting is thought to occur year round. Recorded flowering months include January and May–November, with fruiting recorded in March, May–August, and November. In Vanuatu, the species also flowers and fruits year-round. In the Philippines it has been observed flowering in January and May–June and fruiting in January and May.

Yields

Yields have not been well documented but are estimated to be about 4–6 m^3/ha/yr (57–86 ft^3/ac/yr) during the rapid growth phase to age 8–10 years. Trees at spacing of 400/ha (162/ac) would produce about 800 pieces of 3 m (10 ft) length poles and the same number of smaller diameter posts for fencing over an 8–10 year rotation.

Reaction to competition

During the first few years after planting poumuli grows well at close spacings; that is, it is not especially sensitive to competition.

PROPAGATION

Poumuli is regenerated from seed in several different ways:

- nursery-raised seedlings (usually by forestry departments)
- transplanted wildlings—the most common method for villagers in Samoa (70–90%)

- natural seedling regeneration: protecting and weeding such plants
- direct-seeding—in Vanuatu, seed is sometimes broadcast over newly planted food crop gardens to supplement natural regeneration (Wheatley 1992).

Propagation of seedlings

Seed collection

In Samoa seeds/fruits may be collected throughout the year, with the main period in Vanuatu being from the end of April to July. Mature dark-colored fruits are collected directly from the canopy or by lopping off small branches and picking the ripe fruits.

Seed processing

Ripe fruits should be soaked in water overnight and then depulped by rubbing and washing over a fine mesh sieve to remove the pulpy material. Seeds should be sown in potting mixture and shallowly covered to about 1–2 mm (0.04–0.08 in) depth. First germination occurs in 2–5 weeks.

Seed storage

Seeds are orthodox, i.e., they retain viability when dried and stored. They may be kept for many years in airtight containers under refrigeration (4°C [39°F]).

Germination

Seeds do not require scarification prior to sowing. Sow in a well drained, neutral, fertile loamy soil. The tiny seedlings grow very rapidly and can be transplanted into final nursery pots at the two- or four-leaf stage (about 10 days after germination). Seedlings prefer full sun.

Time to outplanting

Under normal growing conditions, seedlings are ready to plant out in 16–20 weeks. The ideal seedling height for outplanting is about 25 cm (10 in).

Guidelines for outplanting

Poumuli is a light-demanding species, although it can be established under an open canopy of other species such as coconut. Plants grow at a moderately fast rate after outplanting, especially on fertile soils with good weeding.

DISADVANTAGES

Potential for invasiveness

Has a very limited potential to become an environmental weed. In most cases this would not be the case: the species appears to have only a limited ability to invade undisturbed and more closed forest types and farm lands, and any such trees are likely to be sought-out and utilized for timber by people.

Poumuli has been adopted as a beloved tree of Samoa. PHOTO: T. POULI

Susceptibility to pests/pathogens

Generally low susceptibility to pests and diseases. Brown root rot (*Phellinus noxius*) was observed on Kolombangara in the Solomon Islands (Chaplin 1987). Plantings may require protection from termites.

Host to crop pests/pathogens

The tree is not known to be a host for crop pests and pathogens.

AGROFORESTRY/ENVIRONMENTAL PRACTICES

Soil stabilization and improvement

The tree appears to be useful for soil stabilization. It can be expected to improve soil organic matter, but it is not generally planted with this purpose in mind.

Pest control

When planted together with mahogany in the Solomon Islands, the mahogany appears to suffer less damage from shoot borer (*Hypsipyla robusta*) than in pure stands. This may be due to higher numbers of predators attracted into the mixed stands and eating and reducing the population of shoot borer moths/larvae.

Crop shade/overstory

The species is well suited to provide varying levels of shade (depending on planting spacing) for a wide range of crop species. In the Solomon Islands it is considered to have good potential as a shade tree for cacao (*Theobroma cacao*) because it:

- is a long-lived, small, even-canopied tree
- provides a valuable round timber product in small or large dimensions appropriate for village use
- is a host for ants (*Oecophylla smaragedina*) which control a bug (*Amblypelta cocophaga*) that feeds on new shoots and young pods of cacao
- is not as susceptible to brown root rot (*Phellinus noxius*) as are other shade trees, such as *Leucaena,* and therefore is less likely to spread the disease onto cacao.

Alley cropping

Poumuli is an excellent species for growing in wide-spaced alleys, and it has been used successfully on Santo, Vanuatu, in this role.

Homegardens

The species is commonly included in homegardens in Samoa; it is well suited to such plantings due to its compact, low stature, wind firmness, and attractive appearance.

Improved fallows

Poumuli is not known to have specific soil-improving attributes, other than general attributes of trees such as cycling of mineral nutrients from deeper soil layers to crop root zone, and addition of organic matter. However, it is an economically attractive planted fallow and income-generating crop during crop fallow periods as it can be harvested at a relatively early age, e.g., 7–8 years.

Living fences

The tree is little used for live fencing (as it cannot be propagated by large branch cuttings), but it would be well suited to this purpose, due to its longevity and narrow crown.

Fence posts

Cut stems make durable fence posts and are widely used for this purpose. Both early thinnings, e.g., 5–7-year-old plants, and the narrow, upper stem sections of older trees may be utilized for fence pots.

Boundary markers

A useful boundary marker due to its longevity and compact crown, it is commonly planted along farm boundaries in Samoa.

Windbreaks

Poumuli makes an excellent narrow, low windbreak, especially younger trees with more dense foliage, up to about 10 years of age.

Silvopasture

The tree is not known to be included in silvopastoral systems, but it ought to be suitable for providing some shade and as a windbreak.

Animal fodder

Grazing animals do not normally eat the foliage. However, young seedlings may have their leaves eaten by cattle.

Woodlot

It is very widely planted as a woodlot species in Samoa for production of *fale* poles. It may be planted in pure woodlots or mixed with other exotic and native species.

Native animal/bird food

The fruits (small berries) may be produced almost year-round and are consumed by various fruit-eating birds wherever it is found.

Wildlife habitat

The tree provides excellent habitat and a food source for many bird species, both insect- and fruit-eaters, e.g. white-eye, Pacific pigeon, and fruit doves, as well as flying foxes.

Bee forage

The species flowers heavily over a long period, and the flowers are well visited by honey bees. They appear to be an excellent food source for bees, providing both pollen and nectar. It is considered a tree of moderate importance for apiaries in the Solomon Islands (Forster et al. 1988), but the quality of honey produced by bees feeding on nectar of poumuli is yet to be determined.

Coastal protection

The tree may be included in less exposed portions of coastal protection plantings.

Ornamental

Poumuli is an attractive tree with ornamental potential.

USES AND PRODUCTS

Poumuli is highly regarded throughout the South Pacific for production of highly durable timber, being especially favored for building construction uses, especially as round fence posts and construction poles. Its moderately rapid growth, good bole form, and wood and non-wood uses make it a promising tree for agroforestry plantings, including those on infertile soils. In the Solomon Islands and Vanuatu, the species grows rapidly and straight without big branches and is widely exploited for local uses. Traditional non-wood product uses in Melanesia include herbal medicines and a dye.

In Samoa the tree is extensively planted in rural gardens and house yards, and has become the main source of logs for posts and rafters in construction of traditional Samoan houses. It is also often planted as a border tree in Samoan villages, including boundaries and along roads. The species has potential as an intercrop species along with high-value timber species, such as whitewood (*Endospermum medullosum*), mahogany (*Swietenia macrophylla*), and sandalwood (*Santalum* spp.), and would itself be a valuable component of the crop. In some places the tree has moderate importance for honey production, providing both pollen and nectar to honey bees during the flowering season.

Top: Poumuli is commonly planted in homegardens at close spacing, here with pineapple, ginger, bananas, yams, and coconut. PHOTO: C. ELEVITCH
Bottom: Harvesting logs, Samoa. PHOTO: T. POULI

Medicinal

A medicinal drink made from the rasped bark is used to treat fever in the Solomon Islands (Maenu'u 1979). The shredded root is used medicinally in New Guinea. It is also used in traditional medicine in Vanuatu.

Timber

Poumuli yields a heavy heartwood; the density has been variously recorded as 900 kg/m³ (56 lb/ft³) on a dry weight basis, 770 kg/m³ (48 lb/ft³) at 12% moisture content (m.c.) (Kininmonth 1982), and 810–935 kg/m³ (50.5–58 lb/ft³) at 15% m.c. (van Welzen, 1998). The heartwood is pale yellowish brown or reddish brown, and sometimes hardly distinguishable from the pale sapwood, present as a 1–3 cm (0.4–1.2 in) wide band (Chaplin 1993, Walker 1948). The grain is straight and the texture moderately fine. Although very hard and strong, the timber is easily worked, resistant to drywood termites and fungi, and very well suited for service in ground contact. The sapwood is not durable in the ground but is non-susceptible to *Lyctus* attack. Uses include house poles, fence posts, ground posts, and light aerial members in house construction, bridges, and marine piles (Henderson and Hancock 1988, Wheatley 1992, Chaplin 1993, Martel & Associates 1998, van Welzen 1998).

Fuelwood

The wood makes an excellent, hot-burning fuel (Chaplin and Ngoro 1988, Wheatley 1992, Foliga and Blaffart 1995).

Craft wood/tools

It may be suitable for wooden buttons and other uses where a fine-grained, strong timber is required (Chaplin 1993). In Samoa its uses include:

- wood on which tapa cloth is beaten
- short, sharpened sticks for husking coconuts (Whistler 2000)
- planting sticks for planting taro, other crops, and tree seedlings.

Canoe/boat/raft making

In Samoa the wood is used for making booms for outrigger canoes (Whistler 2000).

Tannin/dye

Leaves of the red-veined form are used to stain *Pandanus* leaves a charcoal color (Chaplin 1993). In Samoa and Uvea (Wallis), the purple juice from the fruit is used as a dye (Smith 1981, Foliga and Blaffart 1995).

COMMERCIAL PRODUCTS

The primary commercial products include wooden posts and poles that are sold in local markets, e.g., Bougainville, Santo in Vanuatu, and Apia, Samoa. Price varies depending on the length and diameter of the log.

Spacing for commercial production

A stocking rate of over 1000 stems/ha (405 stems/ac) at age 6 years is appropriate for pole production (Chaplin 1993, Foliga and Blaffart 1995).

In pure plantations various spacings have been used including 2 x 2 m, 2.5 x 2.5 m, 3 x 3 m, 2 x 5 m, 4 x 3 m, and 4 x 4 m, but currently 5–6 m x 4 m (16–20 x 13 ft) is preferred in order to avoid crown interference at an early age. In Samoa the most common spacing for mixed-species forestry plantings is 8 x 3 m (26 x 10 ft) (Chaplin 1993, Foliga and Blaffart 1995, T. Alatimu pers. comm. 2004)

Management objectives

Producing long, clear, and straight boles for posts and poles is the objective. Removal of lower branches to a height of 3 m (10 ft) at an age of about 3–4 years is recommended for the production of posts. Additional later pruning of side branches up to a height of 6 m (20 ft) may be desirable for production of larger poles. Due to the rare occurrence of multiple trunks, singling has not proved to be necessary.

Design considerations

At close spacing, the species is able to rapidly dominate the site; this reduces weeding requirements, and early thinnings can provide lighter poles such as rafters. Appropriate thinning regimes will need to be developed to ensure the required size of the end product is achieved.

Small on-farm woodlot, Samoa. PHOTO: T. POULI

New planting of poumuli interplanted with taro. PHOTO: T. POULI

Yield

Yields are estimated to be about 4–6 m^3/ha/yr (57.2–85.8 ft^3/ac/yr) during the early years. Processing includes cutting to length and bark removal. The prepared logs are usually sold only in local markets, e.g., within 50 km (30 miles) of production. In recent years in Samoa, poumuli products from West Savai'i have been supplied further afield to markets in 'Upolu.

INTERPLANTING/FARM APPLICATIONS

Example system 1

Location

Siumu, 'Upolu, Samoa.

Description

This is a newly developed system, including small woodlots and boundary marker plantings as part of private and community forestry. The main product is small durable poles, which are harvested at age 8–10 years. The price in 2004 was about WS$15–30 (equivalent to US$5–10) per 3 m (10 ft) length of small pole (10–15 cm [4–6 in] diameter). Most trees yield 2–3 m (6.5–10 ft) poles, and two fence posts (the latter selling for about WS$2–3 each). Whole trees return for about WS$35–60 each.

Crop/tree interactions

The trees provide a windbreak and shelter for adjacent crops. They also minimize the growth of weeds and need for cutting.

Spacing

Spacing varies; when intercropped with cash crops the spacing may be 8–10 m (26–33 ft) between rows and 6 m (20 ft) within rows. In woodlots the most common spacing is 6 x 4 m (20 x 13 ft).

Cacao growing in the understory of poumuli. Tutuila, American Samoa.
PHOTO: C. ELEVITCH

Example system 2

Location

Solomon Islands.

Description

This is a new system under development combining poumuli in a canarium nut/rattan (*Canarium indicum*/*Calamus* spp.) farming system. In this system poumuli provides early shade for both canarium nut and rattan, as well as quicker economic returns while the longer-maturing crops are developing.

Crop/tree interactions

Poumuli provides early shade for establishment of rattan and prevents weed growth. Depending on development of *Canarium* as a shade and support crop for rattan, poumuli could be retained for a variable period and cut at any time to provide durable poles and/or cash income.

Spacing

In this system, poumuli is planted at close spacing, 3 x 3 m (10 x 10 ft), to provide shade from an early age and more stems for later commercial thinnings.

PUBLIC ASSISTANCE AND AGROFORESTRY EXTENSION

Extension offices for agroforestry and forestry in the Pacific: http://www.traditionaltree.org/extension.html

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Flueggea flexuosa (poumuli)

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Acknowledgments: The author and publisher thank Tito Alatimu, Dale Evans, Tolusina Pouli, Diane Ragone, and Art Whistler for their input. Photo contributions from Tolusina Pouli are greatly appreciated.

Recommended citation: Thomson, L.A.J. 2006. *Flueggea flexuosa* (poumuli), ver. 2.1. In: Elevitch, C.R. (ed.). Species Profiles for Pacific Island Agroforestry. Permanent Agriculture Resources (PAR), Hōlualoa, Hawai'i. <http://www.traditionaltree.org>.

Sponsors: Publication was made possible by generous support of the United States Department of Agriculture Western Region Sustainable Agriculture Research and Education (USDA-WSARE) Program; SPC/GTZ Pacific-German Regional Forestry Project; USDA Natural Resources Conservation Service (USDA NRCS); State of Hawai'i Department of Land & Natural Resources Division of Forestry & Wildlife; and the USDA Forest Service Forest Lands Enhancement Program. This material is based upon work supported by the Cooperative State Research, Education, and Extension Service, U.S. Department of Agriculture, and Agricultural Experiment Station, Utah State University, under Cooperative Agreement 2002-47001-01327.

Series editor: Craig R. Elevitch

Publisher: Permanent Agriculture Resources (PAR), PO Box 428, Hōlualoa, Hawai'i 96725, USA; Tel: 808-324-4427; Fax: 808-324-4129; E-mail: par@agroforestry.net; Web: <http://www.agroforestry.net>. This institution is an equal opportunity provider.

April 2006
ver. 2.1

Gliricidia sepium (gliricidia)

Fabaceae (legume family)

gliricidia, Mexican lilac, mother of cocoa, Nicaraguan cacao shade, quick stick, St. Vincent plum, tree of iron (English); *immortelle*, *lilas étranger* (French); *madre de cacao* (French, Spanish); *rechesengel* (Palau)

Craig R. Elevitch and John K. Francis

IN BRIEF

Distribution Widely naturalized in the tropical Americas, Caribbean, Africa, Asia, and the Pacific islands.

Size Medium tree to 15 m (50 ft), typically reaches 10 m (33 ft) in height; size is usually controlled by regular pruning in cultivated environments.

Habitat Grows best in warm, seasonally dry climates with 900–1500 mm (35–60 in) annual rainfall and elevations 0–1200 m (0–4000 ft).

Vegetation Where introduced, associated with a wide variety of cultivated crops.

Soils Grows in sands to clays, preferring freely draining soils with pH 5.0–8.5.

Growth rate Fast in early years, or when annually pruned back, over 2 m/yr (6.6 ft/yr).

Main agroforestry uses Living fence posts, crop shade, improved fallow.

Main products Fuelwood, fodder, mulch/organic matter.

Yields Fuelwood from stands harvested every 2–3 years are 10–20 m^3/ha (143–286 ft^3/ac).

Intercropping Has been used for shade and organic matter with cacao, coffee, vanilla, tea, yam, and other crops.

Invasive potential Moderate potential for invasiveness, has naturalized in many areas, but is usually not considered to be a pest.

PHOTO: C. ELEVITCH

Boundary planting of gliricidia.

INTRODUCTION

Gliricidia (*Gliricidia sepium*) is a medium-size, semi-deciduous tree that typically grows to 10 m (33 ft) (occasionally reaching 15 m [50 ft]) in height, with a broad canopy. Native to Central America and possibly northern South America, its cultivation is now pantropical. It grows best in tropical, seasonally dry climates. The tree thrives in deep, well drained soils, although it tolerates shallow or skeletal soils that have high available calcium levels. Because of its ability to grow in slightly saline calcareous soils, gliricidia is suitable for cultivation in atoll environments.

It is a fast-growing, nitrogen-fixing tree used throughout the tropics for the many environmental services and products it provides. Gliricidia is widely used to provide crop shade for cacao, coffee, and other shade-loving crops, living fence posts for pasture and property boundaries, and as a fallow tree to improve degraded land. The tree is also an important source of green manure, fodder, and fuelwood. Its ease of propagation by seed and small and large cuttings makes it a very easy tree for farmers to multiply quickly. It is probably the most widely cultivated multipurpose agroforestry tree after *Leucaena leucocephala* (Simons and Stewart 1994).

DISTRIBUTION

Native range

Because gliricidia has been cultivated from pre-Colombian times, the precise native range is difficult to determine. It is certainly native to Mexico (from about 25°30´ N) and Central America (to 7°30´ N in Panama) and may also be native to northern South America in Colombia, Venezuela, and the Guianas.

Current distribution

The species has been cultivated and has naturalized widely in tropical America, the Caribbean, Africa, and Asia. In the Pacific islands, it is found in American Samoa, Cook Islands, Federated States of Micronesia, Fiji, French Polynesia, Guam, Hawai'i, Kiribati, New Caledonia, Papua New Guinea, Samoa, Solomon Islands, Tonga, and Vanuatu.

BOTANICAL DESCRIPTION

Preferred scientific name

Gliricidia sepium (Jacq.) Kunth ex Steud.

Family

Fabaceae (legume family)

Subfamily

Faboideae (Papilionoideae)

Tribe

Robinieae

Non-preferred scientific names

Galedupa pungam Blanco
Gliricidia lambii Fernald
Gliricidia maculata var. *multijuga* Micheli
Gliricidia maculate (Kunth) Walp.
Lonchocarpus maculates (Kunth) DC.
Lonchocarpus roseus (Miller) DC.
Lonchocarpus sepium (Jacq.) DC.
Millettia luzonensis A. Gray
Robinia hispida L.
Robinia maculate Kunth
Robinia rosea Miller
Robinia sepium Jacq.
Robinia variagata Schltdl.

Common names

Pacific islands

gliricidia, Mexican lilac, mother of cocoa, Nicaraguan cacao shade, quick stick, St. Vincent plum, tree of iron (English)
immortelle, *lilas étranger*, *madre de cacao* (French)
rechesengel (Palau)

Other regions

almácigo extranjero, *amory celos*, *bien vestida*, *desnodo florecido*, *floresco*, *madre de cacao*, *madre negro*, *mataratón*, *mataraton*, *palo de hierro*, *palo de parque*, *piñón amoroso*, *piñón de cuba*, *piñón florido*, *varita de San José* (Spanish)
gamal (Indonesia)

Size and form

Gliricidia is a small, thornless, semi-deciduous tree 3–15 m (10–50 ft) in height with a trunk up to 30 cm (12 in) in diameter at breast height (dbh). The canopy diameter is about the same as the height for most provenances if not pruned. The tree may have single or multiple stems and tends to have a diffuse, irregular crown. In agricultural environments, the size and shape are often greatly modified by repeated lopping to suit the farmer's goals.

Flowers

Racemes or panicles 5–12 cm (2–5 in) long are borne at the base of leaves. The individual flowers have a light green (tinged with red), five-toothed calyx and a corolla of five whitish-pink or light purple petals. The flower has a typical pea-flower shape with a broad standard, two oblong, curved wings, and two united petals. There are 10 whitish stamens and a pistil with a red ovary and a whitish style.

Leaves

The alternate, pinnate leaves, 15–30 cm (6–12 in) long, have a silky pubescence when young. There are 7–17 leaflet pairs and a terminal leaflet. The leaflets are elliptical or lanceolate, 3–6 cm (1.2–2.4 in) long and 1.5–3 cm (0.6–1.2 in) wide, short to long-pointed at the tip, and rounded to short-pointed at the base.

Fruit

The fruits are flattened pods, 10–15 cm (4–6 in) long, that contain three to eight seeds. They are yellow-green, becoming yellow and finally brown or blackish at maturity. Flowering and fruiting begins between 1 and 5 years of age.

Seeds

The seeds are circular and flat, about 10 mm (0.4 in) in diameter, shiny, and light to dark brown. There are 4700–11,000 seeds/kg (2100–5000 seeds/lb), varying considerably among seed sources. The seeds are dispersed when the pods dry sufficiently that the two halves separate and curl explosively, propelling the seeds as far as 25 m (82 ft) away from the mother tree.

Bark

The bark is smooth to slightly fissured and gray to brown.

NAME DERIVATIONS

- *Gliricidia* from Latin *glis*, "dormouse" and *caedere*, "to kill" and the Spanish name *mata-ratón* refer to the tree's rodenticidal properties.
- The epithet *sepium* means "of hedges" which is the use of the tree Jacquin observed in Columbia in the mid-eigtheenth century.
- "Mother of cocoa" and the Spanish *madre de cacao* refer to the plant's frequent use as a shade tree for cacao.
- "Quick stick" refers to the ability of cuttings to quickly and easily root and grow into new trees.
- "Tree of iron" and the Spanish *palo de hierro* refer to the hard, durable wood.

Rooting habit

Gliricidia propagated from cuttings produces an extensive, shallow, lateral root system. Seedlings develop taproots, but it is unclear if the taproots endure throughout the life of the plant. One study of trees from seedlings on coastal sands reported poorly developed taproots and well developed lateral roots.

Similar or look-a-like species

Gliricidia looks superficially like several other leguminous tree species. The foliage can be confused with various shower trees that are frequently used as ornamentals, such as *Cassia javanica*. Shower trees have clusters of cream, pink, orange, yellow, or red flowers resembling in shape and size large bunches of grapes hanging from small branches The flowers have five petals of similar size and shape. In contrast, gliricidia has pea-like flowers in clusters

Flowers and leaves. INSET FLOWER PHOTO BY J. PARROTTA, OTHERS BY C. ELEVITCH

 

Left: Nearly mature seedpods turn from green to yellow (shown here), then dry to brown or blackish at maturity. Right: Bark of a 10-year-old tree. PHOTOS: C. ELEVITCH

Although the leaves are similar in appearance to gliricidia, the large clusters of ball-shaped flowers distinguish the shower tree (shown here). PHOTO: C. ELEVITCH

that are much more modest in size, and whitish-pink to light purple in color.

GENETICS

Variability of species

Differences within gliricidia populations have been recognized in stem length, biomass production, flower color, seed size, number of racemes per tree, number of pods per tree, and synchrony of flowering. One study (Simmons 1996) noted 2.5 times as many pods per tree in Monterrico than in Belen Rivas provenance. A high correlation (r = 0.73) between raceme number and pod number was noted, but without provenance or family variation. Another study (Simons and Dunsdon 1992) noted provenance variations in wood and foliage production. Of these, the variation in wood production was highest. Southern provenances (Guatemala and Nicaragua) were generally good performers, while northern provenances (Mexico) were generally poor performers. There is genetic evidence that one provenance (Masaguara) is escaped from domestication and another (Pedasi) has undergone a severe genetic bottleneck, i.e., undergone a large reduction in genetic variability.

Known varieties

There are no formally recognized varieties.

Culturally important related species in the genus

In the genus *Gliricidia*, three species are currently recognized *G. sepium*, *G. brenningii*, and *G. maculate*. *Gliricidia brenningii* has many tiny leaflets, tiny appendages at the base of the leaflet stalks, and longer, darker pods. *Gliricidia maculate* has leathery leaves and usually white flowers in pendulous inflorescences. *Gliricidia sepium* has somewhat elongated, papery leaves, and pink flowers in upward-curved to erect inflorescences. Members of the genus are obligate out-breeders (i.e., cross-pollination between two individuals must take place for seeds to develop), and interspecific hybridization is common between *G. maculate* and *G. sepium* in areas where they grow in proximity. *Gliricidia sepium* is widely cultivated both within and outside of its native range. *Gliricidia brenningii* and *G. maculate* are cultivated within their native ranges for living fence posts and ornamentals but are not commercially cultivated and are generally unknown outside of their ranges.

Genetic resources where collections exist

Germplasm collections have been made by the International Livestock Centre for Africa (ILCA), Centro Agronómico Tropical de Investigacíon y Enseñanza (CATIE, Costa Rica), and Oxford Forestry Institute (OFI, UK). Trials have been conducted by the OFI/Oxford and the University of Hawai'i.

ASSOCIATED PLANT SPECIES

Gliricidia grows naturally in deciduous or semi-deciduous dry forests. The species is a pioneer, colonizing disturbed areas, and so may be found in secondary forests; it is rarely or never found in old-growth high forests.

Associated species commonly found in native habitats

Gliricidia may be found associated with most of the species of the deciduous dry forests of Meso-America. Some commonly associated genera are *Acacia, Bauhinia, Bursera, Brosimum, Caesalpinia, Calicophyllum, Combretum, Crescentia, Dalbergia, Enterolobium, Guazuma, Haematoxylum, Juliania, Lonchocarpus, Lysiloma, Pithecellobium, Senna, Simarouba,* and *Swietenia.*

Species commonly associated as aboriginal introductions in Pacific islands

As a relatively recent introduction to Pacific islands, gliricidia is generally found below elevations of 350 m (1150 ft) and generally only on farms, but to a limited extent in urban areas, where it is associated with a wide range of mainly introduced cultivated species.

Species commonly associated in modern times or as recent introduction

In Central and South America in disturbed habitats and where introduced, it is commonly associated with *Tabebuia* spp., *Cordia* spp., *Albizia* spp., *Guazuma ulmifolia, Leucaena leucocephala*, and *Ricinus communis*. In the rest of the tropics, it is associated with the agricultural crops cacao, vanilla, coffee, tea, yam, pepper, vegetables, grains, pasture grasses, and other crops.

ENVIRONMENTAL PREFERENCES AND TOLERANCES

Climate

Gliricidia grows best in warm, seasonally dry climates with moderate mean annual rainfall. It also grows well in areas with precipitation distributed evenly throughout the year and where there is higher rainfall, although seed production is less reliable.

Elevation range

0–1200 m (0–4000 ft)

Mean annual rainfall

(600–) 900–1500 (–3500) mm ([24–] 35–60 [–140] in)

Rainfall pattern

The tree grows in climates with summer, winter, bimodal, or uniform rainfall patterns.

Dry season duration (consecutive months with <40 mm [1.6 in] rainfall)

3–9 months

Mean annual temperature

20–27°C (78–81°F)

Mean maximum temperature of hottest month

27–36°C (81–97°F)

Maximum temperature tolerated

42°C (108°F)

Mean minimum temperature of coldest month

14–23°C (57–73°F)

Minimum temperature tolerated

8–10°C (46–50°F). It does not grow well in areas where the night temperature drops below 5°C (41°F) and does not tolerate frost (<0°C [32°F]).

Soils

The tree does best in deep, medium-textured, well drained, fertile soils, with near neutral acidity. It tolerates rocky (shallow or skeletal) soils that are high in available calcium, and soils with textures from sands to clays. Gliricidia fails or grows poorly on cool, wet, compacted, poorly aerated, very acidic (below pH 4.2), or highly alkaline soils (above pH 9.0).

Soil texture

It grows in light to heavy soils (sands, sandy loams, loams, sandy clay loams, clays, clay loams, and sandy clays).

Soil drainage

It prefers freely draining soils and tolerates seasonally impeded drainage.

Soil acidity

The tree prefers acid to neutral/mildly alkaline soils (pH 5.0–8.5).

Special soil tolerances

Gliricidia can grow in shallow, slightly saline, slightly sodic, and moderately infertile soils. It also tolerates calcareous soils, such as those of atolls.

Tolerances

Drought

Gliricidia tolerates seasonal droughts and climates with mean annual rainfall as low as 600 mm (24 in).

Full sun

It grows best in full sunlight.

Shade

The tree tolerates only light shade. Seedlings that are planted in heavy shade can survive but will not grow. Seedlings that have been suppressed by shade for even 3–4 years will recover and grow rapidly if the sheltering overstory is removed.

Fire

Gliricidia is native to areas of Central America prone to perennial fires. It is often top-killed by fire, but young trees readily regenerate by sprouting from the root collar.

Frost

The tree is intolerant of frost.

Waterlogging

It tolerates brief flooding, but heavily compacted soils or areas prone to waterlogging should be avoided. It can grow in areas with anaerobic or seasonally anaerobic subsoils, although it is not long-lived in such conditions.

Salt spray

Gliricidia can grow in light salt spray. In fact, it is native to many plant communities along the Pacific coasts of Mexico and Central America, which indicates good salt tolerance.

Wind

The tree tolerates trade winds very well, even in wet areas, where it holds its leaves year-round. The trees are moderately resistant to hurricane-force winds, losing leaves and branches but surviving. Trees grown from cuttings are more vulnerable to windthrow than seedlings.

Abilities

Fix nitrogen

Gliricidia is a good nitrogen fixer, although not as good as many other nitrogen-fixing trees (see table below). Nodulation with *Rhizobium* normally occurs in the native and in Central and South American naturalized ranges within 3 months of planting. For Pacific island and other habitats where the tree is newly introduced, the planting holes or nursery media may be sprinkled with rhizobia bacteria inoculant cultures. Alternatively, crude liquid inoculant can be made by collecting soil from the root zone under healthy gliricidia trees, mixing with water, and straining off the particulates to make it easier to sprinkle.

Nitrogen fixation for some important agroforestry trees (after MacDicken 1994)

Species	kg/ha/yr	lb/ac/yr
Casuarina equisetifolia	40–100	36–90
Erythrina poeppigiana	60	54
Gliricidia sepium	13	12
Inga jinicuil	35–40	31–36
Leucaena leucocephala	up to 274	244

Gliricidia growing near coast of 'Upolu, Samoa, where it is subject to wind and salt spray. PHOTO: C. ELEVITCH

Regenerate rapidly

The tree regenerates rapidly following cutting or other top damage.

Self-prune

The trunks are usually clear of side branches below the main crown, although many provenances have short trunks with large, spreading branches.

Coppice

The tree can be managed for coppice production of firewood, stakes, fodder, and green manure. It regrows very well after pruning, especially if cut only during periods of active growth (rather than during the dry or cool seasons) and if about 10% of the foliage is left on the tree.

Pollard

Pollarding is the pruning back of all branches to a framework on a regular basis (usually annually). Gliricidia is tolerant of pollarding and forms a new crown quickly; this is common practice for gliricidia used as live fence posts in pasture in situations where there is a use for the wood or where there is enough scarcity of fodder to justify the effort.

GROWTH AND DEVELOPMENT

Growth rate

Initial growth is rapid (up to 3 m [10 ft] in the first year), slowing until a final height of 3–15 m (10–50 ft) is reached. The tree has a moderate life span of up to 50 years and often becomes hollow and declines before dying.

Flowering and fruiting

Flowering and fruiting may begin as early as the end of the first growing season and almost always begins by the fifth growing season. Flowering occurs during the dry season, depending on the local climate. If rainfall is evenly distributed throughout the year, flowering may occur at any time, irregularly throughout the year, but in lower quantities compared with seasonal climates.

Reaction to competition

New plants are susceptible to competition from grasses during the first year. Once above the grasses, gliricidia is a good competitor. It has been used to reclaim intractable grass swards.

PROPAGATION

Gliricidia is easily propagated by seed or large cuttings. Seedlings are produced in nurseries in pots or bags and are ready for outplanting within 2–3 months. Direct-seeding experiments have given good germination and early survival, but good weed control for the first few months is required. As a living fence post, this species is often propagated by cuttings. Tissue culture has also been done successfully but is rarely used in practice.

Propagation by seed

(after Wilkinson and Elevitch 2003a)

Seed collection

Gliricidia is highly variable in form and productivity, and for this reason superior provenances (e.g., "Retalhuleu" and "Belen Rivas") should be sought out for propagation (Simons and Dunsdon 1992). Time of flowering and seeding varies with climate, elevation, and dry season duration. Trees usually flower in the dry season (November–March in Kona, Hawai'i; January–March in Mexico; December–May in Puerto Rico). The time between flowering and pod ripening can be very short, 5–7 weeks in some areas. During certain years, and for certain provenances, seed production can be very low.

As the seedpods dry they release their seeds (dehisce) explosively, flinging them up to 25 m (82 ft) away from the tree. For this reason, seed collectors must observe carefully and collect seedpods from the tree when they are ripe but before they dehisce. Seedpods are 10–15 cm (4–6 in) long and 12–15 mm (0.5–0.6 in) wide. Each contains three to eight seeds. Pods are collected after they turn from yellow-green to brown but before they are dry enough to curl and release their seeds.

Pods are collected with a minimum of effort by hand from low branches or with pruning poles from moderately sized trees. Pruning trees back to a stump 1–2 m (3.3–6.6 ft) in height during or after the seed harvest controls tree size and promotes flowering the next season. The highest seed-producing areas (in Puerto Rico) receive around 1250 mm (50 in) of mean annual precipitation. Areas with 1900 mm (75 in) or more rainfall have produced little seed. Although usually not recommended, seeds may also be collected from the ground, particularly in dry areas.

Seed processing

Ripe pods are spread out in the sun on plastic tarps or a concrete slab. As they dry in the sun, the pods curl and explode, making a popping sound. The drying area should be covered with a fine mesh netting to prevent seeds expelled from dehiscing pods from escaping the area. Once the

Seeds drying on a tarp in the sun. The fragments of dried seed pod will be removed along with other particulates before storage PHOTO: C. ELEVITCH **Right: Same-age seedlings that are inoculated with *Rhizobium* (left) are much more vigorous than those that are not inoculated (right). This holds true for the life of the tree.** PHOTO: K. MUDGE

seedpods are dry and crunchy, seeds that are still attached to pods are separated by hand or with a thresher. Seeds are further dried to 6–10% moisture.

Seed storage

The seed is orthodox, meaning they remain viable after being dried. At a moisture content of 6–10%, and free of pests, seeds can be stored in an airtight container at 4°C (39°F) for over 10 years and retain viability of up to 90% (Allison and Simons 1996). Insect pests can be killed by freezing fully dried seeds at –10°C (14°F) for 48 hours prior to storage.

Pre-planting treatments

No scarification is necessary. Soaking seeds overnight in cool water will cause them to swell, hastening germination. For fresh seed collections free from insect infestations, germination is usually high, over 90%. Germination takes 3–15 days.

Growing area

Seedlings are best grown in full sun in an uncovered growing area. Root-training tubes 14 cm (6 in) deep and 3.8 cm (1.5 in) in diameter work well, as do polyethylene plastic bags 10 x 15 cm (4 x 6 in), when laid flat.

Germination

Seeds are placed in containers filled with premoistened potting medium and covered with about 5 mm (0.2 in) of medium and a thin layer of mulch (such as poultry grit, fine gravel, or finely screened volcanic cinder). Water is applied with a fine-headed sprayer to keep the medium moist. Daily watering is usually necessary, by hand or with an automated system. At seeding time or within 2 weeks of germination, seedlings should be inoculated with rhizobia bacteria, either manufactured or made from nodules or soil collected from under a compatible host. Early inoculation with rhizobia ensures good nodulation and growth.

Media

A standard well drained potting medium such as 50% peat moss, 25% perlite, and 25% vermiculite, amended with a little compost, lime, gypsum, micronutrients, rock phosphate and potassium, can be used.

Time to outplanting

When grown in full sun and under optimal conditions, seedlings are ready to plant out in 8–12 weeks. About 8 weeks after germination, seedlings are double-spaced to allow maximum penetration of sunlight and air circulation. Assuming seedlings were inoculated with rhizobia bacteria at an early age, no additional nitrogen fertilization is necessary, although a very light topdressing of slow release 8-8-8 fertilizer will aid in growth and development. Remove any weeds that enter the seedling flat. Insect problems are usually minimal, although an occasional infestation of aphids or scale may be treated with an approved garden soap or similar product.

Seedlings should never be allowed to dry out, but watering frequency may be reduced to cause temporary, moderate water stress to harden seedlings before outplanting.

Approximate size

Seedlings are ready to plant at a height of 20–30 cm (8–12 in) with a stem diameter at the base of about 8–10 mm (0.3–0.4 in).

Guidelines for outplanting

Survival is usually very high for this hardy, nitrogen-fixing species. Controlling grasses and other competitive weed growth around the tree until its canopy overtops the height of the weeds is key to good growth and survival. Thereafter, the tree will hold its own, and in fact is used in Indonesia and West Africa to reclaim grasslands infested with blady grass (*Imperata* sp.). On sites with adequate rainfall, trees can easily attain 2–3 m (6.6–10 ft) in height after a year of growth. A planting study on a sandy site in Puerto Rico had 72% survival and seedlings reached 3.8 m (12.5 ft) in 28 months.

Propagation by direct-seeding

In direct-seeding, an area is prepared at each planting spot, cleared of weeds, and cultivated to a depth of 50 cm (20 in) if the soil is compacted. Seeds are planted at a depth of 5 mm (0.2 in).

Direct-seeding is often the best method for outplanting. It is often cheaper because it eliminates nursery container growing and transplanting. The drawbacks of direct-seeding include risk of predator damage (e.g., rats, birds, etc.), lack of rains to sustain the newly germinated seeds, and the mandatory frequent maintenance that must be done to ensure weeds do not overcome the small seedlings.

Propagation by cutting (after Wilkinson and Elevitch 2003b)

Cuttings are often used instead of seedlings, especially in wet areas where seed production is usually poor and soil moisture is favorable for starting cuttings directly in the ground. Gliricidia generally roots very easily from large cuttings, making this the preferred method of propagation in many areas. Other advantages over seedlings are:

- Large cuttings are usually taller than the weeds and can easily be seen for early weed maintenance.
- Many farmers set fence-post-sized cuttings and immediately nail the fence wires to them. Those that take root are maintained as living fence posts, and those that do not root are replaced with new cuttings after they rot off, until a complete living fence system is established. Smaller-diameter cuttings can support fence wire a few months after establishment.
- Cuttings are vegetative clones of the mother trees and therefore can be easily selected for desired qualities such as upright growth.
- Large cuttings provide crop shade within a relatively short period of time.

The disadvantages of using cuttings include:

- They are many times the size and weight of seedlings, so they are harder to transport and require a much deeper planting hole.
- Cuttings are genetically identical to the parent plant and therefore large plantings might be more susceptible to disease and insect attack.
- Parent trees are able to produce fewer cuttings than seeds.
- Cuttings are more vulnerable to windthrow.

Root development of gliricidia from cuttings is poor compared to trees grown from seed. For live fences, the benefits of quick establishment and resistance to animal attack usually outweigh this consideration. For windbreaks or forestry, establishment from seedlings is recommended.

Collecting cuttings

Normally, large cuttings 2–2.5 m (6.6–8.2 ft) long and 6–15 cm (2.4–6 in) in diameter are used for quick establishment of live fence posts supporting barbed wire or hog fencing. For growing in dense stockades, smaller woody cuttings 50 cm (20 in) long, 1–2 cm (0.4–0.8 in) in diameter, and at least 6 months old are used. Gliricidia is highly variable in form and productivity; select cuttings from trees with more upright form for best results for live fence posts.

Cuttings can be taken any time of year, although the ideal time for deciduous trees such as gliricidia is when the new growth is appearing, usually at the onset of the rainy season.

If cuttings are transported, they should be covered or kept in the shade and should not be allowed to dry out or to be bruised. Protect cuttings from bruising during transport by padding with leaves or a blanket.

Harvesting cuttings

Make a clean cut with a sharp pruner or saw. The top should be cut at an angle to preclude water accumulation and rotting on top of the cutting. The angled cut also indicates which side to plant upwards. Cuttings should be pruned clean of major side branches and leaves.

Storage of cuttings

It is ideal to outplant the cuttings immediately. If this is not feasible, cuttings can be stood up in shady conditions and covered with wet sacking or sprinkled frequently. In Central America, farmers often harvest cuttings during the waning moon, followed by 1 week lying horizontal and 3 weeks in the vertical position with the rooting end down, and planting during the next waning moon (Allison and Simons, 1996). In Puerto Rico, they wait for what they consider to be the correct phase of the moon to harvest the cuttings and plant immediately.

Preparing cuttings

At planting time, the lower 30–40 cm (12–16 in) of the cuttings are usually "wounded" using a sharp knife to make several small incisions through the bark to promote side rooting. Without these cuts, roots usually only emerge from the base of the cutting, making for a potentially weak root structure and susceptibility to windthrow.

Growing area

Cuttings are normally planted directly in the field. For cuttings 2–2.5 m (6.6–8.2 ft) tall, the lower portion is buried 30–50 cm (12–20 in) deep. For smaller cuttings, generally about 20% of the cutting's length should be underground. Planters should make sure to plant cuttings correct side down. As described above under "Abilities," the planting hole should be inoculated with rhizobia culture or a crude inoculant made from nodules or soil.

After placing the cutting, ensure there is firm soil contact with the cutting to promote side rooting and to prevent movement in the wind. Soil should be moist during early establishment, but not overly wet. Irrigation may be necessary during dry spells until the cuttings are established.

Barbed wire mounted on a stockade fence of gliricidia cuttings. PHOTO: C. ELEVITCH

Guidelines for outplanting

Removing weeds from the base and root zone around cuttings is important for high success rates. Placing a weed barrier such as a sheet of cardboard or other biodegradable material can greatly reduce the time necessary for weed control.

In areas without adequate rainfall, cuttings should be irrigated once or twice a week until they are well established (i.e., 4–6 months). Overwatering can cause rotting of gliricidia cuttings. Controlling grasses and other competitive weed growth around the tree until its canopy overtops the height of the weeds is key to good growth and survival. Once established, very little maintenance is required.

Cuttings are usually planted for live fence posts, with wire strung between posts. Spacing for live fence posts ranges from 0.5–3 m (1.6–10 ft) between cuttings. For pig containment, gliricidia is also used as live fence posts to make a physical barrier from the tree trunks reinforced with wire mesh, corrugated iron, or organic material; 30 cm (12 in) apart or less is typical spacing for this purpose. Live fences sometimes contain a mix of other species such as *Morus* spp. (mulberry), *Hibiscus* spp., or *Erythrina* spp., in the Pacific, or with *Tabebuia* spp. and *Bursera simaruba* in the Americas.

Top left: Cuttings prepared for planting. Right: Without wounding the lower 30–40 cm of bark, this tree only formed roots at the very base of the cutting, and it was easily toppled in a strong wind. Bottom left: Because this horizontal cut at the top of the cutting retained rainwater, rotting has taken place down into the center of the tree, compromising its health and strength; for this reason, it is best to make the top cut at a 30–45% angle. PHOTO: C. ELEVITCH

DISADVANTAGES

Potential for invasiveness

Gliricidia has naturalized to a limited extent in a number of locations outside its native range, particularly in disturbed environments such as roadsides and abandoned agricultural land. As a light-demanding species, it is unlikely to invade dense plant communities. It has not been reported to be an aggressive invader or a serious pest and is not considered an invasive plant in the Pacific (PIER 2003).

Common pest problems

It is susceptible to aphids (*Aphis craccivora* in Puerto Rico). The leaves of aphid-attacked trees seasonally become blackened and fall prematurely. No data is available on aphid control, but conventional application of insecticides registered for aphids would probably be effective. In addition to aphids, the tree is susceptible to mealybugs, scale insects, and some foliar diseases, in certain areas and under specific circumstances, but these are rarely major problems. Entrance of heart rot fungi can be avoided by protecting the trees from breaks in the bark. However, this cannot be avoided when trees are used for living fences and lopped for firewood or fodder. It is suggested that the trees be replaced as they begin to decline in health and vigor.

Host to crop pests/pathogens

None reported.

AGROFORESTRY/ENVIRONMENTAL PRACTICES

Mulch/organic matter

It is lopped for mulch and green manure in agroforestry applications and regrows very rapidly given sufficient soil moisture and warm temperatures.

Soil stabilization

Gliricidia is planted in contour hedgerows (alley cropping) on sloping lands susceptible to erosion. The hedgerows hold soil together and, when properly planned and managed, can slow erosive surface run-off.

Pest control

There is some evidence that gliricidia can protect certain crops from various fungal, insect, and viral pests. For example, in one experiment, intercropped gliricidia hedges were associated with reduced rust and leafspot in groundnuts (Stewart 1996). In other studies, gliricidia hedges acted as a diversionary host to an aphid that spreads the rosette virus in groundnut, and to a live-wood tea termite (Stewart 1996). It has also been shown to be associated with reduced stem-borer damage in rice (Wiersum and Nitis 1997).

Crop shade/overstory

Gliricidia is a popular shade or nurse tree for crops including coffee, tea, cacao, pepper, passion fruit, and vanilla, in many varied spatial arrangements. Spacing of about 10 x 10 m (33 x 33 ft) interspersed with crops such as coffee and cacao is common. It addition to providing a favorable environment for certain crops, the shade it provides helps suppress light-demanding weeds. The shade trees are pruned seasonally to maximize benefits to the understory crop, and to minimize competition for water and nutrients.

Alley cropping

It has been intercropped in alley cropping systems with maize, cassava, taro, cucurbits, and other food crops. In such systems, pruning gliricidia back regularly provides mulch for the crops and controls competition by the gliricidia for light, water, and nutrients.

Homegardens

The benefits of shade, nitrogen fixation, nutrient cycling, mulch, and fuelwood production can be the same on a smaller scale as for farms.

Improved fallows

It is planted by seed or cuttings as a nitrogen-fixing fallow crop. It has been used to reclaim land infested with blady grass (*Imperata cylindrica*) by shading out the grass—it has been shown to be superior in this respect to leucaena (*Leucaena leucocephala*) and also does not present the weed risk of leucaena.

Living fences

Gliricidia is one of the most widely used species for living fence posts in the tropics.

Fence posts

Cuttings that do not take root, often up to 50% of those planted, serve as temporary fence posts, which hold up the fencing material during the process of establishing living gliricidia fences.

Boundary markers

Gliricidia is sometimes planted to mark property boundaries.

Windbreaks

Although the tree tolerates wind fairly well, it is alone minimally efficient as a windbreak due to its thin crown and deciduous habit in dry regions. If carefully planned, gliricidia can be used as one species in a multi-row windbreak, where the other species offer sufficient protection during the period when the gliricidia crown is bare. It should usually be planted on the windward side of taller species. In warm areas without a dry season, gliricidia trees can be pruned two or three times a year to maintain full, lush growth. By planting two rows alongside one another and pruning each row alternately 3–4 months

Gliricidia provides shade and organic matter in a cacao orchard. PHOTO: C. ELEVITCH

Living fence post supporting barbed wire, strong enough to contain pigs. PHOTO: C. ELEVITCH

apart, a dense windbreak to 3–4 m (10–13 ft) in height can be achieved, while also providing a regular source of organic matter or fodder.

Silvopasture

Living fence posts and field boundary trees can provide fodder when periodically lopped. Animals often are allowed to browse the trees in older plantations.

Woodlot

Gliricidia is a good producer of high-quality fuelwood, both in dedicated woodlots and incidental with other uses. Trees grown for fuelwood are either coppiced on rotations of 1–5 years or harvested and replanted after 6–8 years.

Native animal/bird food

The foliage is consumed by browsing animals. The bark and seeds are not known to be eaten by any mammal or bird. The tree is used as nesting habitat by some species of birds.

Host plant trellising

Gliricidia is used as support for pepper, yam, passion fruit, and vanilla. It is very suitable as crop support due to its upright growth after pruning and the appropriate amount of dappled shade it provides for many crops.

Bee forage

Gliricidia attracts honeybees, carpenter bees, and a wide range of insect pollinators, and it provides limited cover for birds and mammals. In areas with a pronounced dry season, it flowers profusely and is a very good honey plant for the nectar it produces.

Coastal protection

Because of gliricidia's ability to grow in exposed coastal environments, and even in shifting sands (Simons 1996), it has potential for agricultural use in near-shore agricultural environments.

Ornamental

It is planted in residential lots, parks, and on roadsides where small trees are required. It produces copious quantities of lilac-colored flowers when grown in environments with a pronounced dry season.

USES AND PRODUCTS

Leaf vegetable

Cooked gliricidia leaves and flowers are said to be eaten boiled or fried. Placed in containers with bananas, the leaves hasten ripening of the bananas.

Honey

The flowers attract honeybees and are a good source of nectar.

Medicinal

Crushed fresh leaves are applied as a poultice. In Mexico, the plant is used as an antihistaminic, antipyretic, expectorant, and diuretic. Extracts of gliricidia have been shown to have high anti-fungal activity (Stewart 1996).

Animal fodder

The leaves (cut branches with leaves attached or directly browsed from low plants) are widely used as cattle and goat fodder. There are few toxicity problems with ruminant animals. Experiments have shown similar benefit in using gliricidia fodder and mineral mixtures as supplements to grass pasture. Yields of fodder range from 2 to 20 t/ha/yr and can make a significant contribution to dry-season forage. Silage preparation of gliricidia leaves mixed with

LORE

According to Caribbean folklore, planting gliricidia near houses and fields will control rats and mice. Fallen seeds supposedly attract rats and mice that eat them and die of poisoning.

a small percentage of molasses or sugarcane has shown promise (Stewart 1996).

Beautiful/fragrant flowers

The lilac-pink flowers make this a memorable ornamental. However, the flowers are not fragrant.

Timber/wood

The wood is light to dark olive-brown, very hard and heavy, strong, coarse-textured, with an irregular grain. It seasons well and, although difficult to work, takes a high polish. It is highly durable (termite- and fungus-resistant), and valued for house construction and corner fence posts (CABI 2003). Gliricidia timber has been used for posts, railroad ties, construction, furniture, tool handles, and farm implements. The small diameter of the timber and short pieces available, usually less than 30 cm (12 in) in diameter and 2 m (6.6 ft) in length, preclude most commercial use of gliricidia timber.

Fuelwood

Fuelwood produced from gliricidia is used locally for cooking, heating, and drying tobacco. It rarely requires splitting, is of moderately high density (47 to 75 g/cm^3), and has a caloric value of 4900 kcal/kg (2230 kcal/lb). In woodlots the first harvest can be carried out after 3–4 years, giving wood yields of 8–15 m^3/ha (114–215 ft^3/ac) (CABI 2003). Yields may reach as high as 3.5–4.5 kg/tree/yr (1.6–2.0 lb/tree/lb) in Central America. Annually coppiced fuelwood in the Philippines produces fuelwood volumes of 23–40 m^3/ha (330–572 ft^3/ac). The wood is also sometimes used for charcoal production. Production of fuelwood has reached commercial levels in only a few locations such as the Philippines.

Craft wood/tools

Stems and branches are sometimes used for tool handles.

Toxin/insecticide/fish poison

Roots, bark, and seeds are toxic due to the presence of tannins, afrormosin, medicarpin, and isoflavins. The botanical and common names and folklore suggests that the seeds or other parts are useful as a rodenticide. Tests of leaf and wood extracts have shown insecticidal and anti-microbial activity. A leaf extract used in Latin America to bathe animals every 7–14 days has been found to sharply reduce the incidence of torsalo (tropical warble fly) in goats.

URBAN AND COMMUNITY FORESTRY

Gliricidia is suitable for ornamental use in residential and public landscaping, parking lot islands, and along residential streets because of its moderate size, clean appearance, and colorful flowers. Care must be taken that trees are planted in soil that is at least moderately fertile and uncompacted.

Size in an urban environment

It is easily shaped to a desirable size and form by periodic pruning. It is generally kept at 3–6 m (10–20 ft) in height

With profuse flowering during the dry season, and deciduous habit, gliricidia makes an interesting specimen tree. PHOTO: C. ELEVITCH and 2–4 m (6.6–13.2 ft) in crown spread, requiring annual or biannual pruning. When regularly pruned with a framework of side branches (pollarding), gliricidia has a similar appearance to the common landscaping shower trees, e.g., golden shower (*Cassia fistula*) and pink and white shower (*C. javanica*), except that gliricidia is deciduous in areas with a pronounced dry season.

Rate of growth in a landscape

The tree generally grows rapidly at a rate of 1–2 m/yr (3.3–6.6 ft/yr) in early years, slowing to a few cm per year after 6–8 years. Trunk diameter growth is about 2 cm/yr (0.8 in/yr).

Root system

Damage to curbs, sidewalks, and foundations is unlikely unless the tree is both very large and planted in close proximity to such features.

Products commonly used in a Pacific island household

Gliricidia is still relatively uncommon in the Pacific but is increasingly important in Fiji, Vanuatu, Hawai‘i, and other regions.

Light requirements

Full sun is recommended; otherwise, with increasing shade, growth slows and the canopy becomes sparse.

Water/soil requirements

Irrigation is generally not needed except in very dry climates (<600 mm [24 in] of mean annual precipitation). Planting in waterlogged soils should be avoided.

Life span

Good data are not available on lifespan. Gliricidia under favorable conditions can be expected to live up to 50 years, but it is certain that the species is not long-lived.

Varieties favored for use in a homegardens

Although there are no formally described varieties, individual trees vary in form from low and spreading to tall and upright (columnar). The tree is usually propagated by cuttings that are clones of the mother tree and grow with the same habit. Therefore, cuttings should be taken from trees with desired qualities for a particular purpose.

Seasonality of leaf flush, flowering, fruiting

Flowering occurs at the beginning of the dry season when the trees have lost their leaves. In the native range this occurs between November and March. Fruit development and maturation occurs at the end of the dry season. In areas with even rainfall throughout the year, the trees never completely defoliate, and flowering occurs irregularly, but lightly, throughout the year. Fruits often fail to develop in areas with evenly distributed and high rainfall.

Due to its deciduous habit in seasonally dry climates, gliricidia does not make a good year-round single-species windbreak or privacy barrier. PHOTOS: C. ELEVITCH

Exceptional ornamental values

Gliricidia is a very beautiful tree when in bloom, although flowering usually occurs during periods of leaf loss. Its clean appearance and moderate size gives it character during the rest of the season.

Use as living fence, hedge or visual/noise barrier

In addition to its use as living fence posts, when pruned regularly to maintain lush, leafy growth, gliricidia makes a fine hedge, especially in wetter climates where it remains leafy year-round.

Maintenance requirements

Pruning is generally not needed if an open crown at the natural height of the tree (8–15 m [26–50 ft]) is desired. Regular pruning can be done to force trees into desired shapes (hedges, below view planes, etc.) and to encourage lush, leafy growth.

Nuisance issues

Aphids cause the trees to drip honeydew, which is sticky, attracts ants, and can discolor cars, furniture, etc.

Hazards

In dry areas the seedpods tend to open explosively when ripe, especially on hot days. The seeds are thrown up to 25 m (82 ft) from the tree, which can present some danger to people. In high winds, branches can shear off, particularly from trees grown from cuttings and during periods of rapid growth. The roots, bark, and seeds are poisonous to humans and many animals if ingested. Old trees often become hollow, especially those that have received injuries from fence staples, mowers, or by pruning, and because of the weakness they are prone to trunk breakage and windthrow.

COMMERCIAL PRODUCTS

Much of the value of gliricidia is not commercial but the farm services it provides including living fence posts, green manure, shade, fodder, windbreak, etc. There are several areas where there is commercial potential, however. Because much of the commercial seed available is inferior germplasm (unselected for productivity) (Stewart et al. 1996), there is a market for seeds from the better provenances. Similarly, there may be local markets for cuttings from selected germplasm for use in planting living fence posts, shelterbelts, etc. In certain areas, there may also be a market for gliricidia fuelwood.

Fuelwood

Spacing

Fuelwood plantations in Central America are typically established with 1000–5000 trees/ha (400–2000 trees/ac) for rotations of 5 years. In Asia, fuelwood plantations are set out at 1 x 1 m (3.3 x 3.3 ft) to 2.5 x 2.5 m (8 x 8 ft) spacings for pruning at 1- or 2-year intervals.

Management objectives

Trees may be pruned at ground level in fuelwood plantations or intercrop plantings or cut above the wire height in living fences.

Yields

Fuelwood yields from stands harvested every 2–3 years are 10–20 m^3/ha (143–286 ft^3/ac). Wood production from a living fence has been reported at 9 m^3/km (57 ft^3/mi). Yields vary greatly depending on provenance (genetic source).

On intermediate quality sites in Guatemala, Honduras, El Salvador, Nicaragua, Costa Rica, and Panama, annual fuelwood increment reached a peak of 4.5 kg/tree (9.9 lb/tree) at 2 years of age, although cutting usually takes place on rotations of 5–8 years. Statistical analysis for site index, mean tree height, basal area, and dry fuelwood for plantations 12–60 months of age are available (Hughell 1990).

Processing required

Fuelwood is often stacked and dried for a few weeks before marketing.

Markets

Fuelwood markets are usually close to the point of origin.

INTERPLANTING/FARM APPLICATIONS

In many countries such as Indonesia, Brazil, and Costa Rica, cacao is traditionally established under the shade of trees such as gliricidia, *Erythrina poeppigiana*, *Inga* spp., and other species. These shade trees are used due their rapid growth, ability to biologically accumulate atmospheric nitrogen, ease of establishment, adaptability to many different site conditions, and ability to regrow vigorously after pruning. During establishment, the shade trees are planted within the cacao orchard at a spacings of 2 x 2 m to 4 x 4 m (6.6 x 6.6 ft to 13 x 13 ft) for a cover of about 30–55% shade. After 2–3 years as the canopy of cacao closes, the shade trees are usually thinned to a spacing of 6 x 6 m (20 x 20 ft).

PUBLIC ASSISTANCE AND AGROFORESTRY EXTENSION

Extension offices for agroforestry and forestry in the Pacific: <http://www.traditionaltree.org/extension.html>.

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Species Profiles for Pacific Island Agroforestry (www.traditionaltree.org)

Gliricidia sepium (gliricidia)

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Acknowledgments: The authors and publisher thank Keola Childs, Dale Evans, John Parrotta, Diane Ragone, and Jim Roshetko for their input. Photo contributions by J. B. Friday, Kenneth Mudge, and John Parrotta are greatly appreciated.

Recommended citation: Elevitch, C.R., and J.K. Francis. 2006. *Gliricidia sepium* (gliricidia), ver. 2.1. In: C.R. Elevitch (ed.). Species Profiles for Pacific Island Agroforestry. Permanent Agriculture Resources (PAR), Hōlualoa, Hawai'i. <http://www.traditionaltree.org>.

Sponsors: Publication was made possible by generous support of the United States Department of Agriculture Western Region Sustainable Agriculture Research and Education (USDA-WSARE) Program; SPC/GTZ Pacific-German Regional Forestry Project; USDA Natural Resources Conservation Service (USDA NRCS); State of Hawai'i Department of Land & Natural Resources Division of Forestry & Wildlife; and the USDA Forest Service Forest Lands Enhancement Program. This material is based upon work supported by the Cooperative State Research, Education, and Extension Service, U.S. Department of Agriculture, and Agricultural Experiment Station, Utah State University, under Cooperative Agreement 2002-47001-01327.

Series editor: Craig R. Elevitch

Publisher: Permanent Agriculture Resources (PAR), PO Box 428, Hōlualoa, Hawai'i 96725, USA; Tel: 808-324-4427; Fax: 808-324-4129; E-mail: par@agroforestry.net; Web: <http://www.agroforestry.net>. This institution is an equal opportunity provider.

Gnetum gnemon (gnetum)

Gnetaceae (jointfir family)

ambiam, ***ambiamtupee*** (PNG: Maring); ***bago*** (Philippines: Bataan, Tayabas, and Camarines); ***belinjo***, ***melinjo*** (Indonesia); ***blinjo*** (E. Java); ***dae***, ***daefasia***, ***daemalefo*** (Solomon Islands: Kwara'ae); gnetum, joint fir, Spanish joint fir, two leaf (English); ***maninjau*** (Malaysia); ***melindjo*** (Singapore); ***sikau***, ***sukau***, ***sukau buli***, ***sukau motu*** (Fiji); ***tulip*** (PNG: Tok Pisin); ***voe***, ***khalet*** (Cambodia)

Harley I. Manner and Craig R. Elevitch

IN BRIEF

Distribution Found in Southeast Asia and Melanesia.

Size Can grow to 10–15 m (33–50 ft) in height.

Habitat Thrives in a tropical rainforest climate, rainfall 750–5000 mm/yr (30–200 in/yr), elevations of 0–1700 m (0–5600 ft).

Vegetation Associated with the diverse flora of Indomalayan and Melanesian humid rainforests and the cultivated species in homegardens and orchards.

Soils Prefers slightly acid to neutral, well drained soils and tolerates infertile and shallow substrates.

Growth rate Estimated at 0.75–1.5 m/yr (2.5–5 ft/yr) in height.

Main agroforestry uses Improved fallow, windbreak, living trellis.

Main products Nut, leaf vegetable, timber.

Yields Nut production may reach 80–100 kg/tree/yr (176–220 lb/tree/yr).

Intercropping Shade tolerant, it is intercropped with many species including *A. camansi*, *Pandanus* spp., durian (*Durio* spp.), rambutan (*Nephelium lappaceum*), *Parkia* sp.

Invasive potential Although not reported as invasive, its shade tolerance indicates the potential for invasiveness in new environments.

Leaves and flowers.

INTRODUCTION

Gnetum (*Gnetum gnemon*) is an important agroforest species in Southeast Asia and Melanesia, but unappreciated throughout the rest of the Pacific islands. This small- to medium-size tree up to 15 m (50 ft) in height is native to Indo-Malaya and perhaps Melanesia. The species is found in dry and humid forests of the region. It is a spontaneous regrowth species in fallow forests and is also planted as a cultivated species in both backyard gardens and orchards. The species is tolerant of shade, open areas, a fairly large temperature range, a wide rainfall regime, and in all likelihood infertile soils. Young seedlings respond positively to phosphorous. As indicated by its absence in atoll islands, the species may not be tolerant of salt spray. Gnetum is an important food and cordage species in for Melanesia. It is also used as a timber species and medicine. It is used as a trellis for climbing species, i.e., *Dioscorea* yams.

DISTRIBUTION

Native range

Gnetum is native from Assam (northeastern India) eastward through Malesia to Fiji. The tree is present in Assam, Cambodia, Vietnam, Thailand, Malaysia, Malayan Peninsula and islands, Fiji, Papua New Guinea, Solomon Islands (Santa Anna), and Vanuatu (Pentecost, Ambae, Maewo, Torres Islands). It is native to dry to humid tropical forest to lower montane forest (up to 1700 m [5600 ft] in elevation in Papua New Guinea). The tree is commonly found along rivers and streams, in both cultivated and natural ecosystems. In the Bismarck Mountains of Papua New Guinea, the tree is a component of breadfruit and pandanus orchards. In Fiji, the species is found at up to 850 m (2800 ft) in elevation. Gnetum also native to Vanuatu, where it is rare, and Samoa (Walter and Sam 2002).

Current distribution

It is said to have been introduced to the Andaman Islands, Sumatra, and Java. Several sources indicate that the species is present in the Caroline Islands of Micronesia (e.g., Walter and Sam 2002, Smith 1979). However, a careful review of Fosberg et al. (1979, 1982) indicates that the species is not present in any of the islands of Micronesia and that any reference to the species is most likely based on a misidentification. Specifically, *Phalaria nisidai* Kaneh., which is found on Babeldaob and Urukthapel in Palau (Fosberg et al. 1979), was probably misidentified as *Gnetum gnemon*. Additionally, after some 30 years of plant collecting, the curator of the Guam Herbarium has not found the species in Micronesia. Finally, there is no vernacular name for *Gnetum gnemon* in Palau (Fosberg et al. 1980). It would also be expected that if *Gnetum gnemon* was present and/or culturally significant in Palau, it would have a Palauan name. Therefore any reference to this species being present in Micronesia should be considered dubious.

BOTANICAL DESCRIPTION

Preferred scientific name

Gnetum gnemon L.

Family

Gnetaceae (jointfir family)

Non-preferred scientific names

G. gnemon var. *sylvistris* L.
G. acutatum Miq.
G. gnemon var. *ovalifolium* (Poir.) Blume
G. vinosum Elmer

Common names

ambiam, *ambiamtupee* (PNG: Maring)
bago (Philippines: Bataan, Tayabas, and Camarines)
belinjo, *melinjo* (Indonesia)
blinjo (East Java)
dae, *daefasia*, *daemalefo* (Solomon Islands: Kwara'ae)
gnetum, joint fir, Spanish joint fir, two leaf (English)
maninjau (Malaysia)
melindjo (Singapore)
sikau, *sukau*, *sukau buli*, *sukau motu* (Fiji)
tulip (PNG: Tok Pisin)
voe, *khalet* (Cambodia)

Size

Gnetum is a small- to medium-size tree that reaches 10–15 m (33–50 ft) in height and attains a trunk diameter of up to 40 cm (16 in). Branches are noticeably swollen at the base.

Typical form

The tree is slender with a straight main stem. There are numerous whorls of branches down to the base.

Flowers

The species is dioecious, having male and female reproductive organs on separate plants, but not completely so. As a member of the gymnosperms, gnetum does not have flowers. Instead, the species has cones or strobili (singular, strobilus) which are an aggregation of sporangia-bearing structures at the tip of a slender stem or axis. The staminate strobilus is an axis (analogous to a slender spike), 3–5 cm

(1.2–2 in) in length, having many pairs of cup-shaped bracts arranged in whorls. The staminate strobilus or male cone which bears the microsporangia (pollen sacs) is also called a microsporanginate strobilus. The ovulate (female) strobilus is 6–10 cm (2.4–4 in) in length and bears the ovules or seeds. It is also called a megasporangiate strobilus. This axis bears a "pair of opposite sheathing bracts at the base, followed by five or six whorls of ovules, with five to seven ovules in a whorl" (Chamberlain 1935).

Top: Fruits still attached to branch. Bottom: Stem and branch attachments. PHOTOS: B. TOMLINSON

Leaves

Leaves are dark green, shiny, smooth, acute at both ends, opposite, and variable in size and shape. Typical size of leaves is 10–20 cm (4–8 in) long and 4–7 cm (1.6–2.8 in) wide. Leaf shape is elliptic, lanceolate, and ovate oblong. Branches flush and flower throughout the year.

Fruit

Fruits are yellow, turning purple-red or orange-red with maturity, and ovoid, 1–3.5 cm (0.4–1.4 in) in length. The skin is thin. In Indonesia this species fruits three times per year, March–April, June–July, and September–October (Cadiz and Florido 2001).

Seeds

There is one large ovoid or ellipsoid seed per fruit.

Bark

The bark is gray and marked with conspicuous raised rings in the position where older branches have fallen off.

Rooting habit

The trees are deeply rooted with a strong taproot.

Similar or look-a-like species

Gnetum costatum is a similar looking tree. Fruit of *G. costatum* is spindle shaped and its leaves are leathery compared with the ovoid or ellipsoid fruits and smooth leaves of *Gnetum gnemon*.

GENETICS

Known varieties

There are several varieties of *Gnetum gnemon* including the tree form (var. *gnemon*) and shrub forms (vars. *brunonianum*, *griffithii*, and *tenerum*). *Gnetum gnemon* var. *gnemon* is the commonly cultivated variety that is characterized by its tree form and large fruits.

ASSOCIATED PLANT SPECIES

The general flora includes the many components of the species-diverse Indomalayan and Melanesian humid rainforests. Walter and Sam (2002) report that in New Guinea a close relative, *G. costatum*, is found in forests of *Lithocarpus*, *Anisoptera*, and *Hopea*.

Associated species commonly found in native habitats

Gnetum is often planted as a cultivated species in homegardens and orchards. In Papua New Guinea, this species can be found in association with breadfruit (*Artocarpus* spp.), *Pandanus conoideus* and other food and fiber species (Kennedy and Clarke 2004). Some of these arboreal complexes are quite old, as evidenced by the macrobotanical remains found in archaeological sites. For example, macrobotanical remains of *Canarium* from New Guinea have an age date of 14,000 BP (Before Present). The species is a natural component of the rainforest, and is often a spontaneous component of fallow forests.

ENVIRONMENTAL PREFERENCES AND TOLERANCES

Climate

This species is best suited to a tropical rainforest climate as it is very common at low elevations in the Indomalayan and Melanesian regions.

Elevation range

0–1700 m (0–5600 ft) in Papua New Guinea

Mean annual rainfall

750–5000 mm (30–200 in/yr). It thrives best where the rainfall is 3000–5000 mm/yr (120–200 in/yr).

Rainfall pattern

The tree grows in climates with bimodal or uniform rainfall patterns.

Dry season duration (consecutive months with <40 mm [1.6 in] rainfall)

2–7 months (CABI 2003)

Mean annual temperature

22–30°C (72–86°F)

Mean maximum temperature of hottest month

32–36°C (90–97°F)

Mean minimum temperature of coldest month

13.8–22°C (57–72°F)

Minimum temperature tolerated

12.8°C (55°F)

A 10 m (33 ft) tall gnetum at Kompiai Village, Jimi Valley, Western Highlands District, Papua New Guinea, 1600 m (5200 ft) above sea level (1967). PHOTO: H. MANNER

Soils

It prefers generally slightly acid to neutral soils. As a tropical rainforest species, gnetum is probably adapted to soils of low fertility.

Soil texture

It grows in light to heavy soils (sands, sandy loams, loams, sandy clay loams, sandy clays, clay loams, and clays).

Soil drainage

It requires freely draining soils.

Soil acidity

Neutral to mildly alkaline soils (pH 6.1–7.4)

Special soil tolerances

The tree tolerates infertile and shallow soils. It can grow on soils high in clay or sand, and also on calcareous rocks, given continuous soil moisture.

Tolerances

Drought

The tree can tolerate several months of drought, assuming soil moisture retention, seepage water, or irrigation through the dry season.

Full sun

The tree can grow in full sun.

Shade

Gnetum is very tolerant of shade.

Frost

Its native range is frost free, so it is unlikely to tolerate frost.

Waterlogging

The tree does not tolerate waterlogging.

Salt spray

The tree is intolerant of salt spray as it is not a coastal species.

Wind

This species is a favored species in the arboriculture of the Reef Islands because of its resistance to cyclones (Henderson and Hancock 1989 cited by Walter and Sam 2002).

Abilities

Regenerate rapidly

Gnetum is probably a rapid regenerator as evidenced by its spontaneous growth in fallow forests. The tree has been recommended for environmental protection (regreening) programs (CABI 2003).

Coppice

The tree regrows readily from pruning. Pruning can be used to control tree size, induce shoot flushing for harvest of leaf vegetable, or to improve tree shape.

Other

It has a mycorrhizal association (with *Scleroderma sinnamariense*) that makes phosphorous and some micronutrients more readily available (Cadiz and Florido 2002).

GROWTH AND DEVELOPMENT

Growth rate

While the growth rate is moderate at 0.75–1.5 m/yr (2.5–5 ft/yr), the rate is probably higher when the tree is young and in sunlight and lower when it is in the understory. In experimental conditions, mycorrhizal inoculation appears to enhance seedling growth under shaded conditions in acidic soils (Salim et al. 2002).

Flowering and fruiting

Trees flower several times a year, with maximum fruiting probably occurring with the rainy season. In Indonesia gnetum flowers at least three times per year, with fruiting coinciding with the rainy season (Cadiz and Florido 2001). Fruiting begins within 5–8 years in seedlings.

Reaction to competition

There is little information as to the reaction to competition. However, as this species can regenerate spontaneously in fallow forests and is tolerant of shade and open conditions, the species is probably a good competitor.

GNETUM GENETICS

From an evolutionary perspective, *Gnetum gnemon* is an interesting taxa, whose origin and relationships to angiosperms are not completely understood. The plant is a gymnosperm (seed plants with naked ovules), which unlike angiosperms does not have flowers in the true sense of the word. Chamberlain (1935) wrote that the Gnetales arose during the Upper Cretaceous as a branch of the Coniferales, which in turn evolved from the Pteridophytes (ferns). However, because *Gnetum gnemon* and other members of the order (*Ephedra* and *Welwitschia*) have some characteristics also found in the angiosperms (for example, leaves that look like angiosperm leaves), some botanists believe that the Gnetales are ancestors of the angiosperms (Chamberlain 1935). There is evidence suggesting that the process of double fertilization in *Gnetum gnemon* evolved in a common ancestor of angiosperms and Gnetales, which are the closest living relatives of the flowering plants (Carmichael and Friedman 1996). Additionally, early phylogenetic analyses, based on morphological similarities, placed the angiosperms and gnetophytes in a clade called "anthophytes," which emphasized their shared possession of flower-like reproductive structures (Winter et al. 1999). However, based on genetic evidence, it appears that *Gnetum gnemon* is more closely related to the conifers (in contrast to the the anthophyte clade), and that the process of double fertilization and the reproductive structures of the angiosperms and gnetophytes evolved independently (Winter et al. 1999).

PROPAGATION

This species is fairly easily propagated. It can be propagated by seed, air-layering, grafting, cutting, or budding (Cadiz and Florido 2001). To propagate a few trees, an appropriate method is to transplant volunteers from under a tree. Direct-seeding in the field is a popular propagation method.

Propagation by seed

Seed collection

Large, mature fruits are collected from the ground. Embryo development may not be complete when the fruit drops, as full development of the embryo takes place on the ground.

Seed processing

The outer skin is removed and the seeds air-dried in the shade.

Seed storage

The seeds are classified as orthodox in terms of storage, which means they remain viable when stored dry for extended periods.

Pre-planting treatments

No pre-planting treatments are recommended.

Growing area and media

The seed is pre-germinated in a bed of alternating layers of seed and sand. The germination bed is kept in shady conditions. Additional phosphorous may improve seedling development. Inoculation with the mycorrhizae fungi *Scleroderma sinnamariense* also improves seedling growth (Cadiz and Florido 2001).

Germination

Seeds take 45–360 days to germinate (Cadiz and Florido 2001). The germination bed should be watered daily to hasten germination.

Time to outplanting

Germinated seedlings are transplanted to containers, where they are raised for about 6 months prior to outplanting.

DISADVANTAGES

The species has no major drawbacks. Yield potential, products, and markets for gnetum products all require further research.

Potential for invasiveness

Due to its shade tolerance, this species could be considered a potential weed threat to native plant communities.

Diseases and pests

No major pests or diseases have been observed (Cadiz and Florido 2001). The trees should be guarded against rats and squirrels, which eat the seeds.

AGROFORESTRY/ENVIRONMENTAL PRACTICES

As an agroforest species, this tree serves as a trellis for yam and other climbers. It also is used as a border species and has some value as a soil enhancer.

Crop shade/overstory

The tree is used to provide shade for shade-loving plants (Salim et al. 2002).

Homegardens

The tree is found occasionally in homegardens.

Improved fallows

It can be used for dryland rehabilitation and afforestation, as it has the ability to improve soil physical properties (Salim et al. 2002).

Boundary markers

Gnetum is grown along field borders (Cadiz and Florido 2001).

Windbreaks

It is cultivated in the Reef Islands because of its resistance to cyclones (Walter and Sam 2002).

Host plant trellising

The tree is used as a support for yam and other shade-tolerant climbers (Thaman 1990).

Ornamental

The tree is attractive and can be pruned to size. Therefore it is suitable for use in homegardens as an ornamental.

USES AND PRODUCTS

Gnetum is more utilized in Southeast Asia and Melanesia (Vanuatu, Papua New Guinea, Solomon Islands, and Fiji) than in the rest of the Pacific islands. The primary products are the seeds and leaves for human consumption.

Nut/seed

The seeds are eaten raw, boiled, fired, or roasted. In East

Java, "blinjo" chips made from gnetum seeds are an important home industry. The mature nuts are husked, mashed, made into a small flat cake, and sun dried. The chips are fried in oil and sold by street hawkers (Cadiz and Florido 2001, Anon nd:b). In Mejono village, East Java, chips are manufactured by some 320 home-based companies that employ 780 workers and produce 600 mt (660 t) of chips per year (Yayuk nd.).

Leaf vegetable

In Vanuatu the leaves and young inflorescence are boiled or braised in small bamboo pots and flavored with coconut cream. In parts of Papua New Guinea, the leaves and inflorescence are cooked with game, pork, or a sauce made from red pulp of *Pandanus conoideus*. *Gnetum gnemon* var. *tenerum* is an important leaf vegetable in southern Thailand (Verheij and Sukendar 1991).

Other vegetable

In addition to the young leaves, flowers and fruits are used as vegetables, eaten raw, boiled, or roasted (Salim et al. 2002). The outer flesh of the nut, ripe or unripe (still green), can be fried to make a chewy snack or added to other dishes (Potter 2004).

Medicinal

The leaf sap is used medicinally to cure an eye complication.

Timber

The wood is used for tool handles and house beams. In Indonesia the wood is employed for paper pulp and house construction. In Malaysia and Hong Kong the wood is used for paper, boxes, and house construction (Agroforestry 2005).

Fuelwood

The wood can be burned for firewood.

Rope/cordage/string

The bast fibers are used to make cordage for fishing lines, fishnets, and string bags (known in New Guinea pidgin as bilum). The fiber is durable in seawater. The fiber is also used for a well known musical bowstring (Verheij and Sukendar 1991).

Other

The fungus *Scleroderma sinnamariense*, a usual mycorrhizal associate of gnetum, produces a fruiting body that is edible.

COMMERCIAL PRODUCTS

As described above, the pounded and dried nuts form the basis of an important home industry in Java, Indonesia. Cadiz and Florido (2001) state that the chips are an Indonesian export. A potential economic use of this plant is the utilization of its bark in rope making (Salim et al. 2002).

Spacing

Trees are planted 5–12 m (16–40 ft) apart in fields prepared by removing weeds and shrubs.

Management objectives

After planting, occasional weeding is required (Cadiz and Florido 2001, Verheij and Sukendar 1991). Trees can be pruned to encourage new shoot growth for leaf vegetable. It is not known how harvesting of shoots affects fruiting, as the inflorescences are borne both on young shoots and older branches (Verheij and Sukendar 1991).

Advantages and disadvantages of growing in polycultures

Advantages of gnetum include shade tolerance and amenability to cultivation. Additionally, the tree provides useful nuts and a leaf vegetable throughout its life, which can be 100 years or longer.

Yields

In West Sumatra, large trees are said to yield 20,000–25,000 fruits per year. The maximum production of nuts is projected to reach 80–100 kg/tree/yr (176–220 lb/tree/yr) (Cadiz and Florido 2001).

Processing required

Processing the seeds, such as in the making of blinjo chips, can greatly enhance marketability of gnetum.

INTERPLANTING/FARM APPLICATIONS

Example system 1 (CABI 2003)

Gnetum gnemon var. *tenerum* plants are raised from seed, air-layers or root suckers and planted 2 m (6.6 ft) apart, usually as intercrop among durian (*Durio* spp.), rambutan (*Nephelium lappaceum*), *Parkia* sp., etc., to benefit from the shade of the trees.

Example system 2 (Ragone 2004)

Gnetum is grown for its edible leaf in *Artocarpus camansi* and *Pandanus* orchards in the Jimi Valley, Papua New Guinea.

PUBLIC ASSISTANCE AND AGROFORESTRY EXTENSION

Extension offices for agroforestry and forestry in the Pacific: http://www.traditionaltree.org/extension.html

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Gnetum gnemon (gnetum)

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Acknowledgments: The authors and publisher thank Dale Evans, Diane Ragone, and Barry Tomlinson for their input. Photos contributed by Gerry Carr and Barry Tomlinson are greatly appreciated.

Recommended citation: Manner, H.I., and C.R. Elevitch. 2006. *Gnetum gnemon* (gnemon), ver. 1.1. In: Elevitch, C.R. (ed.). Species Profiles for Pacific Island Agroforestry. Permanent Agriculture Resources (PAR), Hōlualoa, Hawai'i. <http://www.traditionaltree.org>.

Sponsors: Publication was made possible by generous support of the United States Department of Agriculture Western Region Sustainable Agriculture Research and Education (USDA-WSARE) Program; SPC/GTZ Pacific-German Regional Forestry Project; USDA Natural Resources Conservation Service (USDA NRCS); State of Hawai'i Department of Land & Natural Resources Division of Forestry & Wildlife; and the USDA Forest Service Forest Lands Enhancement Program. This material is based upon work supported by the Cooperative State Research, Education, and Extension Service, U.S. Department of Agriculture, and Agricultural Experiment Station, Utah State University, under Cooperative Agreement 2002-47001-01327.

Series editor: Craig R. Elevitch

Publisher: Permanent Agriculture Resources (PAR), P.O. Box 428, Hōlualoa, Hawai'i 96725, USA; Tel: 808-324-4427; Fax: 808-324-4129; E-mail: par@agroforestry.net; Web: http://www.agroforestry.net. This institution is an equal opportunity provider.

April 2006
ver. 1.2

Hibiscus tiliaceus (beach hibiscus)

Malvaceae (mallow family)

'au **(Cook Islands);** ***ayiwo, fa'alo, fa'ola, fakasu, kwara'ae*** **(Solomon Islands); beach hibiscus, sea hibiscus, mahoe, linden hibiscus (English);** ***bourao*** **(French);** ***burao*** **(Vanuatu); coast cottonwood, Cuban bast (Trade Names);** ***emajagua*** **(Spanish);** ***ermall*** **(Palau);** ***fau*** **(Samoa, Tonga);** ***fau, fautu'u*** **(Tuvalu);** ***fou*** **(Niue);** ***gaal'*** **(Yap);** ***hau*** **(Hawai'i);** ***kalau*** **(Pohnpei);** ***kilife*** **(Chuuk);** ***lo*** **(Kosrae, Marshall Islands);** ***pago*** **(Guam);** ***purau*** **(French Polynesia);** ***te kiaiai, te rau*** **(Kiribati);** ***vau, vau ndamu, vau ndamundamu, vau ndina, vauleka, vaundra*** **(Fiji);** ***vo, vole*** **(New Caledonia)**

Craig R. Elevitch and Lex A.J. Thomson

PHOTO: C. ELEVITCH

Trees along shoreline, Uafato, Samoa.

IN BRIEF

Distribution Found throughout the tropics.

Size Typically reaches 3–10 m (10–33 ft) in height, with a crooked, tangled, sprawling form.

Habitat Usually found in coastal and low-elevation habitats, but can be found up to elevations of 800 m (2600 ft) with annual rainfall of 900–2500 mm (35–100 in).

Vegetation Grows together with coastal, near-coastal, and riverine flora.

Soils Adapted to a wide range of well drained to poorly drained, acid to alkaline soils.

Growth rate Annual growth rate is estimated at 0.75–1.5 m/yr (2.5–5 ft/yr) in height.

Main agroforestry uses Soil stabilization, coastal protection, living trellis, hedge.

Main products Craft wood, fuelwood, fiber, medicinal.

Yields Data unavailable.

Intercropping Planted as boundary and windbreak around food crops or as a living fence around pastures.

Invasive potential Has some potential to invade undisturbed native plant communities, particularly when introduced into moist environments.

INTRODUCTION

Beach hibiscus (*Hibiscus tiliaceus*) is an evergreen, sprawling tree that typically grows to 3–10 m (10–33 ft) in height with a sprawling form. It is indigenous to many parts of the tropics and has been introduced to new regions by people. It is most at home in coastal and near-coastal environments, but it has been introduced into agricultural environments up to 800 m (2600 ft) elevation. Once established, the tree often persists and spreads, especially in moist gullies, streambeds, and other wet areas.

The tree can grow in a wide range of soils, including inhospitable brackish swamps, waterlogged soils, and limestone. It stands up well to salty ocean winds. High winds can cause trees to fall over, contributing to its tangled and intertwined form. Beach hibiscus is highly variable in form, leaf and flower color, etc., and several taxonomic varieties have been recognized. The tree serves as a coastal windbreak, hedge or boundary plant, and as a living trellis or fence post. The wood is used for canoe parts, crafts, short-term utility, and for fuel wood. The fibrous inner bark is utilized for cordage, and parts of the plant are used medicinally. Beach hibiscus is culturally significant throughout the Pacific.

DISTRIBUTION

Native range

The species is indigenous throughout the tropics and subtropics. It is not known if the species originated in the Americas or tropical Asia. The seeds can remain viable after floating in seawater for several months, which partially accounts for the tree's wide dispersal. Due to its many traditional uses, beach hibiscus has doubtless been spread by humans. It is possibly an aboriginal introduction to some isolated islands, such as Hawai'i, and to atolls, where it does not grow well (Thaman and Whistler 1996).

Current distribution

The tree is now found in tropical and subtropical America, Africa, Asia, Australia, and throughout the Pacific islands.

Threats to the species

The near–sea level habitats that it mainly frequents are threatened by climate change and sea level rise and accompanying land inundation.

BOTANICAL DESCRIPTION

Preferred scientific name

Hibiscus tiliaceus L.

Family

Malvaceae (mallow family)

Non-preferred scientific names

Hibiscus celebicus Koord.
Hibiscus hastatus L. f.
Hibiscus similis Blume
Paritium tiliaceum (L.) St.-Hil., Juss. & Camb.
Pariti tiliaceum (L.) Britton

Common names

Pacific islands

'au (Cook Islands)
ayiwo, *fa'alo*, *fa'ola*, *fakasu*, *kwara'ae* (Solomon Islands)
beach hibiscus, sea hibiscus, mahoe, linden hibiscus (English)
burao (Vanuatu)
ermall (Palau)
fau (Samoa, Tonga)
fau, *fautu'u* (Tuvalu)
fou (Niue)
gaal' (Yap)
hau (Hawai'i)
kalau (Pohnpei)
kilife (Chuuk)
lo (Kosrae, Marshall Islands)
pago (Guam)
purau (French Polynesia)
te kiaiai, *te rau* (Kiribati)
vau, *vau ndamu* (purple variant), *vau ndamundamu* (purple variant), *vau ndina*, *vauleka*, *vaundra* (Fiji)
vo, *vole* (New Caledonia)

Other languages

bourao (French)
coast cottonwood, Cuban bast (Trade Names)
emajagua (Spanish)

Size and form

Beach hibiscus typically reaches 3–10 m (10–33 ft) in height, and attains 20 m (66 ft) in rare cases, with a maximum stem diameter of 50 cm (20 in). The tree often has a short trunk with numerous crooked, sprawling, intertwined branches forming an impenetrable thicket. It can also have a shrub-like form, with prostrate branches. Usually the canopy is much wider than the height of the tree, although erect forms with upright branches are also known.

Flowers

The flowers are typical of the *Hibiscus* genus, showy, fragile, and short-lived, falling the same day that they open. They are borne in terminal or axillary, few-flowered cymes (3–6 flowers), or else solitary. Individual flowers are cup-shaped, with the corolla consisting of five radiating, obovate, lemon-yellow petals (4–6 cm [1.6–2.4 in] long), dark maroon at the base. The central staminal column is covered in yellow anthers with a terminal, red, five-parted style. The five sepals are elongated-triangular and light greenish-pink. The flowers fade to pink prior to falling. Flowering and fruiting may occur at any time of the year. The time to first flowering and fruiting is typically 2–3 years from seed.

Typical tangled, sprawling branches. PHOTO: C. ELEVITCH

Leaves

The leaves are simple, heart shaped, rather large (8–20 cm long by 6–15 cm across [3–8 x 2.4–6 in]), often wavy, discolorous, bright green on the upper surface, and grayish-green and hairy below. In some Pacific islands there is a variant with bronze–reddish-green shoots and new leaves.

Fruit

The fruits are a light brown, ovoid, dry capsule, about 2 cm [0.8 in] long, splitting into 5 segments and 10 cells of seeds at maturity. Fruiting may occur throughout the year. Vegetatively propagated plants may flower in less than a year, while seedlings first produce mature fruits at about 2–3 years of age.

Seeds

There are about 5–7 kidney-shaped seeds per cell. The seeds are rich brown to brown-black in color, roughened, and hairy.

Rooting habit

The plant has a highly spreading, near-surface, lateral root system, often comprised of only a few main roots.

Bark

The bark is gray to light brown, smooth to slightly longitudinally fissured with horizontal cracks, becoming thick and rough with age.

Similar species

In the Pacific, beach hibiscus is most commonly confused with the related *Thespesia populnea*, which also occupies similar, coastal strand habitats. *Thespesia* is distinguished by its glossy green, sparsely or non-hairy foliage, pale yellow flowers that have an undivided style and quickly turn dark pink-reddish, and its large, round, indehiscent, green fruits (resembling small apples) that turn black and wrinkled at maturity.

GENETICS

Variability

Hibiscus tiliaceus in a broad taxonomic sense is a highly variable species with seven distinctive subspecies (see below), some of which are regarded as worthy of classification as a species. There is considerable variation for many morphological traits. Vegetative characters are especially variable, although much of this variation is likely due to environmental factors.

Known varieties

The seven commonly accepted subspecies are:

- *Hibiscus tiliaceus* subsp. *celebicus* (Koord.) Borss. Waalk. (only known from Sulawesi, Indonesia)
- *Hibiscus tiliaceus* subsp. *crestaensis* Borss. Waalk. (only known from the island of Luzon, Philippines)




Top left: Flower. PHOTO: L. THOMSON **Top right: Fruit capsules.** PHOTO: L. THOMSON **Bottom left: Leaves.** PHOTO: C. ELEVITCH **Bottom right: Bark of older branch.** PHOTO: L. THOMSON

- *Hibiscus tiliaceus* subsp. *elatus* (Hochr.) Borss. Waalk. (stout habit and large flowers native to tropical east American and West African coastal regions)
- *Hibiscus tiliaceus* subsp. *genuinus* (Hochr.) Borss. Waalk.
- *Hibiscus tiliaceus* subsp. *hastatus* (L. f.) Borss. Waalk. (found in Pacific islands; distinctive in its three-lobed leaves)
- *Hibiscus tiliaceus* subsp. *similis* (Blume) Borss. Waalk. (native to Southeast Asia. Rarely develops mature capsules; may have evolved as a hybrid with *H. macrophyllus*)
- *Hibiscus tiliaceus* subsp. *tiliaceus* (widespread)

Many forms are found that are not formally recognized as taxonomic subspecies or varieties. A rare upright form grown for its stem fiber is known in Hawai‘i, called hau oheohe. This form was present before European contact in Hawai‘i (Staples and Herbst 2005).

Forms with variegated leaves, double flowers, white petals with maroon spots at the base, and pure yellow flowers are known.

ASSOCIATED PLANT SPECIES

In the Pacific islands the species is mainly found in strand and near-coastal plant communities, but it has been widely planted, especially as live boundary fences in inland, low elevation areas. Its natural habitats are mainly low, rather open, coastal thickets, and open to closed forest.

Associated native species commonly found

Commonly associated species are the typical Pacific islands strand and coastal species including *Acacia simplex, Barringtonia asiatica, Casuarina equisetifolia, Cerbera* spp., *Cocos nucifera, Cordia subcordata, Guettarda speciosa, Hernandia nymphaeifolia, Neisosperma oppositifolium, Pandanus tectorius, Scaevola taccada, Schleinitizia insularum, Sophora tomentosa, Terminalia catappa, Terminalia littoralis, Thespesia populnea, Tournefortia argentea,* and *Vitex trifoliata.*

Species commonly associated as aboriginal introductions in Pacific islands

Beach hibiscus is planted with many Polynesian tree introductions to the Pacific islands, including *Abelmoschus manihot*, *Aleurites moluccana*, *Artocarpus altilis*, *Musa* spp., *Spondias dulcis*, and *Syzygium malaccense*.

Species commonly associated in modern times or as recent Pacific island introduction

The species may be grown with a wide range of exotic tree species and is not exclusively planted or associated with particular exotics, other than those which are also used in live fences, e.g., *Gliricidia sepium*, *Pterocarpus indicus*, and *Cinnamomum* sp.

ENVIRONMENTAL PREFERENCES AND TOLERANCES

Beach hibiscus thrives in coastal habitats, near brackish coastal swamps, along inland watercourses, and along the inner margins of mangroves. It is commonly naturalized in disturbed forest areas, fallow or degraded cultivated lands, grazing lands, and around villages.

Climate

Elevation range

0–800 m (0–2600 ft). It is found inland to 800 m (2600 ft), in cultivation or naturalized after cultivation.

Mean annual rainfall

900–2500 mm (35–100 in)

Rainfall pattern

It favors environments with summer and uniform rainfall patterns.

Dry season duration (consecutive months with <40 mm [1.6 in] rainfall)

0–6 months

Mean annual temperature

12–32°C (54–90°F)

Mean maximum temperature of hottest month

24–41°C (75–106°F)

Mean minimum temperature of coldest month

5–24°C (41–75°F)

Minimum temperature tolerated

0–14°C (32–57°F)

Soils

The tree tolerates a broad range of soil types including various coastal and riverine soils such as coralline sands, skeletal soils on raised limestone terraces, and waterlogged swamp soils of medium to heavy texture. It occurs over a broad pH range, typically from 5 to 8.5, and is tolerant of brackish conditions and shallow flooding for many months.

Soil texture

It can grow in light- to heavy-textured soils (sands, sandy loams, loams, sandy clay loams, sandy clays, clay loams, and clays).

Soil drainage

It grows in soils with free or impeded drainage.

Soil acidity

The tree tolerates acid to alkaline soils (pH 5.0–8.5).

Other

The tree can grow in waterlogged soils, marl, sand, and limestone (Allen 2003).

Tolerances

Drought

Once established, the tree handles drought very well.

Full sun

The tree grows best in full sun.

Shade

It tolerates moderately high levels of shade, up to about 50–75%, but grows much more slowly under shade and has characteristically larger leaves.

Fire

The species has an intermediate tolerance of fire, being killed by severe fire, but is able to regenerate from mild fire damage.

Waterlogging

Beach hibiscus can grow in waterlogged soils, including shallow swamps.

Salt spray

It tolerates ocean spray very well and is often found growing adjacent to the seashore.

Wind

The tree can handle high winds but may suffer high levels of branch breakage during major storms.

Beach hibiscus (far left and near right) growing in near-shore, brackish soils together with red mangrove (*Rhizophora samoensis*, center), 'Upolu, Samoa. PHOTO: C. ELEVITCH

Abilities

Regenerate rapidly

The species regenerates very rapidly, especially from branches that bend over to ground level and take root. Such regeneration often occurs from trees partially flattened by cyclones and can quickly lead to almost impenetrable thickets.

Self-prune

Beach hibiscus does not self-prune, instead holding on to its lower, older branches, which contributes to its sprawling, branched habit.

Coppice

It tolerates heavy pruning and regrows well.

Pollard

Pollarding is the pruning back of all branches to a framework on a regular basis (usually every 1–3 years). Beach hibiscus is tolerant of pollarding, which would normally be done when the tree is used as a living fence post.

GROWTH AND DEVELOPMENT

In its early years, beach hibiscus is a very fast growing tree, both from seed and from branch cuttings, the latter of which is the main method of propagation. After about 5–7 years, height growth slows, and most of the plant's energy is directed to diameter growth (up to about 50 cm [20 in] dbh) and lateral spreading.

Growth rate

Annual growth rate is estimated at 0.75–1.5 m/yr (2.5–5 ft/yr) in height.

Reaction to competition

Beach hibiscus is a highly competitive species and resistant to competition from grasses and other plants, especially if propagated from branch cuttings.

PROPAGATION

Beach hibiscus is easily propagated both from seed and stem or branch cuttings.

Seedlings (after Wilkinson and Elevitch 2004a)

Seed collection

The tree flowers and bears mature fruits throughout the year. Capsules ripen 5–7 weeks after pollination. Capsules should be collected from the tree just prior to turning brown, because at maturity capsules dry, split open, and release most of their seeds. Each capsule contains 5–15 seeds.

Seed processing

Capsules should be air dried in a paper bag or other breathable container to prevent seeds from being lost when the

Mature seed capsule showing exposed seeds. PHOTO: L. THOMSON

capsules split. After a few days, the seeds can easily be removed from capsules by shaking.

Seed storage

Dried seeds of other *Hibiscus* species have lost viability when stored for 2 years in a refrigerator (Allen 2003). Immediate preparation for sowing is therefore recommended.

Seed pretreatment

Seeds are 3–5 mm (0.12–0.2 in) long. They can be scarified by lightly nicking the seed coat with a knife or nail clippers. Other growers report scarifying seeds by rubbing them on 400 grit sandpaper. Others soak the seeds in water to remove any inhibitors and to allow them to fully swell with water (Liyagel 2005).

Growing area

A rain- and wind-protected but sunlit area (such as a cold-frame with translucent film roof) is recommended for germination in trays.

Germination

Seeds can be germinated in trays filled with one part peat to three parts perlite or vermiculite. Warm, moist, and light conditions are beneficial for optimum germination. After the germination and early establishment phase, full sun is used for growing out the individual seedlings in containers. Scarified seeds will begin germinating in 2–4 weeks. Emergents are transplanted once they reach about 5 cm (2 in) in height. When transplanted into their individual containers, they can be mulched with a thin layer of medium-size poultry grit, coarse sand, or fine cinder. Germination is usually around 50%.

Media

Forestry tubes of 150 cm^3 (9 in^3) or larger volume can be used, as can small polyethylene bags 0.5–5 l (0.5–5 qt) in volume. A well drained medium is recommended such as 1/3 peat moss, 1/3 perlite, and 1/3 vermiculite, amended with a little compost, dolomite lime, gypsum, and a slow-release, balanced-nutrient fertilizer with minor elements.

Approximate size at outplanting

Seedlings are ready to plant out in 5–6 months at a target height of 25 cm (10 in) and stem diameter 10 mm (0.4 in).

Guidelines for outplanting

Seedlings need to be planted into thoroughly weeded and maintained areas, preferably with light to moderate shade to encourage apical dominance and better stem form.

Cuttings (after Wilkinson and Elevitch 2004b)

The most common method of propagation is branch cuttings for living fences. Typically this involves taking cuttings of fairly straight branches sections, about 2–3 m (6.6–10 ft) long. These cuttings are buried to about 1/3 of their length during the rainy season or wet weather.

Collection of propagation material

Cuttings can be collected any time of year. It is best to make a clean cut with a sharp lopper or saw. Remove all leaves. On moist sites, branches may bend down and take root; if desired, cuttings with roots attached can be collect-

Collecting branch cuttings for use in live fences, 'Eua, Tonga. PHOTO: L. THOMSON ed from such branches. As beach hibiscus is highly variable in form, select cuttings from trees with the desired form for the intended use (e.g., prostrate for soil stabilization or upright for living fence posts).

Cutting characteristics

For direct field outplanting, cutting size is usually 20–45 cm (8–18 in) in length, and 1–3 cm (0.4–1.2 in) in diameter. If plants are to be propagated from cuttings in the nursery, smaller cuttings may be used.

Cutting storage

Cuttings should be planted as soon as possible after collection. If immediate planting is not possible, cuttings should be placed upright in a bucket of water and kept moist and shaded.

Pretreatment

Medium-strength commercial rooting hormones may be applied as a pretreatment, but this is not required. At planting time, the lower 30–40 cm (12–16 in) of the cuttings should be "wounded" using a sharp knife to make several small incisions through the bark to promote side rooting. Without such cuts, roots usually only emerge from the base of the cutting, making for a potentially weak root structure and susceptibility to windthrow.

Growing area

It is usually most efficient and cost-effective to start cuttings directly in the field. However, smaller cuttings can be started containers in partial shade or full sun, if container-grown plants are desired.

Starting cuttings

Cuttings are buried 1/2 to 2/3 of their length deep into moist soil. Make sure the soil is firm around the base of the cutting, i.e., that there are no air pockets next to the cutting that could inhibit root development.

Performance on typical sites

Survival is 50% or higher when cuttings are started directly in the field.

Other comments on propagation

Removing weeds from the base and rooting zone around cuttings is essential to establishment. A weed barrier such as a sheet of cardboard or other organic material can make weed control around trees easy. If conditions are dry, supplemental water should be supplied once or twice a week until cuttings are established (which should take place within about 4 months). Once established, very little maintenance is required.

DISADVANTAGES

The main disadvantage of beach hibiscus is that it is difficult to manage and to eradicate once it is well established. The tree also reportedly harbors several agricultural insect pests.

Potential for invasiveness

Although rarely considered a pest, it does have a tendency to naturalize when introduced into moist environments. Its usually tangled, sprawling habit with root suckering makes the tree somewhat difficult to remove.

Pests and diseases

The tree has few problems with pests or diseases. Occasional infestations of pink hibiscus mealybug (*Maconellicoccus hirsutus*) and Chinese rose beetle (*Adoretus sinicus*) have been reported in landscape situations.

Host to crop pests/pathogens

Planted near taro (*Colocasia esculenta*), the tree is thought to increase the incidence of infestations of *Pythium* corm rot. In Vanuatu it is reported to be a host plant for a leafhopper (*Myndus taffini)* that spreads a lethal viral disease of coconut known as foliar decay.

AGROFORESTRY/ENVIRONMENTAL PRACTICES

Mulch/organic matter

The species has a noted ability to improve soil organic matter and fertility, most likely through leaf drop and decomposition, which occurs at a moderately fast rate.

Soil stabilization

The long, spreading branches root where they touch the ground, enhancing the tree's ability to stabilize soil on slopes, along riverbanks, swampy areas, and shores exposed to moderate coastal tides. The tree has also been used to stabilize sand dunes.

Crop shade/overstory

It has limited use as a crop shade. It is difficult to control its spread, and the shade is too heavy for most crop plants.

Alley cropping

Beach hibiscus is difficult to manage in alley cropping systems because frequent maintenance is required in order to restrict its rapid, spreading branching habit.

Left: Trellis stakes of beach hibiscus support pumpkin vines, 'Upolu, Samoa. Right: Cattle grazing among beach hibiscus trees, 'Upolu, Samoa. PHOTOS: C. ELEVITCH

Improved fallows

It is commonly cleared to make new garden areas, indicating that it is valued for its improvement of the soil of fallow areas (Thaman and Whistler 1996).

Living fences

A hedge of beach hibiscus planted on 1–2 m (3.3–6.6 ft) centers can be trimmed regularly to form a dense living fence.

Fence posts

As the tree easily grows from cuttings, branches can be started in the field as living fence posts for supporting wire fencing. Such living fence posts are pruned periodically to provide firewood, utility wood, and organic matter for mulch.

Boundary markers

Beach hibiscus is commonly used as a living boundary tree (e.g., in Fiji, Samoa, Solomon Islands, Tonga, and Vanuatu).

Windbreaks

Space permitting, it makes a useful low- to medium-height windbreak.

Host plant trellising

Branch cuttings can be used to support netting for vegetables. The trees are often ringbarked and dead trees used as support for growing yam.

Coastal protection

The tree is well suited for coastal area protection from salt spray and strong winds.

Ornamental

Beach hibiscus makes an interesting ornamental, especially the variegated or purple-tinged selections. Lower branches can be pruned away to provide open space underneath the canopy.

USES AND PRODUCTS

Vegetable

In times of famine, the leaves, bark, and roots have been eaten.

Honey

The plant is reputed to be a good forage plant for bees.

Medicinal

The flowers, roots, and bark have served as herbal medicines. Hawaiians used the slimy sap from the inner bark as a laxative or enema. The flowers were thought to aid in digestion. In Fiji, the leaves are wrapped around limb fractures, and the stem is used as part of a remedy for treating ulcers (Smith 1981).

Beautiful/fragrant flowers

The flowers are fairly showy and produced over a long period. In Hawai'i and presumably elsewhere the flowers are made into colorful leis.

Timber

The wood can be used for utility timber, although due to its softness and low durability, it is used mainly for light and transient construction.

Left: Making a traditional cricket bat, Savai'i, Samoa. PHOTO: L. THOMSON **Right: Preparing fiber for kava strainers, Apia, Samoa.** PHOTO: C. ELEVITCH

Fuelwood

The wood makes acceptable firewood, especially for slow-smoking of food (Thaman and Whistler 1996). This is an important product in many countries (e.g., Vanuatu).

Craft wood/tools

The wood is moderately soft and porous, with a specific gravity of 0.6. The sapwood is white, while the heartwood is dark greenish-brown. The freshly cut wood has an odor reminiscent of coconut. The wood has been used occasionally for carved and turned bowls, bracelets, and other minor products such as swimming goggles. Carving such items from branches that are mostly sapwood gives the products a marbled appearance from the heartwood inclusions within the white sapwood. Presumably due to its strength combined with light weight, poles are used to make a breadfruit-picking tool in Samoa (Whistler 2000). The wood was also used by Hawaiians for spears for games and for kite sticks.

Canoe/boat/raft making

The wood is durable in seawater and was used by Hawaiians for canoe parts and fishing floats. The bast fiber is used as a canoe calking.

Fiber/weaving/clothing

Hawaiians fashioned the bark into sandals. The inner bark can also be beaten into inferior tapa cloth. A strainer made from the inner bark is used to strain kava (e.g., Fiji, Samoa). The leaves are used as toilet paper.

Rope/cordage/string

The tree is widely used for cordage and rope by braiding together several long strips of inner bark. The number of strips used depends on the strength required. The fiber is also used for such things as foot nooses for coconut palm climbing.

Wrapping/parcelization

The leaves are used to wrap food (especially seafood), as plates, and to line earthen cooking ovens (Thaman and Whistler 1996).

Body ornamentation/garlands

Hawaiians made the leaves and plentiful flowers into leis. "Grass skirts" used in ceremonial occasions (e.g., in Fiji) and exported from Samoa and other Pacific islands are made from the bark fiber.

Tannin/dye

The leaves were pounded and boiled to make a dye.

Illumination/torches

Rubbing the pointed end of a hardwood stick in a groove in a piece of beach hibiscus wood was a preferred method of making fire in Hawaiʻi.

URBAN AND COMMUNITY FORESTRY

Size in an urban environment

Along boundaries, within gullies, and in inaccessible areas such as rocky slopes, beach hibiscus can be allowed to grow to its full size, typically about 6–10 m (20–33 ft) tall with large, spreading side branches. When used as a specimen tree, hedge, or trained onto a trellis, size and shape can be controlled by pruning.

Rate of growth in a landscape

The rate of growth is fast, approximately 0.75–1.5 m (2.5–5 ft) of new growth per year. As trees grow older, increase in height tapers off and side growth continues.

Root system

The root system is classified as invasive, especially due to the tendency to sucker from the root. It is important to keep this plant away from fixed landscape and building

Trees can make a nice canopy in landscaping, but require regular pruning. Right: Hedges can be pruned back periodically to control their size, and leaves regrow quickly. PHOTOS: C. ELEVITCH

 

Left: A hedge of a variegated clone makes a dense privacy barrier. Right: Form with a purple leaf flush. PHOTOS: C. ELEVITCH

features such as walkways, fences and walls, sewer lines, foundations, and irrigation pipes.

Products commonly used in a Pacific island household

The bark is a ready source of rough cordage and rope. The flowers and leaves are plentiful and can be used in leis. The tree provides an abundant source of firewood.

Light requirements

Beach hibiscus prefers full sun. It does not grow well in shade.

Water/soil requirements

The tree prefers lowland coastal environments, especially along waterways. It can thrive in a wide variety of light- and medium-textured soils with either free or impeded drainage. Once the tree is established, it tolerates drought very well. The tree can tolerate saline conditions and presumably would do well even with brackish irrigation water.

Life span

The life span is estimated to be several decades.

Varieties favored for use in homegardens or public areas

There are a number of white, pink, or purple variegated selections that are favored for ornamental use (see “Known varieties” above).

Seasonality of leaf flush, flowering, fruiting

Beach hibiscus produces new leaves, flowers, and fruit throughout the year.

Exceptional ornamental values

Beach hibiscus has been planted throughout the tropics as an ornamental for its showy flowers and leaves. Highly ornamental forms with variegated leaves are propagated vegetatively.

Use as living fence, hedge, or visual/noise barrier

Beach hibiscus is frequently used in urban environments as a hedge or privacy screen. Regular pruning to maintain appropriate size and a groomed appearance is necessary.

Maintenance requirements

The unruly habit of the tree can be tamed by regular pruning 1–3 times per year into a hedge or specimen tree, or by training the branches on a trellis or pergola. Otherwise, the tree requires little attention once established.

Nuisance issues

The tangled habit of the tree can become a nuisance in public environments and almost always requires pruning along pathways, near structures, etc. The invasive roots can also cause problems in urban landscapes.

Other comments

As one of the most useful trees of the Pacific, planting this tree in urban environments forms a connection to traditional Pacific island cultures.

COMMERCIAL CULTIVATION

The tree is primarily used for its environmental services such as coastal protection and hedges and has little commercial value except in the landscaping industry in certain countries.

PUBLIC ASSISTANCE AND AGROFORESTRY EXTENSION

Extension offices for agroforestry and forestry in the Pacific: <http://www.traditionaltree.org/extension.html>.

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traditional tree initiative

Species Profiles for Pacific Island Agroforestry (www.traditionaltree.org)

Hibiscus tiliaceus (beach hibiscus)

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Acknowledgments: The authors and publisher thank Dale Evans, Eileen Herring, and Diane Ragone for their input.

Recommended citation: Elevitch, C.R. and L.A.J. Thomson. 2006. *Hibiscus tiliaceus* (beach hibiscus), ver. 1.2. In: Elevitch, C.R. (ed.). Species Profiles for Pacific Island Agroforestry. Permanent Agriculture Resources (PAR), Hōlualoa, Hawai'i. <http://www.traditionaltree.org>.

Sponsors: Publication was made possible by generous support of the United States Department of Agriculture Western Region Sustainable Agriculture Research and Education (USDA-WSARE) Program; SPC/GTZ Pacific-German Regional Forestry Project; USDA Natural Resources Conservation Service (USDA NRCS); Kaulunani, an Urban Forestry Program of the DLNR Division of Forestry and Wildlife and the USDA Forest Service; State of Hawai'i Department of Land & Natural Resources Division of Forestry & Wildlife; USDA Forest Service Forest Lands Enhancement Program; and Muriel and Kent Lighter. This material is based upon work supported by the Cooperative State Research, Education, and Extension Service, U.S. Department of Agriculture, and Agricultural Experiment Station, Utah State University, under Cooperative Agreement 2002-47001-01327.

Series editor: Craig R. Elevitch

Publisher: Permanent Agriculture Resources (PAR), PO Box 428, Hōlualoa, Hawai'i 96725, USA; Tel: 808-324-4427; Fax: 808-324-4129; E-mail: par@agroforestry.net; Web: <http://www.agroforestry.net>. This institution is an equal opportunity provider.

Inocarpus fagifer (Tahitian chestnut)

Fabaceae (legume family)

aila **(Papua New Guinea);** ***chataignier de Tahiti*** **(French);** ***ifi*** **(Samoa, Tonga, Niue, Horne Islands, 'Uvea);** ***ihi*** **(Marquesas);** ***i'i*** **(Cooks);** ***ivi*** **(Fiji);** ***mape*** **(Society Islands);** ***mworopw*** **(Pohnpei);** ***namambe*** **(Vanuatu: Bislama);** ***naqi*** **(Solomon Islands: Nduke); Tahitian chestnut, Polynesian chestnut (English);** ***te ibi*** **(Kiribati)**

Richard L. Pauku

IN BRIEF

Distribution Found in many countries of Melanesia, Micronesia, and Polynesia.

Size Typically grows to 20 m (66 ft) in height, with a crown diameter of 4–6 m (13–20 ft).

Habitat Grows at elevations of 0–500 m (0–1640 ft), although is found most commonly at low elevations along shorelines and rivers; mean annual rainfall 1500–4300 mm (60–170 in).

Vegetation Associated with lowland secondary forest, stream banks, swamps and marshes, mangrove areas, and coconut plantations.

Soils Grows in a wide range of soils with pH 5–14.

Growth rate Moderate, up to 2 m (6.6 ft) per year.

Main agroforestry uses Coastal stabilization, soil stabilization, crop shade/overstory.

Main products Edible nut, wood.

Yields Up to 75 kg (165 lb) fruits/tree/yr for trees 25+ years old.

Intercropping Can be used as a component of a multistory planting, both as a middle story or overstory tree.

Invasive potential Not considered invasive.

PHOTO: R. LEAKEY

Mature tree, Tututi, Kolombangara Island, Solomon Islands.

INTRODUCTION

Tahitian chestnut (*Inocarpus fagifer*) is a medium size, evergreen tropical tree found in secondary forests, homegardens, and coconut plantations. It is most common along riverbanks, in swamps and marshes, and within coastal shorelines. It appears that Tahitian chestnut was cultivated more intensively in the past. Today the species is found mostly in wild form. The native distribution spreads across Melanesia, Micronesia, and Polynesia, extending eastward to Johore in Sarawak and Sabah in Malaysia.

Tahitian chestnut is a leguminous, evergreen tree producing a seed that is edible when cooked and is among the most important nut species in the Pacific. The tree is shade-tolerant, although heavy shading may decrease its yield. It has a dense canopy, which makes it unsuitable for close planting between light-demanding agricultural crops such as sweetpotato (*Ipomoea batatas*), taro (*Colocasia esculenta*), sugarcane (*Saccharum officinarum*), and corn (*Zea mays*). However, it is suitable as a boundary tree to provide shade and shelter for more shade-tolerant crops. Some types are compatible with other trees such as vi (*Spondias cyathera*), canarium nut (*Canarium* spp.), and breadfruit (*Artocarpus altilis*). It also grows together well with cutnut (*Barringtonia* spp.), sago palm (*Metroxylon salomonense*), betel nut palm (*Areca catechu*), and coconut (*Cocos nucifera*). There is no record that suggests Tahitian chestnut is invasive, and this is supported by *in situ* observation.

DISTRIBUTION

Native range

Tahitian chestnut is indigenous to many South Pacific countries (from Java in the west to the Marquesas in the east). It is found in Melanesian countries (the Solomon Islands, Vanuatu, Fiji, and Papua New Guinea) where it is believed to be indigenous.

Current distribution

In parts of Polynesia (Samoa, Tonga, Cook Islands, and French Polynesia) and Micronesia (Pohnpei, Marshall Islands, and Kiribati), the species is believed to be an aboriginal introduction. In Pohnpei, Tahitian chestnut is found growing in coastal locations and in the uplands to an elevation of 200 m (650 ft) and is most common along riverbanks and in giant taro patches (Kostka, pers. comm., 2004). It has been introduced to the Philippines.

BOTANICAL DESCRIPTION

Preferred scientific name

Inocarpus fagifer (Parkinson ex Zollinger) Fosberg

Family

Fabaceae (legume family)

Non-preferred scientific names

Inocarpus fagiferus (Park.) Fosb.
Inocarpus edulis Forst.
Aniotum fagiferum Park.

Common names

aila (Papua New Guinea)
chataignier de Tahiti (French)
ifi (Samoa, Tonga, Niue, Horne Islands, ʻUvea)
ihi (Marquesas)
iʻi (Cook Islands)
ivi (Fiji)
mape (Society Islands)
mworopw (Pohnpei)
naqi (Solomon Islands: Nduke)
namambe (Vanuatu: Bislama)
Tahitian chestnut, Polynesian chestnut (English)
te ibi (Kiribati)

In the Solomon Islands it is well known in rural villages in numerous dialects. It is called *ailali* in Kwaraʻae (Malaita Is.), *dulafa* in Toʻoabaita (Malaita Is.), *dola* in Varisi (Choiseul Is.), *mwaqe* in Santa Ana (Santa Ana Is.), *naqi* in Nduke (Kolombangara Is.), *ivi* in Roviana (New Georgia Is.), Marovo (New Georgia Is.), *julapa* in Bugotu (Isabel Is.), and *zulapa* in Zabana (Isabel Is.).

Size and form

Tahitian chestnut is a medium size tree reaching a typical height of 20 m (66 ft). Some trees in Santa Cruz, Vanuatu, grow to less than 10 m (33 ft) in height and trees in Choiseul and Kolombangara in the Solomon Islands reach 30 m (100 ft) tall. Mature fruiting trees have a typical crown diameter of 4–6 m (13–20 ft). The trunk diameter at breast height (dbh) of mature trees ranges from 7 to 90 cm (3–35 in) and is typically 30 cm (12 in). The trees have a distinctive, short, thick, irregular, and very fluted bole. Branches have a spirally alternate arrangement. Secondary branching creates a network of branches within the dense canopy.

Flowers

The flowers are fragrant and clustered along a short rachis found at the apex of branches, stems, and twigs. They are about 1 cm (0.4 in) long and have five petals that vary from white to yellowish. Trees begin flowering at an age of 3–5 years in the Solomon Islands. Flowering is seasonal and in most cases occurs in November–December, with fruiting in January–February of the following year. A similar pattern is found in PNG and Vanuatu.

Leaves

The leaves are simple, oblong, alternately arranged, dark green, and leathery to the touch. They are 16–39 cm (6.3–15 in) long and 7–13 cm (2.8–5.1 in) in width, and the petiole is 0.5–2.5 cm (0.2–1 in) long. The leaf apex is slightly pointed, the base lobed, and the margin entire. Leaf veins are opposite, yellow, and conspicuously arranged along the mid-vein.

Fruit

The fruits are ovoid but irregular, slightly flattened, and rounded or oblong with a flange down one end. They are produced either singly or in clusters. Fruits weigh 50–110 g (1.8–3.9 oz) and measure 46–130 mm (1.8–5.1 in) in length, 34–120 mm (1.3–4.7 in) in width, and 40 mm (1.6 in) in thickness. The skin is smooth and covers a fibrous shell encasing the kernel. Young fruits usually are green, but as they ripen the color usually changes from green to orange-brown. However, in some types the fruits remain green even when ripe. At maturity the fruits are usually indehiscent, although there are some dehiscent types. The division of the shell is visible when the mesocarp is removed. Tahitian chestnut generally fruits once a year. In Vanuatu fruits reach maturity between January and April. In the Milne Bay region of PNG and parts of the Solomon Islands, especially in Choiseul and Kolombangara Island, fruiting occurs from November to February. In Fiji two seasons per year have been reported (January–March and May–July), although fruiting is more pronounced in the former. Considerable year-to-year variation in the fruiting season has been reported in Fiji and the Solomon Islands.

Seeds

The white, kidney-shaped seed or kernel is contained in a fibrous, brownish, relatively thin (about 2–3 mm [0.08 in] thick) shell. Kernels (seeds) are large, each weighing 5–50 g (0.2–1.8 oz), and measuring 20–70 mm (0.7–2.8 in) in length by 16–40 mm (0.6–1.4 in) in width. The kernel is edible when cooked but is highly perishable and has a short shelf life. It rapidly changes color from white to reddish brown after being extracted from the shell. The fleshy mesocarp, or pulp, is eaten by flying foxes and cockatoos. These animals bite off fruits and fly with them to other trees, dispersing the seeds. The kernel (seed) must remain encased inside the shell to be viable.

Bark

The bark is rough and flaky and varies from brown to grayish. The grayish color is more common in older trees. Other bark characteristics appear relatively constant with age.

Rooting habit

The tree has a shallow taproot and well formed network of lateral roots that are most prevalent in the topsoil layer. At the base of the trunk are 3–4 thin buttresses that extend up the trunk up to a height of 1 m (3.3 ft) and reach laterally, snake-like, for a long distance. Sometimes lateral roots extending from the buttresses are exposed on the soil surface (not buried in the soil); this could well be due to soil erosion.

GENETICS

Variability of species

Tahitian chestnut displays a variety of forms. There is great diversity in leaf and fruit size, shape, and color. In Vanuatu, four morphotypes can be distinguished mainly by fruit shape and color—the most common morphotype bears broadly rounded or quadrangular fruits that are green or brown at maturity. Significant intraspecific variation was observed in fruit shape and color in the Solomon Islands, but a quantitative characterization study is needed to accurately determine the extent to which this occurs elsewhere. Typically, the species has buttresses at the base of the trunk, but a type found in the east of Johore, Sarawak, and Sabah does not form these.

Known varieties

Given the great diversity in the size, shape, color, and form of the tree and its leaves, flowers, and fruits and its long history of cultivation, it is highly likely that Tahitian chestnut has a number of farmer-selected cultivars that have not been formally recognized or described.

Culturally important related species in the genus

Currently, Tahitian chestnut is the only edible and culturally important species in the genus *Inocarpus*.

ASSOCIATED PLANT SPECIES

Tahitian chestnut appears to have been cultivated more frequently in the past, and today the wild type is widely



Left and top right: Leaves, fruits on tree, 'Upolu, Samoa. PHOTOS: C. ELEVITCH **Bottom right: Kernels of varying sizes, Babarego, Choiseul, Solomon Islands.** PHOTO: R. PAUKU

distributed in its native range. It is commonly found in lowland woody regrowth, edges of old gardens, along rivers and streams, in swamps and marshes, along shorelines, and in coastal locations including mangrove areas and coconut plantations.

Associated species commonly found in native habitats

Other species that are found within the natural range of Tahitian chestnut include canarium nut (*Canarium* spp.), breadfruit (*Artocarpus altilis*), coconut (*Cocos nucifera*), cutnut (*Barringtonia* spp.), *Flueggea flexuosa*, sago palm (*Metroxylon salomonense*), Malay apple (*Syzygium malaccense*), *Mangifera minor*, *Ficus* spp., beach hibiscus (*Hibiscus tiliaceus*), beach she-oak (*Casuarina equisetifolia*), *Intsia bijuga*, *Terminalia* spp., and narra (*Pterocarpus indicus*). In Choiseul, Solomon Islands, Tahitian chestnut is commonly naturalized together with coconut in coastal locations and in woody secondary regrowth. The species occurs with mangrove on muddy shorelines in Kolombangara, Solomon Islands. It is also found naturalized east of Johore in Sarawak and Sabah.

In its native range, mature trees of Tahitian chestnut are found scattered with varying density. In Veratalevu, Fiji, for example, 206 trees/ha (83 trees/ac) have been found, compared with an estimated density of 10–20 trees/ha (4–8 trees/ac) in Kolombangara, Solomon Islands.

Species commonly associated as aboriginal introductions in Pacific islands

Commonly associated aboriginal introductions in the Pacific islands include canarium nut, Malay apple, cutnut, *Burckella obovata*, and several mangrove species.

Species commonly associated in modern times or as recent introduction

Species commonly associated as more recent introductions include banana and plantain (*Musa* spp.) and coconut.

ENVIRONMENTAL PREFERENCES AND TOLERANCES

Climate

The tree grows in the lowland humid tropics with moderate to high, uniformly distributed rainfall.

Elevation range

0–500 m (0–1640 ft)

Mean annual rainfall

1500–4300 mm (60–170 in)

Rainfall pattern

The tree grows in climates with summer or uniform rainfall patterns.

Dry season duration (consecutive months with <40 mm [1.6 in] rainfall)

Up to 1 month.

Mean annual temperature

26.4–27.7°C (80–82°F)

Mean maximum temperature of hottest month

29.4–34.5°C (85–94°F)

Mean minimum temperature of coldest month

20–23°C (68–73°F)

Minimum temperature tolerated

No data available. Prolonged temperatures below 20°C (68°F) may negatively affect tree growth.

Soils

The tree has been classified as a beach-forest species and is often found in swamps, marshes, waterlogged areas, and highly alkaline soils along shorelines. It also grows along the banks of rivers and streams, at the edges of villages, and in homegardens. Tahitian chestnut generally grows in a wide range of soils that include highly calcareous and saline soils and poorly drained seasonal to permanently waterlogged valleys, swamps, and marshes. It occurs in soils with medium to very low fertility rating. It can grow in mildly acidic to very alkaline coastal soils.

Soil texture

It grows in light to heavy soils (sands, sandy loams, loams, sandy clay loams, clays, clay loams, and sandy clays).

Soil drainage

The tree grows in soils that have free or impeded drainage as well as seasonally waterlogged or even continually waterlogged soils.

Soil acidity

It can grow in mildly acid to alkaline soils (pH 5–14). Trees are found along shorelines, river banks, and even in estuaries and are frequently found in high-calcium soils with pH up to 14.

Special soil tolerances

The tree tolerates shallow, saline, and infertile soils.

Tolerances

Drought

Prolonged drought of more than several months duration may not be tolerated.

Full sun

Tahitian chestnut is commonly found in areas with full sunlight, although seedlings can grow up through the understory, i.e., in partial shade.

Growth in a swampy area, 'Upolu, Samoa. PHOTO: C. ELEVITCH

Shade

It can tolerate 20–80% shade. Heavy shading appears to slow down growth of seedlings. Mature trees are likely to be less sensitive to shade than young seedlings.

Fire

As a swamp species, Tahitian chestnut rarely experiences fire and is likely to be intolerant.

Frost

Its natural range is frost free.

Waterlogging

Tahitian chestnut tolerates and is adapted to permanent and seasonal waterlogging.

Salt spray

The species is tolerant of salt as it naturally grows close to the sea.

Wind

It has medium to high tolerance of steady and strong winds. The tree tolerates tropical cyclones that usually occur during the wettest months of November to March in the Solomon Islands. Branches and twigs do not easily break, but they may be sheared off during strong winds. The trees are windfirm due to a strong lateral root system including buttresses. The medium height of the tree contributes to its windfirm character.

Abilities

Fix nitrogen

Tahitian chestnut is a leguminous species and may fix atmospheric nitrogen. Nodulation with *Rhizobium* bacteria has been found, although nitrogen fixation has yet to be confirmed. The tree is reported to improve soil fertility in Fiji and the Cook Islands.

Regenerate rapidly

Seedlings commonly regenerate only below the canopy of the parent tree unless the fruits are distributed by animals or by rolling down a slope. Therefore, the tree is generally not a colonizer of open areas.

Self–prune

Self-pruning of side branches occurs naturally. Trees normally have a single trunk clear of branches to 3–4 m.

Coppice

Trees coppice well, usually producing new leafy shoots even from stumps. Some large trees are known to have regrown after cutting, while others have died.

Pollard

Pollarded trees of Tahitian chestnut regrow well. In Kolombangara, Solomon Islands, one to four shoots per pollarded branch of mature fruiting trees resprouted after 3–4 weeks.

Nodules on root system. PHOTO: R. PAUKU

GROWTH AND DEVELOPMENT

Growth rate

Generally, Tahitian chestnut growth is moderate, but this varies significantly among trees. Seedlings can reach 1–2 m (3.3–6.6 ft) in the first year in ideal conditions. The tree is reported as a fast growing tree in Fiji and the Cook Islands.

Reaction to competition

At early stages of growth, Tahitian chestnut can be smothered by rapidly growing vines such as *Mikania* and *Merremia*, but mature trees compete well with other tree species within their native range. Generally, reduced vegetation is found beneath the canopy of mature trees, although seedlings are usually abundant under the canopy.

PROPAGATION

The common method of propagating Tahitian chestnut is by direct-seeding into the field or by raising seedlings in the nursery before transplanting into the field. Vegetative propagation techniques such as air-layering (marcott) and stem cuttings have proved successful and promising for reproduction of preferred clones.

Propagation by seed

Seed collection

Fruits mature in about 3 months from flowering and take at least a month to ripen. Fruits fall when they are ripe; collect well formed ones from the ground. Collecting fruits directly from the tree requires that fruits be judged correctly for ripeness. Mature fruits that are harvested prior to ripening will take longer to germinate. Generally, ripe fruits are those that have changed color from green to yellowish brown or yellowish red. For some trees, how fibrous the mesocarp has become can also be used to judge fruit maturity.

Seed processing

No processing is necessary. The exocarp can be artificially removed by cutting along the split in the fibrous pericarp, but it is unnecessary to do so. The most appropriate way of sowing seed is as a whole fruit, i.e., including the mesocarp. The fruits are large; there are about 10–20 fruits/kg (5–10 fruits/lb).

Seed storage

The seeds are recalcitrant, do not withstand drying, and do not remain viable for more than a few weeks. It is best to keep the fruit intact (nut-in-shell) and store them in a shady, cool (19–25°C, 66–77°F) area with low humidity (<20%) if storage is necessary. Fruits need to be protected from pests such as crabs and rodents.

Pre-planting treatments

There is no information on special pre-planting treatments for the seeds. Seed viability can be tested by placing the seeds in water. Fruits that float are usually non-viable (although some non-viable fruits will sink together with viable seeds).

Growing area

Seeds may be sown directly into the field or raised in the nursery in polyethylene bags or root-training containers. In both cases, it is important to avoid direct exposure of seeds to full sunlight. Shade of 30–50% provides adequate protection for the germinated seeds from direct solar heat. Sown seeds must be watered regularly until the first leaves emerge. Excess watering may encourage secondary fungal infection and rotting. When direct-seeding, only one seed is required per planting hole.

Germination

Depending on the stage of fruit ripening, seed germination may start as early as 7 days from sowing. Fruits usually ripen and then fall to the ground. Fruits also may fall unripe but already mature due to wind and animals (flying foxes, etc.). Mature seeds that fall to the ground or are picked unripe will take longer to germinate than ripe seeds.

Seeds should be buried in the media at a depth of 3–5 cm (1.2–2 in). Placing the seed flat on its side is acceptable, but it may take longer for the young roots to get established in the ground. It is best to plant the seeds with the radicle pointing down. The nut does not degenerate rapidly and can remain intact on the young developing seedlings for up to 6 months.

Media

Well drained soils, potting mix, or coir are ideal. Coir (shredded, decomposed coconut husk) is light, permeable ,and has good water retention capacity. Coir should be sterilized prior to use (100°C [212°F] for 30–45 minutes).

Time to outplanting

Seedlings are ready for field planting about 1–2 months after germination. They should be weaned from shade by exposing them to increasing light intensity (80–100%) over a couple of weeks. Transplanting to the field should be carried out during wet periods to minimize adverse field effects on the young seedlings.

Approximate size

Ideally, seedlings are 20–30 cm (8–12 in) tall and have more than five true leaves when they are outplanted. Under good nursery management, seedlings take 1–2 months to reach this size.

Other comments on seedlings

Wildings (natural seedlings) can be transplanted. Ensuring the seed remains attached to the seedling during transplanting assures survival. Wildings whose seed is detached at a young age must be treated with special care in order to maintain vigor and viability. Holding wildings with their roots in water in a shady and cool environment was found successful for overnight storage.

Guidelines for outplanting

Spacing of 10 x 10 m (33 x 33 ft) along the boundaries of a polycultural farming system has been used (Reef Islands, the Solomon Islands). In an orchard planting a spacing of 5 x 5 m (16 x 16 ft) is suggested. Seedlings may be planted in the open or as line plantings in secondary forests. As the seedlings grow older and their demand for space and light increases, other trees and shrubs can be selectively removed. Open plantings should ideally be in mixtures with other multipurpose trees and crops such as canarium nut, gliricidia (*Gliricidia sepium*), narra, *Flueggea flexuosa*, coconut, and *Musa* spp. These are incorporated to provide shade as well as to diversify production and minimize risk. Ideally, these other species should be planted a year in advance of the Tahitian chestnut. This requires planning so that correct final spacing is achieved.

Before planting, seedlings should be sprayed with water to reduce stress through transpiration, especially during transportation. It may also be necessary to trim the leaves to reduce transpiration losses. Temporary shade made of coconut fronds or forest branches can also be used to shade seedlings before and after planting to reduce physiological stress.

A planting hole should be dug 5–10 cm (2–4 in) diameter with a slant-cut digging stick or a digging spade and be filled with a good mixture of topsoil and organic materials such as compost to maximize survival and growth of seedlings. Watering may be necessary if prolonged dry weather is experienced in the weeks following planting.

Propagation by leafy stem cutting

A relatively inexpensive, air- and water-tight enclosure called a poly-propagator (Leakey et al. 1990) is well suited for starting cuttings of Tahitian chestnut. After about 3 weeks the cuttings will have developed a strong enough root system to be transplanted into individual containers for growing in open conditions.

Collecting cuttings

Cuttings may be collected from stumps or pollarded trees and branches. They may also be collected from wildings or seedlings raised in the nursery. Ideally, a multiplication garden of stock plants (wildings, seedlings, and clones) from selected superior parent trees is established under moderate shade of mixed species in secondary forest. The multiplication garden should be established at close proximity to the nursery for easy access.

A crop of cuttings can be taken from stock plants in the multiplication garden within 6–12 months of initial planting. By this time the trees should have attained 0.5–1.5 m (1.6–5 ft) in height and produce six to nine single-node cuttings with varying diameter (2–5 mm, 0.08–0.2 in) and length (2–10 cm, 0.8–4 in).

At first harvest, the seedling should be trimmed back to a height of 20–50 cm (8–20 in) leaving side branches intact on the main stem. After pruning, new shoots will rapidly emerge from axillary buds on the stem, and seedling generally makes a full recovery after harvesting cuttings from it. Harvesting cuttings can be done about every 4–6 weeks during the growing season. This period can be lengthened, but leaving new shoots too long will result in increased lignification and a decline in rooting ability. Regularly cropped stock plants can be managed as a hedge. Side branches along the main stem should be trimmed to encourage top shoot production.

When collecting from stumps and pollarded mature trees rather than seedlings in a stock plant garden, coppices and sprouts are ready for harvest within 3–6 months of cutting. About two to five shoots are produced from individual stumps or managed stock plants. A shoot or secondary branch reaching 20–30 cm (8–12 in) in stem length generally has up to nine internodes.

Harvesting cuttings

Single-node cuttings should be collected in the morning or late afternoon when it is cool. Harvest young, six- to nine-node shoots that are healthy, disease-free, and have 5–10 cm (2–4 in) internodes. Sever shoots with a clean cut using a sharp pair of pruning shears, and avoid damaging the stem. It may be necessary to reduce the number of leaves to one per internode and to trim them down by half before transporting the plants back to the nursery. Place the shoots in a bucket filled with water. Alternatively, wrap them with a moist piece of cloth or paper and place them in a closed polyethylene bag for transport.

Storage of cuttings

For best results, the cuttings should be immediately set in the poly-propagator. Leaving cuttings overnight in water or under high humidity (i.e., in a sealed plastic bag) is acceptable but may result in a reduced strike rate due to the increase in leaf abscission.

Treatments

It is unnecessary to treat cuttings with fungicide prior to setting. However, it may be necessary to disinfect the poly-propagator with conventional fungicide as a precautionary measure. Cuttings may be treated with rooting hormone. The need for auxin treatment on cuttings is not critical, but it enhances the number of roots formed. To treat, dip the base of the cutting in the rooting powder and tap gently to remove excess powder before placing the cutting inside the poly-propagator. An auxin concentration of 0.8% IBA gives the best results.

Growing area

The poly-propagator is made of clear plastic sheeting and wood. The base is filled with layers of sand, stones, and pebbles that are saturated with water. A layer of rooting medium such as sterilized coir 10–15 cm [4–6 in] deep is placed on top of these layers. Coir provides a good rooting medium for the cuttings because it is easy to work with during transplanting. Well drained garden soil, which may be sterilized as a precaution against soil-borne diseases, also makes a good rooting medium. Water is supplied through a pipe and retained within the underlying layers. The water keeps the temperature and relative humidity fairly constant inside the propagator; these conditions are maintained by opening the lid only when absolutely necessary. Whenever the enclosure is opened, the cuttings should be sprayed with water before closing the lid. The water level is checked regularly through an observation pipe inserted in the medium and refilled if low. The poly-propagator should be placed under shade, protected from wind, and treated with fungicide every 1–2 months.

Time for rooting

Rooting occurs 14 days from the time cuttings are set. Preferably the cuttings are left in the propagator for 3 weeks, by which time most cuttings will have produced root systems that are strong enough for transplanting. Dead leaves and cuttings should be removed immediately from the propagator, as they are a source of fungal infection. A strike rate of 95–100% was obtained in Kolombangara, Solomon Islands.

Media

Rooted cuttings can be transplanted into 1–2 l (1–2 qt) polyethylene nursery bags or other similar containers filled with a potting medium that is well drained, has good water retention capacity, and is light in weight for ease of transport. Coir has proven to be excellent for this purpose, although freely drained garden soil (clay loam

Top down: Multiplication garden of stock plants of selected trees at Ringgi, Kolombangara, Solomon Islands. Poly-propagator system, Ringgi nursery, Kolombangara, Solomon Islands. PHOTOS: R. PAUKU

Six month old clone propagated from cutting, Ringgi nursery, Kolombangara, the Solomon Islands. PHOTO: R. PAUKU

or sandy loam), which may be sterilized, is also good. Coir must be heated to 100°C (212°F) for 30–45 minutes to prevent potential occurrence of fungal infection, and left overnight to cool down before use. This may be done using a 200 l (55 gal) barrel cut in half lengthwise and placed over a wood fire. During heating, the coir must be turned over thoroughly four or five times to ensure thorough heating throughout.

Hardening

Potted cuttings are weaned progressively from shade to full-sun over a period of 2–3 months. A shade level of 30–50% is best at first. Plants should be exposed to full sunlight for at least a month before field planting.

Approximate size at outplanting

When about 5–6 months old, cuttings usually have attained 30–50 cm (12–20 in) in height and are fit for field planting. Such plants have stem diameters of 4–5 mm (0.16–0.2 in) and more than five well formed leaves.

Other comments on vegetative reproduction

Propagules can also be obtained from air-layering. Air-layering can be done on primary, secondary, or tertiary branches, but this technique is especially suited for propagating mature shoots from pollarded trees that are difficult to root as stem cuttings. In Kolombangara, Solomon Islands, air-layers made on branches with a stem diameter of 5–14 mm (0.2–0.6 in) attained a 86% strike rate in 2–3 months. Coir or freely drained soil can be used as growth medium in the air-layering process.

Guidelines for outplanting

There is little if any research or experience on growing Tahitian chestnut in planted stands, although there is the time-tested experience of farmers growing trees within homegardens and villages. There are no clonal field plantings known.

DISADVANTAGES

The seeds are recalcitrant and can easily lose viability during international transport. This limits germplasm exchange between countries and reduces opportunities for comparing provenances.

The lack of appropriate postharvest extraction, drying, and storage of kernels at the village level may be a production constraint. Centralized extraction units may be impractical due to unreliable transportation. Deterioration of kernel quality before reaching market is of major concern. Lack of awareness of the potential economic benefits of the species may be limiting the cultivation of Tahitian chestnut.

Potential for invasiveness

The tree is unlikely to be an invasive species outside its natural range and does not appear to have potential to become a pest.

Diseases and pests

Very moderate infestation of leaf miners was found on seedlings at Ringgi nursery on Kolombangara Island, Solomon Islands. No major pests or diseases are known that attack mature foliage, although developing flowers and fruits are susceptible to fruit flies. The fruit flies lay eggs on the skin of immature fruits. As the eggs hatch the larvae burrow into the fleshy mesocarp and feed on the kernel, which deteriorates the eating quality. Severe fruit fly infestation may result in 100% loss of the edible kernel. Some types are more resistant to fruit fly infestation than others.

Top: Four-week-old air-layer on tree. Bottom: Rooted end after removal from the tree. Tututi, Kolombangara, the Solomon Islands. PHOTO: R. PAUKU

Host to crop pests/pathogens

No cases have been reported in the literature. However, fruit flies as well as cockatoos and flying foxes that feed on the mesocarp of fruits could potentially be drawn to other tree and field crops that are interplanted with Tahitian chestnut.

Other disadvantages or design considerations

Flatulence caused by eating the cooked kernels has a very offensive odor.

AGROFORESTRY/ENVIRONMENTAL PRACTICES

Tahitian chestnut is important in traditional agroforestry in Melanesia, Micronesia, and Polynesia. The tree grows well among other trees such as canarium nut (*Canarium* spp.), cutnut (*Barringtonia* spp.), oceanic lychee (*Pometia pinnata*), sea almond (*Terminalia catappa*), *Burckella obovata*, Malay apple (*Syzygium malaccense*), and other multipurpose trees that are either planted or protected in land boundaries, secondary forests, homegardens, and within the surroundings of human settlements. Although yet to be confirmed, it is probably a nitrogen-fixing tree that makes atmospheric nitrogen available within agroecosystems. Tahitian chestnut provides good shade and shelter.

Mulch/organic matter

Fallen leaves, flowers, and dead branches enrich surrounding soil.

Soil stabilization

The tree is rated high (by more than 60% of farmers interviewed in Kolombangara, Solomon Islands) for soil stabilization due to a good network of lateral roots including three or four structured buttresses at the base of the trunk. In Pohnpei, it was found that Tahitian chestnut stabilizes soils along the riverbanks and prevents rapid erosion (Kostka, pers. comm., 2004).

Crop shade/overstory

With appropriate spacing, the tree can provide medium shade that may be suitable for understory crops such as cocoa (*Theobroma cacao*), *Gnetum gnemon*, and betel nut (*Areca catechu*). It is also a good support tree for betel vine (*Piper betle*). Tahitian chestnut was reported in Pohnpei to provide suitable shade for the shade-loving giant taro (*Alocasia macrorrhiza*) (Kostka, pers. comm., 2004).

Homegardens

The tree is a good candidate species for inclusion in homegardens, particularly as a boundary line species for shade, windbreak, and a companion crop.

Improved fallows

Unlikely to be of importance for short-duration, high-density fallows.

Living fences

Highly suitable, especially for a rural pig fence at early stages of growth. The buttresses can be chipped off to accommodate the fencing.

Fence posts

Rated moderately suitable for fence posts because it is fairly durable as poles (10–15 cm [4–6 in] diameter). As sawn timber it may be more susceptible to termites.

Boundary markers

It makes a good boundary marker, although was less common traditionally than cutnut and canarium nut.

Windbreaks

The tree is a good medium-height tree for windbreaks because it tolerates strong winds and resists breakage.

Silvopasture

It ameliorates soils and recycles nutrients within silvopastoral systems and is probably a nitrogen-fixing species that can benefit grass pastures. A low planting density (10–15 trees/ha, 4–6 trees/ac) is recommended to avoid too much shading of pasture grass.

Woodlot

It is adaptable for mixed or single-stand species woodlots for the provision of edible nuts, medicinal products, and wood for handicrafts.

Native animal/bird food

Birds (e.g., cockatoos, parrots) and flying foxes feed on the fleshy mesocarp of fruits and the flower nectar.

Wildlife habitat

The tree provides a good wildlife habitat for some nesting bird species. It also provides habitat for red ants (*Oecophylla smaragdina*) that are a biological control of *Amplypelta cocophaga* (Hemiptera), a major pest of cocoa in the Solomon Islands.

Host plant trellising

It is a good trellis tree for betel vine and other lianas.

Bee forage

Bees forage on flowers and act as pollinators during flowering season.

Fish/marine food chain

The fallen kernels and mesocarps are food to some freshwater fish and prawns and potentially can be useful in fish farming.

Coastal protection

It was found in Choiseul, Solomon Islands, to provide very good coastal protection, especially for slowing down the shoreline erosion created by rise in tides. This has been observed, for example, along beaches and shorelines in Choiseul and the Kolombangara Islands.

Ornamental

Tahitian chestnut is an attractive evergreen tree with potential for use in urban centers for beautification while also providing shade and shelter. It is planted and protected in rural villages for such functions as well.

Other

Traditionally there are many ways of climbing huge trees with lengthy clear boles to harvest their fruits, nuts, or leaves. One method is to use neighboring trees that are easier to climb. As climbers reach the top of the companion tree, they can easily reach a branch of the taller tree or make a transfer by rope. Tahitian chestnut is a good medium-story companion tree that can provide access to the top of taller clear-bole species such as canarium nut (*Canarium* spp.), breadfruit (*Artocarpus altilis*), and sago palm (*Metroxylon salomonense*).

Young tree growing in homegarden, Tongatapu, Tonga. PHOTO: C. ELEVITCH

USES AND PRODUCTS

Almost every part of the plant has been used traditionally. Leaves and bark are mainly used for medicinal purposes, while fallen branches are used for firewood. Even green wood is burned to dry copra. The wood is also used for crafts, tool handles, canoes, and light construction.

Fruit

The fleshy mesocarp is inedible for humans.

Nut/seed

The edible kernel is an important indigenous food in many island countries in the Pacific. It is available in Vanuatu between the two yam seasons. The kernel is an important traditional supplemental staple in Fiji, although today its importance has declined in favor of cassava and imported rice.

The kernel must be cooked to make it edible. The nutritious kernels have protein and carbohydrate contents of about 5% and 22% respectively. It is prepared in many different ways, including roasting, grilling, boiling, baking, and mashed in pudding in PNG, Fiji, the Solomon Islands, Vanuatu, and Polynesia. Well known dishes include lap lap (Vanuatu), koko (Fiji), and masimasi or robe (the western Solomon Islands). Fruits are harvested either directly from the tree at maturity or from the ground after ripening. The kernels have been sold mainly in domestic markets.

Medicinal

The bark was grated and mixed with coconut milk or bark sap to treat urinary infections in the Solomon Islands. The juice from the mesocarp of green fruits was used in Tonga to treat insect bites and burns. In Fiji, all parts of the tree (roots, stem, bark, and leaves) were thought to have various medicinal properties.

Animal fodder

The kernel is a good feed for free-range chickens.

Beautiful/fragrant flowers

The flower buds can be used in short-term decorations.

Timber

The wood is of moderate quality and reported to be used for flooring in Temotu, Solomon Islands. Treating the wood with appropriate preservatives may provide protection against wood borers and increase its suitability for light construction purposes.

Fuelwood

Fallen branches and felled trees are good firewood when dried. Green wood also burns well and is used in Choiseul, Solomon Islands, for firewood to dry copra.

Craft wood/tools

The wood is used for carvings and tool handles in Fiji, the Solomon Islands, Vanuatu, and Tonga. The buttress is used in the Reef Islands (Solomon Islands) as a platform for dancing; when placed over a hole it provides a resounding tone.

Cooked nuts on skewers for sale at Nuku'alofa market, Tongatapu, Tonga. PHOTO: C. ELEVITCH

Canoe/boat/raft making

The wood is used for making canoes in Rennell and Bellona, the Solomon Islands. In Wallis, the leaves were sewn together to make sails for boats.

Wrapping/parcelization

The large leaves were traditionally used for wrapping and parceling throughout the Pacific islands. In Fiji, cooked kernels were wrapped with the leaves when sold in the market. In Tonga, the leaves were used for making belts.

Thatch/roofing/mats

In Tonga, the leaves were once used to cover the ground beneath mats.

URBAN AND COMMUNITY FORESTRY

Tahitian chestnut is rarely found in abundance in homegardens in the Solomon Islands. In Temotu province

LORE

In Samoa, it was believed that the human race originated from Tahitian chestnut (Kramer 1906 cited in Walter and Sam 2002). In Vanuatu, there is a myth that a man was emasculated and became the first woman after having hot Tahitian chestnut leaves applied to his genitals (Walter and Sam 2002). A myth in Choiseul (Varisi), Solomon Islands, relates Tahitian chestnut to the death of a man named Porana, who betrayed the Chief of a particular tribe. The people ate large quantities of the cooked kernels and the ensuing flatulence suffocated Porana in a packed meeting room from which he could not escape.

of the Solomon Islands, this species has been grown with other species such as mango (*Mangifera indica*) and sea almond (*Terminalia catappa*) as boundary-line crops in the Improved Temotu Traditional Agriculture (ITTA). The tree's medium stature makes it suitable for providing shade for parks and streets.

Size in an urban environment

It is a medium-size tree, typically growing to a mature height of 20 m (66 ft).

Rate of growth in a landscape

Seedlings can potentially reach 1–2 m (3.3–6.6 ft) height within a year in optimal growing conditions.

Root system

Roots of mature trees are unlikely to be invasive. However, it has a well developed lateral root system and, in old trees especially, the thin buttresses can extend for long distances. Surface roots are occasionally partly exposed as the soil erodes. Large lateral roots may interfere with other plantings within its surroundings.

Products commonly used in a Pacific island household

The nuts are widely used for food in many Pacific island countries. Leaves, bark, and sap are important traditional medicines. The wood is used for making tool handles and canoes, and in a dry form as firewood. Green wood is also used for firewood, mainly for drying copra.

Light requirements

It is mid-story tree tolerant of light to moderate shade. Heavy shading is detrimental to growth and yield. Its dense foliage prevents other species from growing directly under its canopy.

Water/soil requirements

The tree is adapted to poorly drained soils and even permanently waterlogged locations, although it grows even in soils with low water retention capacity (e.g., sandy soils). Mature trees may withstand a prolonged dry spell but may never experience one in their native habitat.

Life span

The life span is 80–90 years.

Varieties favored for use in a homegardens

None.

Maintenance requirements

Mulching may be necessary at the early seedling stage. In mature trees, it is not required. Tall and old trees may be pruned to rejuvenate the tree physiologically and encourage new vegetative growth, but fruit production is initially greatly decreased.

The tree is very suitable for urban areas where people make use of the fruit. Tongatapu, Tonga. PHOTO: C. ELEVITCH

Hazards

Under normal circumstances there are no hazards from leaf, branch, or fruit drop. Trees that are considered to be too tall for a particular situation may be pollarded to reduce height and ensure safety around homes and in villages. The kernel is toxic raw and must be cooked to be edible. If not attentive, a person could slip and fall by stepping on a fruit.

Common pest problems

No major pests and diseases affect young seedlings. However, fruits can be severely attacked by fruit flies, resulting in low kernel production per tree. Fruit fly traps containing a lure (pheromone) and impregnated with insecticide may be placed at random on trees 50–100 m (165–330 ft) apart. The technique is expensive but reasonably effective in the Solomon Islands against melon fly. Encouraging farmers to plant less susceptible varieties is recommended for locations suffering from fruit fly infestation.

COMMERCIAL PRODUCTS

The kernel is the primary commercial product. In Fiji it is estimated that around 35 mt (38.5 t) are sold in domestic markets annually, fetching about US$28,000 or US$0.80/kg (US$0.36/lb). In the Solomon Islands, kernels are sold fresh for US$0.15 to US$0.30 per kg (US$0.07–0.14/lb) during peak seasons. The domestic market for the product of this species can be increased if processing technology to improve the shelf life of the kernel is developed. A market study in Fiji revealed export opportunities to Polynesian communities in Australia, New Zealand, and the U.S. However, while export markets may be an option, success cannot be fully realized without additional research in postharvest processing, storage, conservation, and tree improvement.

Farmers should plant new trees instead of relying solely on wild populations for increased food security and meeting market demand. Research into developing superior cultivars should be a priority to maximize benefits to farmers in terms of monetary return and sustainable supply of edible kernels for household consumption.

Spacing

Suggested spacing is 5 x 5 m (16 x 16 ft) or 400 trees/ha (162 trees/ac). A 1-hectare block (2.5 ac) can potentially produce 4–30 mt (4.4–33 t) of fresh fruits per peak season. A plantation area of 100 ha (250 ac) from one farm or several combined could yield 400–3000 mt (440–3300 t) of fresh fruits per year. Based on a kernel to fruit ratio of 60%, such a quantity would provide 240–1800 mt (264–1980 t) of fresh kernels per year and is likely to support an export market.

In agroforestry systems, 40 trees/ha (16 trees/ac) interplanted with other species is suggested. This is estimated to give about 0.4–3 mt (0.44–3.3 t) fresh fruits or 0.2–1.8 mt (0.22–2.0 t) fresh kernels per ha (2.5 ac).

Management objectives

Pollarding stimulates vegetative growth of trees, but fruit set in reproductively mature trees will drop in the following year due to loss of the woody framework. No thinning is necessary if wide enough spacing is used, unless trees require replacement due to infertility. Weeding is crucial at an early age (first 2–3 years in the field). As the trees mature, weeding operations may be scaled down to once a year (mostly vine removal). The requirements for field fertilization are unknown but application of slow-release fertilizers at the nursery stage should provide nutrients for the seedlings to compete well in their new environment in the first 6 months.

Advantages and disadvantages of growing in polycultures

The tree has been grown under other overstory species, such as coconut (*Cocos nucifera*), canarium nut (*Canarium* spp.), breadfruit (*Artocarpus altilis*), narra (*Pterocarpus indicus*), sago palm (*Metroxylon salomonense*), and *Flueggea flexuosa*, and it provides a balanced ecosystem through soil amelioration and consolidation. It may also provide easy access for climbers to harvest difficult-to-climb species such as sago palm. Older trees are not always easy to climb, because they sometimes have fluted or clear boles up to half their height. When incorporating Tahitian chestnut into a polycultural system, careful consideration is needed to take into account potential interference from the lateral root system and shade.

Yields

Based on limited data, the potential yield for trees in the Solomon Islands is 4–30 mt/ha (1.8–13.4 t/ac) fresh fruit annually at a density of 400 stems/ha (162 stems/ac). Annual yields are estimated to increase with age. For example, a 5–10-year-old tree is estimated to produce 10 kg (2.2 lb) fresh fruits per tree, increasing to 75 kg (165 lb) fruits per tree older than 25 years. Usually, fruiting begins after 5 years, but some plants bear fruits on the third year from planting. Thus, yield estimates for 5–10-year-old trees at a spacing of 400 stems/ha (162 stems/ac) is 4 mt (4.4 t) of fresh fruits. With that planting density, the yield is estimated to increase up to eight-fold by the time the trees reach 25 years old. Because fresh kernel is about 60% of fruit weight, the potential annual kernel production is 5 mt (5.5 t) in a 1-ha (2.5 ac) block of 5–10-year-old trees.

Processing required

The common method for extracting kernels is to cut through the fruit with a sharp knife. The use of mechanical methods is possible but cannot be done unless uniformity in fruit size is achieved, and this will only occur through the development of cultivars with desirable fruit and/or kernel qualities. In a commercial sense, farmers would be better off extracting kernels on-farm in order to fetch a higher market price, but this requires appropriate storage facilities located in rural villages.

On-farm processing methods

In Vanuatu, fruits are dried on bamboo racks in darkness and stored for several months. These fruits are turned regularly, and as they become dry the kernels are removed. Also in Vanuatu, the fruits may be buried or stored between layers of grass. In Fiji, the Solomon Islands, and Polynesia, fruits are smoked and roasted for longer storage. Extracted kernels that have been boiled or roasted do not store longer than a few days. Limited shelf life of the product necessitates the establishment of central processing and storage units within a rural setting accessible to farmers. This requires personnel training and enforcement of quality standards to meet export market requirements.

Market

Ideally, plantings should be connected by feeder roads and accessible to reliable transportation links to major markets within the area. Strengthening domestic markets for Tahitian chestnut products is more logical and feasible than vigorously pursuing export markets. On the other hand, more market research is required in order to develop niche international markets for the long term. Potential export markets to Polynesian communities in New Zealand, Australia, and the U.S. could be a market opportunity. Greater attention needs to be drawn to the rapid deterioration of the kernel and how it can be preserved to meet export market qualities and standards. Other issues of concern are consistency and continuity of supply, high-quality end-products, and packaging. There may be opportunities in the future for organic certification to diversify export markets.

INTERPLANTING/FARM APPLICATIONS

In general, Tahitian chestnut is not extensively cultivated in the Pacific, although it is commonly found in homegardens and within coconut plantations on many Pacific islands. The species has a well formed lateral root system that could cause some impediments during soil preparation for understory crops, e.g., during plowing or mounding.

Example system

Location

Temotu, Solomon Islands.

Description

The Improved Temotu Traditional Agriculture (ITTA) system was developed in the 1980s. The system uses 23 different crop species within a 0.5 ha (1.25 ac) block at appropriate spacing. The placement of crops at different positions within the planting block is crucial due to the inevitable competition between species for water, light, and nutrients. For example, boundary-line tree crops such as Tahitian chestnut and sea almond (*Terminalia catappa*) over 25 years old yielded 75 kg and 60 kg (165 lb and 132 lb) fresh fruit per tree, respectively. In the space between the planting rows and the boundary line, tree crops such as *Barringtonia* spp. and *Gnetum gnemon* of about the same age yielded 13 kg and 25 kg (29 lb and 55 lb) of fresh fruits per tree, respectively. Yield also varies for different root crop species interplanted in the system. Yam (*Dioscorea* spp.) production, for example, is 37 mt/ha (16.5 t/ac) compared to 12.3 mt/ha (5.5 t/ac) of giant taro (*Alocasia macrorrhiza*).

Crop/tree interactions

Crop-to-crop interaction exists between the species in terms of shade, shelter, and the improvement of soil structure. However, the level of interactive benefits derived from each species in this system is very much dependent upon correct spacing and species choice.

Spacing

Spacing of 10 x 10 m (33 x 33 ft) or 100 trees/ha (40 trees/ac) between trees has been suggested. The spacing varies with species and the appropriate placement of different crops within different planting rows. For example, companion crops are usually planted at least 1 m (3.3 ft) from the main tree.

GENETIC RESOURCES

A few clones have been developed at Ringgi, Kolombangara Island, in the Solomon Islands, by the author.

PUBLIC ASSISTANCE AND AGROFORESTRY EXTENSION

Extension offices for agroforestry and forestry in the Pacific: http://www.traditionaltree.org/extension.html

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Inocarpus fagifer (Tahitian chestnut)

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Acknowledgments: The author and publisher thank Dale Evans, Roger Leakey, Diane Ragone, and Art Whistler for their input. Photo contributions by Roger Leakey are greatly appreciated. The author thanks farmers in Kolombangara Island for allowing their tree resources to be studied. The author also gratefully recognizes the sponsors of his *Inocarpus* research: Australian Centre for International Agriculture Research (ACIAR), Rainforest Cooperative Research Centre (CRC), James Cook University (JCU) and Kolombangara Forest Products Limited (KFPL).

Recommended citation: Pauku, R.L. 2006. *Inocarpus fagifer* (Tahitian chestnut), ver. 2.1. In: Elevitch, C.R. (ed.). Species Profiles for Pacific Island Agroforestry. Permanent Agriculture Resources (PAR), Hōlualoa, Hawai'i. <http://www.traditionaltree.org>.

Sponsors: Publication was made possible by generous support of the United States Department of Agriculture Western Region Sustainable Agriculture Research and Education (USDA-WSARE) Program; SPC/GTZ Pacific-German Regional Forestry Project; USDA Natural Resources Conservation Service (USDA NRCS); State of Hawai'i Department of Land & Natural Resources Division of Forestry & Wildlife; and the USDA Forest Service Forest Lands Enhancement Program. This material is based upon work supported by the Cooperative State Research, Education, and Extension Service, U.S. Department of Agriculture, and Agricultural Experiment Station, Utah State University, under Cooperative Agreement 2002-47001-01327.

Series editor: Craig R. Elevitch

Publisher: Permanent Agriculture Resources (PAR), PO Box 428, Hōlualoa, Hawai'i 96725, USA; Tel: 808-324-4427; Fax: 808-324-4129; E-mail: par@agroforestry.net; Web: <http://www.agroforestry.net>. This institution is an equal opportunity provider.

April 2006
ver. 3.1

Intsia bijuga (vesi)

Fabaceae (legume family)

***choyo*, *show*, *kebuk* (Pohnpei); *cohu*, *faux teck* (French); *dort*, *thort*, *zort*, *zolt*, *show*, *wantal* (Yap); *dort*, *wantal* (Palau); *fehi* (Tonga); *fesi* (Rotuma); *kwila*, *iban*, *mboan*, *bon*, *menau* (Papua New Guinea); *ifilele* (Samoa); *ifit*, *ifet*, *ipil* (Guam and Mariana Islands); ipil, Moluccan ironwood, Borneo teak (English); *kohu* (New Caledonia); *kubok*, *kubuk* (Marshall Islands); *kuren*, *nityanmis*, *tuamis* (Chuuk); *natora* (Bislama, pidgin), *tora*, *tor*, *atora*, *nator*, *n'tor* (Vanuatu); *u'ula* (Kwara'ae), *nyia nwola*, *vei*, *nkengia*, *kivili*, *huhula*, *rurula*, *gugura* (Solomon Islands); *vesi*, *vehi*, *vesiwai*, *vesi dina* (Fiji)**

Randolph R. Thaman, Lex A. J. Thomson, Robin DeMeo, Francis Areki, and Craig R. Elevitch

IN BRIEF

Distribution Primarily in Southeast Asia and found on many islands of Melanesia, Micronesia, and Polynesia.

Size Typically reaches 7–25 m (23–82 ft) at maturity, usually with a single trunk.

Habitat Favors coastal and lowland forest, on well drained or swampy sites, especially on limestone, 0–450 m (0–1480 ft) with rainfall of 1500–2300 mm (60–90 in).

Vegetation Associated with mangroves, limestone forests, riverine forests, some atoll forests on wetter atolls, and lowland coastal forests.

Soils Grows in light, medium, and heavy soils; tolerates soils with impeded drainage and seasonally waterlogged, shallow, saline, sodic, and limestone (calcareous) soils, often growing on bare limestone on upraised limestone islands.

Growth rate Moderate growth rate, <1.5 m per yr (5 ft/yr).

Main agroforestry uses Coastal protection, windbreak, coastal soil stabilization, ornamental, living fence.

Main products Timber, medicinal, fuelwood, and craftwood for high-quality carving.

Yields Timber production data unavailable.

Intercropping Rarely used in farm cultivation.

Invasive potential Not considered to be invasive.

PHOTO: C. ELEVITCH

Vesi has a spreading form especially when grown in the open, as seen here in this young tree.

INTRODUCTION

A spreading tree up to 40 m (130 ft) tall, vesi (*Intsia bijuga*) is undoubtedly one of the most highly valued trees in the Pacific islands, both in terms of its traditional cultural importance and its value for commercial timber. Its durable, easy-to-work, attractive dark red-brown wood is especially favored for use in house building, furniture, and woodcarving. It is in very high demand and decreasing in abundance in most locations due to overexploitation for house posts, canoe making, and for woodcarving of valuable cultural artifacts such as kava bowls and weapons, and due to indiscriminate modern commercial logging.

In addition to the wide cultural use of its timber throughout its range, it also has potential as a boundary marker or living fence post, for the production of fuelwood (from its branches when harvested for timber or woodcarving), as well as for its considerable medicinal value.

Vesi tolerates a very wide range of environmental conditions. It grows in rough limestone terrain, in sandy and muddy coastal soils, and on the inner margins of mangroves in very dry climates as well as in seasonally wet coastal windward habitats and along freshwater streams at considerable distances inland, sometimes along ridges.

It is a tree that should be considered under threat. Human population pressure, extensive traditional use, and increasing logging and commercial production of kava bowls and other artifacts for sale to the expanding tourist market, coupled with the lack of a tradition of replanting, have rendered exploitation of current populations unsustainable. There is a critical need for systematic propagation and replanting programs to address the situation.

It is a tree that should be replanted in forestry and agroforestry schemes, even though it is relatively slow growing. It could also be considered for coastal reforestation programs because of its adaptability to coastal habitats, and it is an excellent tree for roadside plantings, urban areas, and tourist resorts. It also has considerable potential as an ornamental, given its attractive glossy green leaves and beautiful orchid-like flowers. It could also be tested on the larger wetter islands of Kiribati and Tuvalu, as it seems to grow well on some of the wetter atolls of the Marshall Islands to the north and Kapingamarangi Atoll to the west in Pohnpei state of the Federated States of Micronesia.

DISTRIBUTION

Native range

Vesi is native to the western Pacific and Indo-Malaysian region, from New Guinea and Palau in the west to Fiji, Tonga and Samoa in the southeast, and to the Mariana, Caroline and Marshall Islands in the north and northeast in the Pacific. It is found in Madagascar, the Seychelles, Indonesia, Malaysia, Thailand, Philippines, Papua New Guinea, and Australia. The typical habitat is lowland areas, riparian zones, or strand and inner margins of mangroves; it is also found on limestone soils and rocky coastal outcrops. Vesi is the dominant species in some areas of limestone forest on the Isle of Pines in New Caledonia and on the limestone islands of Kabara and Fulaga in Fiji.

Current distribution

It is found in its native range of Madagascar, the Seychelles, Indonesia, Malaysia, Thailand, Philippines, Papua New Guinea, Guam, Australia, New Caledonia, Solomon Islands, Vanuatu, Fiji, Samoa, and Tonga, and in Micronesia to Palau, Yap, Chuuk, Pohnpei, and the Marshall Islands. In some islands, particularly in the easternmost extent of its range, it could be an aboriginal or early post-European-contact introduction; e.g., in the Marshall Islands and Tonga. For example, the only reported presence of it in Tonga was by Yuncker on the uninhabited volcanic island of Kao on the margin of forest near an abandoned plantation, as well as in cultivation on other islands in more recent times.

BOTANICAL DESCRIPTION

Preferred scientific name

Intsia bijuga (Colebr.) O. Kuntze

The botanical name stems from the word *intsia*, an Indian plant name; the species name *bijuga* comes from the Latin *bi*, meaning two, and *juga*, meaning yoked, referring to the pairs of joined or yoked pinnae.

Family

Fabaceae (legume family), subfamily Caesalpinoideae

Non-preferred scientific names

Afzelia bijuga (Colebr.) A. Gray
Afzelia cambodiensis Hance
Afzelia retusa Kurz
Albizia bijuga (Colebr.) A. Gray
Eperua decandra Blanco.
Intsia cambodiensis (Hance) Pierre
Intsia amboilensis DC.
Intsia madagascariensis Thouars ex DC.
Intsia retusa (Kurz.) O.Kuntze
Macrolobium bijugum Colebr.

Common names

Pacific islands

choyo, *show*, *kebuk* (Pohnpei)
cohu, *faux teck* (French)
dort, *thort*, *zort*, *zolt*, *show*, *wantal* (Yap)
dort (Palau)
fehi (Tonga)
fesi (Rotuma)
kwila, iban, *mboan*, *bon*, *menau*, *arir*, *ariri*, *babili*, *babrie*, *bat*, *bauw*, *bendoro*, *bon*, *duhum*, *epna*, *ferraai*, *ganam*, *gommagome*, *haboe*, *haero*, *jep*, *kaboei*, *amele*, *mep*, *milimbu*, *paseh*, *patoem*, *pian*, *pota*, *rang*, *raung*, *rong*, *seka*, *tangibe*, *wohne*, *yambwan* (Papua New Guinea)
ifilele (Samoa)
ifit, *ifet*, *ipil* (Guam and Mariana Islands)
ipil, Moluccan ironwood, Borneo teak (English)
kohu (New Caledonia)
kubok, *kubuk* (Marshall Islands)
kuren, *nityanmis*, *tuamis* (Chuuk)
natora (Bislama, pidgin), *tora*, *tor*, *atora*, *nator*, *n'tor*, *nitortat*, *nato*, *tou*, *nip*, *niv*, *ni-iv*, *we-iv*, *nipf*, *kimau*, *hmau*, *umau*, *nakumau*, *purkam*, *botpamau*, *vumalatora*, *noghuma*, *leav, hive*, *ntarauvi*, *liv*, *vutora*, *nator*, *aivornarat*, *ekmau*, *nokomo*, *nokmo miel* (Vanuatu)
u'ula (Kwara'ae), *nyia nwola*, *vei*, *nkengia*, *kivili*, *huhula*, *rurula*, *gugura* (Solomon Islands)
vesi, *vehi*, *vesiwai*, *vesi dina* ("true vesi") (Fiji)

Other regions

ipil, *ipeh*, *ipil tandok*, *malapari*, *merbau ayer*, *merbau changkat*, *merbau laut* (Malay Peninsula)
ipil, *ipil laut* (Philippines: Tagalog)
merbaoe, *merbau*, *merbo*, *taritish* (Java)
merbau (trade name)
merkau, *merkau ajer* (Sumatra)
pradwu thale, *lumpho-thale* (Thailand)

Form

Normally 7–25 m (23–82 ft) at maturity, and in exceptional cases reaching 40 m (130 ft), with a spreading canopy; the bright green foliage often grows in subcrowns. The tree grows upright in full sun (100–75% sun) and spreading in shade (50–25% sun). The trunk can attain 0.5–1 m (1.6–3.3 ft) or more in diameter, with small buttresses. The bole is usually straight and long, although it is often crooked and leaning in coastal situations. Its bark is a distinctive light pinkish to reddish brown, weathering to light gray, smooth overall, slightly dappled, peeling in irregularly sized scales (exposing fresh color underneath), sometimes flaky. The inner bark is light pinkish brown grading to light yellow brown on the wood; sapwood is white; heartwood is red-brown.

Flowers

Vesi trees each have both male and female flower parts (bisexual). Individual flowers are moderately large with four greenish sepals, corolla reduced to one large petal, three stamens with seven staminodes. The petal is white (with red center) or pink to purple or red. Flowers occur in axillary or terminal corymbose panicles. In PNG, flowers have been observed year-round, with a peak in August around Madang. Flowers are reported in May–June in Vanuatu and October–May in Fiji, and April–November in Samoa. Insects (such as bees), birds, and wind are considered to be the major pollinators.

Top: Pinkish-purple flowers. PHOTO: R. DEMEO **Bottom: White to rose-purple flowers.** PHOTO: L. THOMSON

Leaves

Vesi's bright, shiny, light-green foliage distinguishes the tree from others in the forest. The leaves are pinnately compound, usually with four leaflets each 8–15 cm (3.1–4.6

Left: Vesi's paired (even-pinnate) terminal leaflets. PHOTO: R. THAMAN **Right: Immature pod and mature seed.** PHOTO: C. ELEVITCH

in) long, broadly elliptic, asymmetrical and medium to dark green. Two terminal leaflets are very distinctive and hanging. Although vesi trees are evergreen, they tend to loose their leaves periodically due to infestation of the species-specific psyllid *Insnesia glabrascuta*, where present.

Fruit

Fruits are thick, rigid, oblong, or pear-shaped pods up to 10 cm (4 in) wide and up to 30 cm (12 in) long. Each pod contains two to eight dull-brown, rounded, flattened seeds about 2–4 cm (0.8–1.6 in) wide, with hard seed coats. In PNG, fruiting has been reported in all months, with a peak in February. Fruiting is reported to be around December–January in Vanuatu and between April and October in Fiji. In Samoa fruiting has been observed in October–February and June–July and probably occurs in all months of the year.

Rooting habit

Mature trees of the species have wide buttresses which, when fully developed, may exceed 4 m (13 ft) wide. Some may also demonstrate a slight root swelling, which depends upon site conditions. As the tree becomes larger it requires sufficient minerals and support to sustain growth. A fibrous system would not work, so the woody roots expand vertically, forming radial walls (buttresses) extending out from the sides of the trunk. This root system enables the tree to cover the large and often thin layer of soil typical of tropical environments or rock/limestone islands. This feature is considered a competitive advantage that prevents the establishment of competing individuals in the space occupied by the buttresses and provides additional tensile force to resist uprooting during cyclones.

Similar species

In the forests of Palau, vesi is easily distinguished by the leaf shape and color, which stand out from the rest of the forest canopy. The asymmetrical leaflet pattern, with the two terminal leaflets, is a very strong field identification characteristic for this species in its native forests.

Another legume closely related to vesi and similar in appearance is *Kingiodendron platycarpum*, which is endemic to Fiji. Vesi can be distinguished from *Kingiodendron* by the slightly more rounded, almost opposite leaflets and terminal, attractive, white and pink to purple flowers, compared to the alternate leaflets and axillary green to dull cream-colored flowers of *Kingiodendron.*

The genus *Intsia* is closely related to *Afzelia*, and it is difficult to assign botanical specimens lacking flowers or fruits to either genus. *Intsia* differs from *Afzelia* by *Intsia*'s three fertile stamens, its flat seeds lacking an aril, and its leathery pods.

GENETICS

Distribution of the genus

The genus *Intsia* comprises two species, *I. bijuga* and *I. palembanica*. *Intsia bijuga* is the more widely distributed species and the only species of this genus that occurs in the Pacific islands to the east of Papua New Guinea. *Intsia palembanica* is widespread in Southeast Asia, extending eastwards as far as the island of New Guinea. Several species formerly included under *Intsia* have been transferred to the genus *Afzelia*.

Variability

The species *Intsia bijuga* has two described forms, *glabra* and *hirsuta*, which are considered to be local modifications of little significance (Smith 1985). In Samoa, where it is used as a favored house post and for furniture and kava bowls, several varieties are recognized based on wood properties (color, hardness, and grain straightness), including *ifilele ulu, ifilele o'a, ifilele ala'*a, *ifi toa*, *ifi'ulu, ififatu,* and *ifisoga.* The most common are ifi toa, which has a hard, dark grain, and ifi 'ulu, which has a smooth light colored grain. In Kabara, in Fiji's Lau Islands, where carving of vesi into kava bowls is the main source of income, there is a similar discriminations of int vesi, which has a darker and harder grain, and vesi uto, which has a lighter color and softer grain and is easier to carve. Vesi is considered to be one of the priority species for conservation and genetic improvement in Samoa due to its local importance for woodcarving and its threatened status in the wild. In Fiji (Kabara Island), the conservation management of vesi requires monitoring the rate of consumption by local people through keeping records of handcraft production and educating people about the need for conservation.

Vesi in the forest of Palau, it's bright green foliage clearly standing out. PHOTO: R. DEMEO

ASSOCIATED PLANT SPECIES

Vesi is associated with mangroves, coastal forests, limestone forests, riverine forests, and lowland coastal and ridge forests on volcanic islands. It is also found in some atoll forests on wetter atolls and in areas of degraded forest and in tree groves in shifting agricultural areas, such as in New Caledonia and Vanuatu, where the tree is still quite common.

Associated native species commonly found

Commonly associated species in limestone forests include, depending on the location, *Pisonia grandis*, *Manilkara dissecta*, *Diospyros elliptica*, *Excoecaria agallocha*, *Cynometra, Maniltoa* spp., *Vavaea amicorum*, *Planchonella grayana, Elattostachys falcata, Polyalthia amicorum*, *Santalum* spp., and *Ficus* spp. In coastal atoll forests, where it might be an introduction, it can be found with *Neisosperma oppositifolia, Pandanus tectorius*, and other inland species. In mangrove associations, it can be found with *Barringtonia asiatica*, *Milletia* (*Pongamia*) *pinnata*, *Inocarpus fagifer, Hibiscus tiliaceus, Thespesia populnea, Xylocarpus granatum, X. moluccensis*, and *Heritiera littoralis*.

Associated introduced species

In some areas, either where vesi has been deliberately planted or protected in fallow vegetation or secondary forest, such as in New Caledonia, it can be found with other aboriginally introduced trees, such as candlenut (*Aleurites moluccana*) and ylang ylang (*Cananga odorata*). In some places, such as New Caledonia, Vanuatu, and Vava'u, Tonga, vesi is sometimes found

Vest growing in a secondary forest on Isle of Pines, southern New Caledonia. PHOTO: R. THAMAN

planted in villages in houseyard gardens or protected in tree groves along with a range of other useful cultivated species.

ENVIRONMENTAL PREFERENCES AND TOLERANCES

Climate

Vesi has a wide range of environmental and climatic tolerances. It prefers wet, hot climates but can tolerate annual dry seasons. The tree occurs most frequently in coastal and lowland forest on well drained or swampy sites. It is also found in tropical rainforest, in primary or old secondary forests, and in open forests. The species also occurs in wet ground on the inner edge of coastal mangrove swamps. The tree grows particularly well on dry leeward sides of main islands or in seasonally dry areas in dry forest, often up to elevations of 450 m (1480 ft), but is also found in coastal and riparian forest and occasionally in inland forest on the drier, leeward sides of both large and small islands. It is particularly dominant on well drained limestone soils and rocky outcrops in coastal areas that suffer from drought.

Elevation range

0–450 m (0–1480 ft)

Mean annual rainfall

1500–2300 mm (60–90 in)

Rainfall pattern

It grows best in climates with bimodal and uniform rainfall patterns.

Dry season duration (consecutive months with <40 mm [1.6 in] rainfall)

0–4 months, very drought resistant.

Mean annual temperature

26–27°C (79–81°F)

Mean maximum temperature of hottest month

23–33°C (73–91°F)

Mean minimum temperature of coldest month
20–31°C (68–88°F)

Minimum temperature tolerated
17°C (63°F)

Soils
Grows particularly well on well drained, high-pH (alkaline) soils, particularly limestone and recent basaltic soils (e.g., on the limestone islands of eastern Fiji, the Isle of Pines in New Caledonia, and in the young basalt soils of north-central Savai'i, Samoa). It also does well as a riparian species and in poorly drained soils on the inner margins of mangroves. The species is said to prefer saline soils (i.e., near coastal regions), although there are populations of vesi that grow well inland in Papua New Guinea and Fiji.

Soil texture
The tree grows in light, medium, and heavy soils.

Soil drainage
Vesi can grow in soils with free drainage as well as soils with impeded drainage and seasonally waterlogged soils.

Soil acidity
It tolerates soils with neutral and alkaline acidity (pH 6.1–7.4+).

Special soil tolerances
Vesi tolerates shallow, saline, sodic, and limestone (calcareous) soils and is commonly found growing on almost soilless limestone outcrops

Tolerances

Drought
It seems to be particularly tolerant of drought, especially the physiological drought characteristic of well drained, rocky limestone habitats.

Full sun
It grows well in full sun in exposed situations.

Shade
The tree tolerates 0–75% shade.

Frost
Vesi does not tolerate freezing temperatures.

Waterlogging
It seems to withstand a high degree of waterlogging, as it is a common component on the inner margins of mangroves and in riparian vegetation.

Salt spray
It has a high tolerance of salt spray, although it is rarely found in the outermost zone of coastal vegetation.

Wind
Vesi is very resistant to wind damage and well adapted to strong gusts in coastal locations and on rock outcrops.

Other
The tree withstands termite attack.

Abilities

Fix nitrogen
The tree has been recorded nodulating with rhizobia of the cowpea type (Allen and Allen 1981).

Regenerate rapidly
Vesi is relatively slow growing and does not regenerate quickly.

Self-prune
The trees typically have a main trunk free of lower side branches, indicating good self-pruning characteristics.

GROWTH AND DEVELOPMENT
Growth rate varies according to the environmental conditions where the species is located. Growth ring boundaries for the species are often indistinct, making growth rate calculations difficult.

Growth rate
The species is in general slow growing, even after an initial phase of rapid growth, and it may take up to 75–80 years to mature. Trial plots in the Solomon Islands using germinated seeds or collected wildings recorded 2 m (6.6 ft) per year in height for the fastest growing individuals. In Bogor, Indonesia, 8-year-old seedlings attained an average height of 10.7 m (35 ft) and diameter of 15 cm (6 in). The average height growth increment in Samoa during the first 3 years was 77 cm (30 in) per year, but thereafter height growth decreased. Studies by Whistler in Samoa in 1994 showed that vesi had a growth rate of 14–18 mm (0.55–0.62 in) in diameter per year (over 14 to 22 years).

Yields
Apart from early growth data, yields over the life cycle of

Trunks of two vesi trees in well drained portion of a mangrove swamp, Valolo Island, Rewa Delta, southeastern Viti Levu, Fiji Islands. PHOTO: R. THAMAN

vesi are not known. Currently harvests are primarily from native stands, which have led to depletion of natural populations to the point of disappearance of the species in many areas.

Reaction to competition

The tree is slow growing compared with many pioneer species, and requires good early maintenance to keep weeds at bay.

PROPAGATION

Vesi is easily propagated by seeds or transplanted seedlings/wildlings. Cuttings from mature trees have been successfully propagated, although this method is rarely used.

Propagation by seed

Propagule collection

Because healthy, mature vesi seeds have a hard seed coat that is resistant to germination under normal circumstances, viable seeds can usually be found in their pods or loose on the ground under trees. Mature seeds are medium brown in color and hard when pressed with the thumbnail. Collect seeds from under trees that have good health and form. Healthy-looking seeds less than a year old usually have high germination.

Propagule processing

The seeds are large (about 160–225 seeds/kg [73–102 seeds/lb]) and are easy to clean in water or a sieve to remove soil or decaying organic matter.

Seed storage

The seeds are orthodox, i.e., they retain viability after drying. Before storing, the seeds should be well dried to less than 10% moisture. At this moisture level, the seeds will remain viable for up to 3 years, which can likely be extended by storing with a desiccant in an airtight container in a refrigerator or freezer. Cleaned and dried seeds require no special treatment for long-term storage.

Pre-planting seed treatments

Without pretreatment, most vesi seeds will not germinate in a timely fashion, even under ideal germination conditions, due to their hard seed coat that keeps water from entering the seed. Without special pretreatment to break the impervious seed coat, only a small percentage of seeds will germinate spontaneously within a reasonable time. The most practical method of treating the seed coat (scarification) is to file or nick through the outer seed coat on the edge of the seed opposite the hilum (the small mark on the edge of the seed where it was once attached to the seed pod). A small triangular file works well; even more efficient is a large nail clippers. A shallow nick just through the outer surface suffices. After nicking, soak the seeds in cool water for 24 hours to ensure the seeds swell with water.

Growing area

Seeds germinate best in full sunlight, although partial shade will work fine. Seedlings adapt to various light and shade levels. Studies of the growth rate (measured in increase in dry weight) at light levels of 100%, 76%, 47%, and 24% showed that 76% gave the best growth of seedlings.

As with most seeds, protection from driving rains is recommended, which is why a shade house with a translucent plastic cover is often used.

Germination

Planting the seeds on edge with the hilum down helps ensure that the seed coat is shed as the growing shoot emerges. Dipping or dusting the seeds with a fungicide just before sowing may help prevent fungal infections. Fresh seeds generally have a germination rate over 90% and will emerge 7–11 days after sowing.

Media/containers

Because of the rapid germination and early growth of vesi seedlings, a rather large container works best. A minimum container volume of 250 ml (about 1 cup) is recommended. To avoid root spiraling, a root-training container is best. The potting medium should be well drained to help prevent fungal diseases. Inoculation with a select rhizobia strain should take place within 2 weeks of germination. If a select strain is not available, a cowpea type inoculant may serve as an adequate substitute, but nitrogen fixation is not guaranteed. Low available nitrogen is important to encourage the symbiotic relationship with N-fixing bacteria. Ample P and micronutrients also support nitrogen fixation and the development of a sturdy stem.

Time to outplanting

Seedlings grow quickly and are ready for outplanting in about 12 weeks.

Approximate size at time of outplanting

An average height of 25–40 cm (10–16 in) is recommended for outplanting. If low available N and high P are used, the stem should have become woody at the base and have a diameter of 10–15 mm (0.4–0.6 in). A strong, short stem is better for outplanting than a tall, weak stem.

Other comments on propagation

The tree is rarely deliberately planted at the community level in the Pacific islands, although replanting should be promoted in order to increase populations in overexploited areas.

DISADVANTAGES

Vesi is relatively slow growing and requires good maintenance during the first few years to reduce competition from weeds. For timber production, the tree is considered to reach a harvestable age at 50–60 years, which is a very long rotation length for a tropical timber tree.

Potential for invasiveness

Vesi is not considered to be invasive.

Pests and diseases

Insnesia glabrascuta, a species-specific psyllid, is problematic in Guam but not in Palau. *Phellinus noxius*, a fungal disease that induces root and crown rot of woody plants throughout the tropics, is considered a major threat to native trees including vesi in Samoa. As a coastal tree, vesi is exposed to periodic cyclones. Damage to branches can facilitate disease. Ants or other insects easily attack the pods. Crabs can also do some damage to harvested logs that are allowed to lie on the ground for long periods. The species has been shown to be susceptible to the following parasitic nematodes: *Rotylenchulus*, *Helicotylenchus*, *Meloidogyne*, *Criconemoides*, and *Hemicriconemoides* at Laguna, Philippines. Vesi was also proved repellent to termite (*Cryptotermes cynocephalus*).

Other disadvantages

Because of its long rotation time, it is questionable whether vesi is an economically viable timber tree.

AGROFORESTRY/ENVIRONMENTAL PRACTICES

Soil stabilization

Vesi is suitable for erosion control, especially along creeks and waterways on the inland side of mangroves.

Crop shade/overstory

The tree has some potential to be used for crop shade.

Homegardens

It makes a good shade tree in homegardens, although its large size may make it unsuitable for urban areas.

Improved fallows

Vesi can be used to regenerate land, especially land degraded by gully erosion. In addition to being a nitrogen fixer, the tree is known to have high uptake of subsoil calcium and to enrich calcium levels in the surface soil, resulting in higher soil pH (ICRAF 2004).

Living fences

The species is not currently used for planting living fences and is unsuitable due to its spreading form and slow growth in the open.

Boundary markers

Vesi is very easily distinguished from other forest trees and surrounding vegetation by the showy leaf arrangement and color. The species is very long lived, and coupled with its sacred significance and high visibility, it is very suitable for boundary marking.

Windbreaks

Vesi is very wind-sturdy and makes an excellent component in a multi-layered windbreak, especially in coastal areas.

Silvopasture

The tree is not normally planted in grazing areas, although some remnant or volunteer trees are sometimes found in grazing areas in Vanuatu and New Caledonia.

Woodlot

Vesi's superb timber makes it a candidate for a long-term (50–60 year) timber planting, even though the economic viability of vesi as a commercial timber tree is uncertain.

Native animal/bird food

Little has been written about relationships between vesi and vertebrate and invertebrate animal life, although in Oro Province of Papua New Guinea vesi is closely linked to the life cycle of the world's largest butterfly, the Alexandra birdwing butterfly (*Ornithoptera alexandrae*), which is listed as endangered on the IUCN Red List.

Wildlife habitat

Vesi provides good shelter and nesting sites for birds.

Bee forage

Many pollinators, including honey bees, frequent the flowers.

Coastal protection

Vesi grows well in swampy coastal areas and on coastal limestone and tolerates wind and salt spray, making it a very good tree for coastal protection.

FIJIAN LORE

The cultural significance of vesi is diverse and is embedded in many Fijian cultural expressions and beliefs. The tree itself was sacred among ancient Fijians, and its hardness and seemingly indestructible nature embodied admired human qualities. The tree was used as the main pole to hold up traditional temples and chiefly bures (traditional houses), to build the drua or waqa tabu (sacred canoe) reserved only for those of noble birth, and to make the traditional gong (lali) used to announce important events. Many native expressions still in use today incorporate the word vesi to indicate a person of noble birth or one of strong character. For instance "sa ciri na vesi" (the vesi is afloat) is used when bidding farewell to a paramount chief and "kaukauwa vaka na vuni vesi" (strong as the vesi tree) refers to one of firm character. Many of the artifacts derived from vesi have also made their way into native proverbs, such as the kali (traditional head rest) used as a taunt in quarrels—na kali oqo, na kali oqori (the headrest here, the headrest there) meaning "If you have power so do I." Likewise when kava is mixed in the tānoa (kava bowl derived from vesi) and presented during ceremonial occasions the mixer will call out "e saqa ena kuro vesi" (it is cooked in the vesi pot).

Kabara Island, Lau

The island of Kabara is one of the few areas in Fiji where vesi stands grow abundantly. Due to the abundance of this wood, the island has become renowned as the historic center of woodcarvers.

Local legend states when the first Kabaran settlers arrived on the island, they found it to be inhospitable, a limestone landscape lacking in sufficient soil for agriculture. Their ancestor god, Berewalaki, seeing their plight, set off for Oloi, an area not far from Suva, to beg for soil to take back to Kabara. The inhabitants of Oloi agreed, and he began the tedious task of transferring soil to Kabara. He made one journey and returned to Oloi for more, but on returning to Kabara for the second time he found his people baking the soil he had previously brought. Furious with them, he angrily hurled the baskets of soil and the sticks he was using to carry them at the island, and it all heaped up in one place. The sticks from the vesi tree immediately sprouted and flourished throughout the island. The heap of soil became a hill (locally called Delai Oloi or Mount of Oloi) and remains the only planting ground on the island. Similarly, to this day, the islanders consider the vesi an ancestral gift incapable of ever being depleted.

An alternative version on how vesi came to be on the island is that another ancestor, Daunisau, who is renowned on the island as a trickster, brought it from Verata. The first Kabara settlers set off from Verata and as they left Daunisau grabbed soil from a headland, which he transferred to Kabara. This soil had vesi trees on it, and this was how they made their way to Kabara. Some village elders claim that if one goes back to Verata, one will find a few vesi trees, which they consider the ones Daunisau left behind.

(Matavura et al. 2004, Thompson 1940)

Vesi growing in a disturbed limestone forest, Isle of Pines, southern New Caledonia. PHOTO: R. THAMAN

Ornamental

The tree is a highly ornamental, with its attractive bright, shiny, light-green foliage and beautiful orchid-like flower. It is quite suitable for landscaping, streets, and parks. Top pruning may be required in urban environments.

USES AND PRODUCTS

Nut/seed

The seeds can be made edible through careful preparation that includes soaking in salt water for 3–4 days and then boiling them.

Medicinal

In Fiji, people often use the juice extracted from the bark of the species for internal injuries. A decoction of the bark is used to treat rheumatism, chills, diarrhea, and muscular rigidity and rheumatoid arthritis in adults and, with the extracts of other plants, to treat broken bones. The juice of the stems is reputed to be used to treat asthma and the juice of the inner bark to treat pains in the bones, colds, and influenza. A decoction of the leaves is drunk to treat the body when it is possessed by a spirit, and with other plant extracts to treat toothache and sore tongue. It is also used along with other plant extracts to treat relapse from any sickness, scabies, and headaches (Cambie and Ash 1994).

Medicinal use is reported from the Reef Islands (Solomon Islands), where it is used to treat a mysterious urinary condition (very dark urine), believed to be produced by sorcery carried out using vesi. It has also been reportedly used to treat rheumatism, dysentery, and diarrhea.

Beautiful/fragrant flowers

The flowers are very attractive, especially close up, but are not known to be used for decoration or as cut flowers.

Timber

Vesi is an excellent tropical hardwood traded as merbau. The heartwood timber is extremely dense (641–961 kg/m^3 [40–60 lb/ft^3]), has limited shrinkage over time, and good insect repellent properties. The wood has reasonable resistance to saltwater and is easily cut and worked for carving. It is one of Samoa's most important timber species, with large stands of it having been cut in northern Savai'i in the early 1990s. Considered one of the finest timber trees in Tonga, it is very rare, except on the Niuas group in far northern Tonga. The wood is highly prized throughout the Solomon Islands, where it is used for heavy construction, boatbuilding, house posts and beams, other timber, fencing, and furniture. Because of its high durability, it was selected as one of only four trees permitted for use as fence posts within the Livestock Development Grant Scheme of the mid-1970s in the Solomon Islands. In Vanuatu, the wood is used for ground posts, heavy aerial timbers in house construction, boat building, and furniture. Because of its combination of wood properties (strength, heavy weight, and low shrinkage), the wood is very suitable for carving. It is also used for furniture, ground posts, and heavy construction because it is hard and strong. The wood is traditionally

Clockwise from left: One of many vesi trees scattered throughout the limestone island of Kabara, Fiji, showing clear bole; newly felled vesi tree showing the creamy sapwood and toffee-brown heartwood; a 127 cm (50 in) *tānoa*, the largest known carved on Kabara Island. PHOTOS: F. AREKI

used for canoes in the South Pacific.

Although vesi is seriously threatened due to its overexploitation, its inclusion in international law to protect threatened species (Appendix II of CITES) in 1992 was thwarted by Malaysia's objection.

Fuelwood

It makes a good fuelwood but is normally considered too valuable for this use. Discards from felled trees are used as a source of good quality fuel.

Craft wood/tools

The wood is highly valued for making handicrafts, house parts, slit gongs (a type of drum), and war clubs. The wood is considered the most valuable one in Samoa, and kava bowls made for ceremonial occasions and for sale to tourists are typically made of this wood. It is used to make house posts, canoe keels, a range of tools, weapons, and other artifacts, such as mallets for beating bark cloth in the production of tapa cloth. Items made from it in the Solomon Islands include walking sticks, food bowls, and carvings.

Canoe/boat/raft making

Historically, vesi has been used for canoe building and construction of houses, buildings, and furnishings in the Pacific. In pre-European times Tongans voyaged to Fiji to obtain double-hulled canoes made of this hard, durable wood.

Tannin/dye

A brown and yellow dye can be made from an oily substance present in the wood and bark.

Toxin/insecticide/fish poison

An insect repellent comparable to that made from the neem tree (*Azadirachta indica*) can be made from the seeds.

Ceremonial/religious importance

The tree was sacred among ancient Fijians (see text box, "Fijian lore").

COMMERCIAL CULTIVATION

In the Pacific, the valuable timber is used for export, woodcarving of bowls, clubs, and other artifacts for sale, especially for the tourist and handicraft market, for boatbuilding, and for furniture manufacture.

Spacing for commercial production

Spacings of 3 x 4 m and 5 x 5 m (10 x 13 ft and 16 x 16 ft) have been used in plantations (Soerianegara el al. 1994).

Management objectives

If phosphorus is a limiting macronutrient, fertilization with super-phosphate or rock phosphate is often necessary for optimum yields. In more acid soils (e.g., less than pH 5), calcium deficiency may be a major limiting factor, which can be remedied by additions of dolomite or calcium sulfate.

Woodcarver carving a kava bowl (tānoa) from vesi in Uafato, Samoa, the main Samoan source of kava bowls and other carvings for the tourist market. PHOTO: R. THAMAN

Weed control is extremely important, because the seedlings cannot tolerate intense competition and require open access to high light intensity for optimal growth. The tree tends to be self pruning when grown close together.

Design considerations

A 50–60 year rotation is recommended for natural stands. Longer rotations have been suggested for Malaysia (120 years).

The species is best grown in polyculture, planted several years after other fast-growing tree species have been established to provide side shade and encourage better stem form. This species is well adapted to low-fertility sites such as the limestone islands of Palau, in part due to its ability to fix atmospheric nitrogen. There may be secondary benefits to associated species from the nitrogen fixation of the roots.

Estimated yields

Although vesi is among native hardwood timbers commonly exported annually from Fiji, Samoa, and other Pacific island countries, data specific to the species in terms of volume and earnings are unavailable.

On-farm processing

In Kabara, Lau, Fiji Islands "blanks" hewn in the general shape of kava bowls are transported from the field on foot, and sometimes by boat, to the villages, where the actual carving and finishing of the kava bowls (tānoa) takes place.

Markets

The primary market for vesi in the Pacific islands is traditional handicrafts such as carvings, especially high-value kava bowls in Samoa and Fiji. In other areas where there is still an abundant supply, it is an important timber for furniture manufacture and heavy structural uses, such as sawn construction timber, heavy decking, piles, poles, and posts. There is a large market for its use as a decking timber in Australia.

INTERPLANTING/FARM APPLICATIONS

Some interplanting systems may include windbreak, field border, riparian buffer tree, and possible interplanting among crops that are shade tolerant. Vesi may also be used for reforestation on poor sites or in limestone areas.

Kava bowl "blank" fashioned from solid log in the field, Uafato, Samoa. PHOTO: C. ELEVITCH

PUBLIC ASSISTANCE AND AGROFORESTRY EXTENSION

Extension offices for agroforestry and forestry in the Pacific: http://www.traditionaltree.org/extension.html

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Species Profiles for Pacific Island Agroforestry (www.traditionaltree.org)

Intsia bijuga (vesi)

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Acknowledgments: The authors and publisher thank Dale Evans, Diane Ragone, and Art Whistler for their input.

Recommended citation: Thaman, R.R., L.A.J. Thomson, R. DeMeo, R. Areki, and C.R. Elevitch. 2006. *Intsia bijuga* (vesi), ver. 3.1. In: Elevitch, C.R. (ed.). Species Profiles for Pacific Island Agroforestry. Permanent Agriculture Resources (PAR), Hōlualoa, Hawai'i. <http://www.traditionaltree.org>.

Sponsors: Publication was made possible by generous support of the United States Department of Agriculture Western Region Sustainable Agriculture Research and Education (USDA-WSARE) Program; SPC/GTZ Pacific-German Regional Forestry Project; USDA Natural Resources Conservation Service (USDA NRCS); State of Hawai'i Department of Land & Natural Resources Division of Forestry & Wildlife; and the USDA Forest Service Forest Lands Enhancement Program. This material is based upon work supported by the Cooperative State Research, Education, and Extension Service, U.S. Department of Agriculture, and Agricultural Experiment Station, Utah State University, under Cooperative Agreement 2002-47001-01327.

Series editor: Craig R. Elevitch

Publisher: Permanent Agriculture Resources (PAR), PO Box 428, Hōlualoa, Hawai'i 96725, USA; Tel: 808-324-4427; Fax: 808-324-4129; E-mail: par@agroforestry.net; Web: <http://www.agroforestry.net>. This institution is an equal opportunity provider.

April 2006
ver. 3.1

Mangifera indica (mango)

Anacardiaceae (cashew family)

kangit **(Chuuk, Pohnpei),** ***idele*** **(Palau),** ***mago*** **(Niue, Samoa, Tuvalu),** ***manako*** **(Hawai'i),** ***manggo*****,** ***am*** **(Fiji),** ***mangko*** **(Kiribati), mango (English),** ***mango*** **(Tonga),** ***mangot*****,** ***mangue*****,** ***manguier*** **(French),** ***mangueira*** **(Yap)**

Ian S. E. Bally

Mango tree with heavy crop.

IN BRIEF

Distribution All tropical and subtropical regions.

Size Reaches heights of 15–30 m (50–100 ft); cultivated trees are usually 3–10 m (10–33 ft) high when mature.

Habitat Grows from sea level to 1200 m (3950 ft) in tropical latitudes; however, most commercial varieties are grown below 600 m (1950 ft); rainfall 400–3600 mm (16–140 in), fruits best with a well defined winter dry period.

Vegetation Grows with a wide range of cultivated species.

Soils Tolerates a range of soils; optimal pH 5.5–7.5.

Growth rate Fast, >1.5 m/yr (5 ft/yr) in ideal conditions.

Main agroforestry uses Homegardens, silvopasture.

Main uses Fruit, flavoring, medicinal, timber.

Yields Typically, yields are often less that 5 mt/ha (2.2 t/ac) but can reach 20–30 mt/ha (9–13.5 t/ac); single trees can produce 200–300 kg (440–660 lb) of fruit in heavy cropping years and as low as 5 kg (11 lb) in bad years.

Intercropping Compatible with other similarly vigorous species, as well as animal grazing.

Invasive potential Not an aggressively invasive species.

INTRODUCTION

Mangos belong to the genus *Mangifera* of the family Anacardiaceae. The genus *Mangifera* contains several species that bear edible fruit. Most of the fruit trees that are commonly known as mangos belong to the species *Mangifera indica*. The other edible *Mangifera* species generally have lower quality fruit and are commonly referred to as wild mangos.

Mango has become naturalized and adapted throughout the tropics and subtropics. Much of the spread and naturalization has occurred in conjunction with the spread of human populations, and as such, the mango plays an important part in the diet and cuisine of many diverse cultures. There are over 1000 named mango varieties throughout the world, which is a testament to their value to humankind. Mango is a common garden tree throughout the tropics.

When ripe, this delicious dessert fruit is particularly high in vitamin A. The fruit is also eaten green, processed into pickles, pulps, jams, and chutneys, and is frozen or dried. The fruit is also an important source of sustenance for birds, bats, insects, and mammals.

Although grown widely, mangos prefer a warm, frost-free climate with a well defined winter dry season. Rain and high humidity during flowering and fruit development reduces fruit yields. The tree generally flowers in mid- to late winter, with fruit maturing in the early to mid-summer months. Mango trees are usually between 3 and 10 m (10–33 ft) tall but can reach up to 30 m (100 ft) in some forest situations. The canopy is evergreen with a generally spreading habit. The heavy canopy of the mango is a source of shelter and shade for both animals and humans.

Mangos are well adapted to cultivation and have been grown commercially for centuries. Today, mangos are recognized and eaten throughout the world and are regarded as one of the most popular and esteemed tropical fruits.

DISTRIBUTION

Native range

The genus *Mangifera* originates in tropical Asia, with the greatest number of species found in Borneo, Java, Sumatra, and the Malay Peninsula. The most-cultivated *Mangifera* species, *M. indica* (mango), has its origins in India and Myanmar.

Current distribution

Mango is now cultivated throughout the tropical and subtropical world for commercial fruit production, as a garden tree, and as a shade tree for stock. In the Pacific region, all mangos were introduced from other parts of the world. The earliest recorded introductions into Hawai'i were prior to 1825; however, most introductions to the Pacific islands have occurred over the past 100 years. Few other *Mangifera* species are found in the Pacific. *Mangifera gedebe*, *M. minor*, and *M. mucronulata* are found in the Solomon Islands and *M. minor* in Micronesia, but these either do not fruit or the fruit is inedible.

Mango fruits of the world. PHOTO: I. S. E. BALLY

BOTANICAL DESCRIPTION

Preferred scientific name and author

Mangifera indica L.

Family

Anacardiaceae (cashew family)

Non-preferred scientific names

Mangifera amba Forssk.
M. anisodora Blanco
M. arbor Bontii
M. austroindica Kosterm.
M. balba Gen.
M. domestica Gaertn.
M. equina Gen.
M. fragrans Maingay
M. gladiata Boj.
M. kukula Blume
M. integrifolia Gen.
M. linnaei Korth.
M. maritima Lechaume.
M. mekongensis anon.
M. montana Heybe
M. oryza Gen.
M. racemosa Boj.
M. rostrata Blanco
M. rubra Boj.
M. sativa Roem. & Schult.
M. siamensis Warb.
M. sugenda Gen.
M. sylvatica Roxb.
M. viridis Boj.

Common names

Mangos have been grown throughout the tropical and subtropical world for thousands of years and have become an integral part of many cultures. The many different names for mango around the world today reflect the cultures and languages spoken by people who grow them. Many of the names have common derivations, reflecting the origins and spread of the mango tree along with the spread of human communities. The more popular names for mango fruit in the Pacific and Asia are listed below with the countries or languages from which they come.

Pacific island names:

idele (Palau)
kangit (Chuuk, Pohnpei)
mago (Niue, Samoa, Tuvalu)
manako (Hawai'i)
manggo, *am* (Fiji)
mangko (Kiribati)
mango (English)
mango (Tonga)
mangot, *mangue*, *manguier* (French)
mangueira (Yap)

Common names from other regions include:

aam, *am*, *amb* (Hindi)
ampleam (Tamil)
bobbie manja, *kanjanna manja*, *maggo*, *manggaboom*, *manja* (Dutch)
ma muang (Indochina)
mamung (Thailand)
manga, *mango* (Spanish)
manga, (Portuguese)
manga, *mempelam*, *ampelam* (Malaysia)
mangga (Tagalog)
mangga, *mempelam* (Indonesia)
mango (Ilokano)
mango (New Guinea, Pidgin)
Mangobaum (German)
mwàngx (Laos)
paho (Bisaya) (Philippines)
svaay (Cambodia)
tharyetthi (Myanmar)
xoài (Vietnam)

Size

Mangos are long-lived evergreen trees that can reach heights of 15–30 m (50–100 ft). Most cultivated mango trees are between 3 and 10 m (10–33 ft) tall when fully mature, depending on the variety and the amount of pruning. Wild, non-cultivated seedling trees often reach 15 m (50 ft) when found in favorable climates, and they can reach 30 m (100 ft) in forest situations. The trees can live for over 100 years and develop trunk girths of over 4 m (13 ft).

Canopy

Mango trees typically branch 0.6–2 m (2–6.5 ft) above the ground and develop an evergreen, dome-shaped canopy. Variability in canopy shape and openness occurs among varieties and with competition from other trees. Mangos grown in heavily forested areas branch much higher than solitary trees and have an umbrella-like form.

Roots

The mango has a long taproot that often branches just below ground level, forming between two and four major anchoring taproots that can reach 6 m (20 ft) down to the water table. The more fibrous finer roots (feeder roots) are found from the surface down to approximately 1 m (3.3 ft) and usually extend just beyond the canopy diameter. Distribution of the finer roots changes seasonally with the moisture distribution in the soil.

Flowers

Mango flowers are born on terminal inflorescences (panicles) that are broadly conical and can be up to 60 cm (24 in) long on some varieties. Inflorescences usually have primary, secondary, and tertiary pubescent, cymose branches that are pale green to pink or red and bear hundreds of flowers. The mango has two flower forms, hermaphrodite and male, with both forms occurring on the same inflorescence.

The ratio of hermaphrodite to male flowers on an inflorescence varies with variety and season and is influenced by the temperature during inflorescence development.

Hermaphrodite flowers are small (5–10 mm, 0.2–0.4 in) with four to five ovate, pubescent sepals and four to five oblong, lanceolate, thinly pubescent petals. Only one or two of the four to five stamens that arise from the inner margin of the disc are fertile. The single ovary is born centrally on the disc with the style arising from one side. The disc is divided into a receptacle of four or five fleshy lobes that forms the nectaries. The male flowers are similar to the hermaphrodite flowers but are without the pistil, which has been aborted.

Leaves

The leaves are simple, without stipules, and alternate, with petioles 1–12 cm (0.4–5 in) long. The leaves are variable in shape and size but usually are oblong with tips varying from rounded to acuminate. Leaf form differs among varieties but is more consistent within a variety. However, a range of leaf sizes can be seen on a single tree. Mature leaves are dark green with a shiny upper surface and glabrous lighter green lower surface. New leaves emerge in flushes (episodic growth spurts) of 10–20 leaves. Leaves emerge green, turning tan-brown to purple during leaf expansion and then gradually changing to dark green as the leaves mature. The color of the young, expanding leaf varies with variety and can be from light tan to deep purple; this can be used as a distinguishing character among varieties.

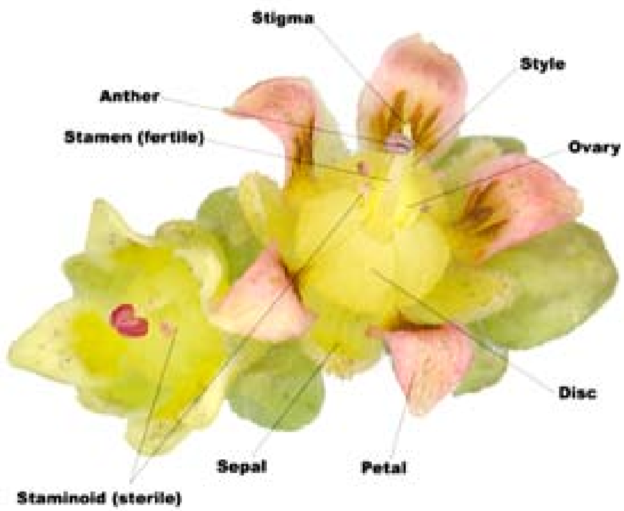
Fruit

Mango fruit is classed as a drupe (fleshy with a single seed enclosed in a leathery endocarp). Fruits from different varieties can be highly variable in shape, color, taste, and flesh texture. Fruit shapes vary from round to ovate to oblong and long with variable lateral compression. Fruits can weigh from less than 50 g (0.35 lb) to over 2 kg (4.4 lb). The fruit has a dark green background color when developing on the tree that turns lighter green to yellow as it ripens. Some varieties develop a red background color at fruit set that remains until the fruits ripen. In addition to the background color, many varieties also have an orange, red, or burgundy blush that develops later in the fruit development, when the rind is exposed to direct sunlight. The mesocarp is the fleshy, edible part of the fruit that usually has a sweet and slightly turpentine flavor. When ripe, its color varies from yellow to orange and its texture from smooth to fibrous.

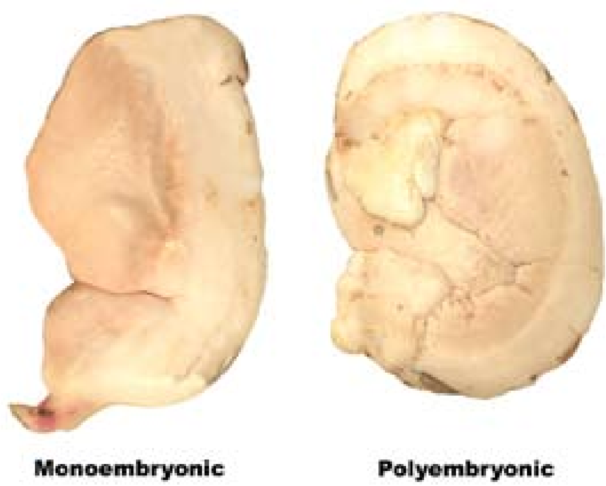
New leaf flush. PHOTO: C. ELEVITCH

Seed

Mango varieties can be classified as having either monoembryonic or polyembryonic seed embryos. In monoembryonic varieties, the seed contains only one embryo that is a true sexual (zygotic) embryo. Monoembryonic seeds are a cross between the maternal and paternal (pollen) parents. Fruit from monoembryonic seedlings will often vary from the parent trees, so propagation by grafting is used to produce true-to-type monoembryonic trees. Polyembryonic seeds contain many embryos, most of which are asexual (nucellar) in origin and genetically identical to the maternal parent. Polyembryonic seeds also contain a zygotic embryo that is the result of cross-pollination. The monoembryonic seedling usually has less vigor than a nu-



Mango flower types: male (left) and hermaphrodite (right). PHOTO: I. S. E. BALLY



A monoembryonic seed is a true sexual cross and has one embryo. A polyembryonic seed has several embryos, many of which are identical to the parent tree. PHOTO: I. S. E. BALLY

cellar seedling for use as a rootstock. In some varieties this is reversed and the zygotic seedling is the most vigorous. The occurrence of off-types in orchards is often attributed to use of zygotic seedlings.

GENETICS

Varieties

There are over a thousand mango varieties around the world, with India having the greatest number (over 500 named). The commercial industries of the world rely on a handful of improved varieties supplemented with local varieties that are less suited to the export trade.

Varieties in the Pacific

The mango varieties found in the Pacific islands have been introduced mainly from India, Florida, and Southeast Asian countries during the past 100 years. Most of the early Indian varieties were monoembryonic, which produced seedlings that did not reproduce true to type. Planting and selection of these seedlings has changed these varieties, with many becoming known as a "common" variety. Common varieties are generally of inferior fruit quality to named, introduced varieties and are usually found growing wild or on roadsides and abandoned home sites.

In Hawai'i, Indian, Floridian, Mexican, and West Indian mango varieties have been introduced and grown since the beginning of the 20th century. Since that time, many improved seedling selections have been made and grown. Popular monoembryonic varieties in Hawai'i include 'Haden', 'Ah Ping', 'Gouviea', 'Momi K', 'Fairchild', 'Pope', 'Rapoza', and 'Harders'. In the Solomon Islands and Fiji, the Australian variety 'Kensington Pride' has been introduced and grown successfully. In Samoa, the mango varieties 'Momi K', 'Fiji', 'Mapulehu', 'White Pirie', 'Rapoza', 'Jara', and 'Kensington Pride' are common. In Tahiti, 'Kopu Reva' is a popular variety.

Selection of mango varieties

The characteristics by which mangos are typically selected are a mix of eating quality, keeping, and growing characteristics. Fruit quality characteristics such as flavor, aroma, flesh texture, and fiber are generally of high importance, as are fruit size, external appearance, and yield performance.

Preferences for mango varieties often differ among countries, regions, ethnicities, and cuisines of markets in which they are consumed. Locally grown and consumed varieties often differ from commercially exported varieties that are selected for their ability to maintain fruit quality after long periods of postharvest storage and transport.

The adaptations of a variety to environmental pressures of drought, wet weather during flowering, temperature, pests, and diseases are also important selection criteria, because they determine the cropping consistency and fruit quality.

Related species

In addition to the many varieties of *Mangifera indica*, there are several other *Mangifera* species that also have edible fruit. The most prominent of these are *M. pentandra* (Malay Peninsula), *M. foetida* Lour. (throughout SE Asia), *M. odorata* Griff. (Philippines, Malay peninsula, Java), and

SOME POPULAR PACIFIC VARIETIES

Ah-Ping

Tree: medium to vigorous tree
Fruit wt: 450–900 g (1–2 lb)
Fruit color: yellow with a crimson blush
Fruit eating: good flavor, low fiber
Seed embryo: monoembryonic
Harvest time: mid-season
Comments: originated at Mapulehu, Moloka'i, and mainly grown in the Hawaiian Islands

Fairchild

Tree: small tree with dense, spreading canopy
Fruit wt: 150–340 g (0.33–0.75 lb)
Fruit color: green/yellow with an orange yellow blush
Seed embryo: polyembryonic
Fruit eating: mild, slightly acidic flavor; medium fiber
Harvest time: early season
Comments: originating in Panama, this variety bears reasonably well in wetter climates. Suitable as a homegarden variety

Gouviea

Tree: large, vigorous tree with spreading canopy
Fruit wt: 300–400 g (0.66–0.88 lb)
Fruit color: light green with mottled red and yellow shoulders
Fruit eating: rich, acidic flavor; low fiber
Seed embryo: monoembryonic
Harvest time: early to mid-season
Comments: selected in Hawai'i 1964; light yielding.

Haden

Tree: vigorous, tree with spreading canopy
Fruit wt: 500–700 g (1.1–1.5 lb)
Fruit color: yellow with bright red blush over half of skin
Fruit eating: good flavor, medium fiber
Seed embryo: monoembryonic
Harvest time: mid-season
Comments: unreliable irregular bearing; susceptible to internal breakdown; not a commercial variety

Kensington Pride

Tree: vigorous tree with spreading canopy
Fruit wt: 300–600 g (0.66–1.3 lb)
Fruit color: yellow-green background with light blush
Fruit eating: excellent flavor, medium fiber
Seed embryo: polyembryonic
Harvest time: early season
Comments: the mainstay of the Australian mango industry; widely grown in Samoa and Fiji

Kopu Reva

Tree: medium-vigor tree with a dense, upright canopy
Fruit wt: 150–250 g (0.33–0.55 lb)
Fruit color: light pink with a red blush
Fruit eating: turpentine flavor; high fiber
Seed embryo: polyembryonic
Harvest time: mid- to late season
Comments: origin Tahiti

Mapulehu

Tree: large tree with an upright canopy
Fruit wt: 300–400 g (0.66-0.88 lb)
Fruit color: yellow/green with pink blush
Fruit eating: sweet-acid turpentine flavor; low fiber
Seed embryo: monoembryonic
Harvest time: mid- to late season
Comments: originally from India; popular in Samoa; is synonymous with Joe Welch from Florida

Momi-K

Tree: medium to large tree, slightly spreading canopy
Fruit wt: 280–400 g (0.62–0.88 lb)
Fruit color: light yellow with a light red/orange blush over the top half of the fruit
Fruit eating: mild flavor; low fiber
Seed embryo: monoembryonic
Harvest time: early to mid-season
Comments: originating in Hawai'i, irregularly bearing

Pope

Tree: medium large tree with a dense, spreading canopy
Fruit wt: 250–450 g (0.55–1.0 lb)
Fruit color: green-yellow ground color with a red/pink blush
Seed embryo: monoembryonic
Fruit eating: spicy flavor, stronger around the fruit shoulders
Harvest time: late season
Comments: originated as a seedling of the Florida variety Irwin; regular-bearing and high-yielding

Rapoza

Tree: small tree with an open canopy
Fruit wt: 700–1000 g (1.5–2.2 lb)
Fruit color: yellow orange with a red orange blush
Fruit eating: excellent flavor; low fiber
Seed embryo: monoembryonic
Harvest time: mid- to late season
Comments: yields heavily and regularly

M. caesia Jack. (Malay peninsula, Papua New Guinea, Java, and the Philippines). Although these species are found growing in the Pacific rim region, none are found naturally in the Pacific islands.

ENVIRONMENTAL PREFERENCES AND TOLERANCES

Climate

Mango grows over a wide range of frost-free climates. The trees produce best in climates that have a well defined, relatively cool dry season with high heat accumulation during the flowering and fruit development period. Rain or free moisture (high humidity, heavy dew, and fog) during the flowering and fruiting period is conducive to the development of fungal diseases that cause flower and fruit drop. Mangos are often found growing in the wetter regions, but they rarely bear fruit there.

Popular varieties: Haden (top left), Kensington (top right), Mapulehu (bottom left), Rapoza (bottom right). PHOTOS: I. S. E. BALLY

Elevation

Mango grows and produces fruit over a wide range of elevations from sea level up to 1200 m (3950 ft) in tropical latitudes. Most commercial varieties do not produce consistently above 600 m (1950 ft) elevation.

Rainfall pattern

Mango trees grow over a wide range of rainfall volumes and patterns. The trees produce best when the most rain falls during summer months and there is a well defined winter dry period. In hot, wet, tropical climates, where soil moisture does not limit growth, the trees remain vegetative with little or no fruit production. Rainfall, foggy weather, and persistent dews during the flowering and fruiting seasons predispose the flowers and fruit to the fungal disease anthracnose. Bearing is best when the dry period lasts from 1 to 2 months before flowering to after harvest.

Mean annual rainfall

400–3600 mm (16–142 in)

Dry season duration (consecutive months with <40 mm [1.6 in] rainfall)

Can tolerate drought for up to 8 months in certain situations.

Temperature

Mango's optimum growing temperature is 24–27°C (75–81°F). They will grow outside this range, however, but frost will kill small mango trees and severely defoliate mature trees. Temperature has a direct effect on tree and fruit growth rates. A leaf flushing cycle takes approximately 20 weeks when growing under 20°C (68°F) days and 15°C (59°F) nights; this is reduced to 6 weeks under 30°C/25°C (86°F/77°F) temperatures. The time taken for fruit to reach maturity is also influenced by temperature. Under high-temperature and low-humidity conditions, mango's photosynthetic efficiency is reduced and respiration is high, resulting in low carbon accumulation, which lowers the tree's ability to hold heavy crop loads. Low temperature stress is necessary for floral induction (see Flowering section below).

Mean annual temperature

24–27°C (75–81°F)

Minimum temperature tolerated

Frost (0°C [32°F])

Soils

Mangos are tolerant of a range of soils from alkaline, calcareous soils to heavy clay soils. The optimal pH range is 5.5–7.5, but the tree will grow outside this range, with low pH (acid) being the most deleterious to growth. Production is best on well drained sandy or gravelly soils that dry out rapidly after the wet season, forcing the trees into a dormant period, essential for heavy flowering. Mangos will grow on coral atolls but usually produce poorly due to the lack of fresh water. On some of the larger, wetter atolls such as Butaritari and other islands in Kiribati, mangos are known to produce well. Mangos do not grow or produce well in saline soils, but the rootstock variety '13-1' from Israel has some salt tolerance.

Soil texture

Mangos tolerate light to heavy soil textures (sands, sandy loams, loams, sandy clay loams, clays, clay loams, and sandy clays).

Soil drainage

Well drained, lighter soils are preferred.

Soil acidity

The optimum range is pH 5.5–7.5.

Tolerances

Drought

Mango is considered a drought tolerant species, being able to withstand seasonal dry periods for up to 8 months. The mango has many adaptive features that give it drought tolerance, such as deep tap/sinker roots, long-lived, tough leaves with thick cuticles for nutrient retention and recycling, resin ducts to reduce wilting, and irregular fruiting patterns, depending on resource availability. Dry conditions during fruit development will cause excessive fruit drop and very low yields.

Full sun

Mango grows best in full sun because its flowers and fruit are produced at the edge of the canopy (the outside of the tree) in full sun. The best fruits are from sun-exposed branches.

Shade

Vegetative growth, flowers, and fruits from shaded areas are prone to increased pest and diseases.

Fire

Young mangos are easily burned beyond regeneration by grass or forest fires. Larger mature trees are more able to regenerate after fire, although their canopies are no more tolerant of fire than younger trees.

Frost

Young trees will be killed outright by the mildest frosts, but larger mature trees can regenerate, although defoliation and death of some branches will occur. Heavy frosts will kill large mango trees.

Waterlogging

Mango trees vary in their tolerance of flooding, with some trees able to tolerate medium-term flooding (10–50 days) by developing hypertrophic (swollen) lenticels on the trunk just above the waterline to aid in the removal of toxic by-products of anaerobic metabolism. Trees that do not develop hypertrophic lenticels will die after 4–5 days of inundation. Hypotrophic lenticels seen in seedlings in pots are a sign of overwatering or unsuitable potting media.

Hypotrophic lenticels on stem of seedling. PHOTO: I. S. E. BALLY

Salt spray

Mangos will not tolerate continuous salt spray, but if the trees are growing with high-quality fresh water, mild, infrequent salt spray will not adversely affect mature leaves if it does not accumulate on them.

Wind

Mangos are relatively wind resistant and are sometimes used in windbreaks. Windbreaks of other species are often

Simultaneous leaf flushing and flowering on different branches. PHOTO: C. ELEVITCH

used to protect commercial mango orchards to reduce disease, improve pollination, and reduce wind-rub blemishes on the fruit.

Young seedlings trees may benefit from staking if over 0.8 m (2.5 ft) high or planted in abrasive, calcareous soils in wind-exposed situations.

Storm winds can be especially damaging to mangos, causing breakage of major limbs or uprooting the whole tree. Although preventing damage from cyclonic winds is difficult, good post-storm management can hasten recovery and minimize secondary effects. Fallen trees should be straightened immediately following the storm, while the soil is soft, to prevent re-damaging roots. Damaged limbs should be removed to prevent disease infections and to promote new growth.

ABILITIES

Regenerate rapidly

Mangos are tolerant of severe pruning and will regain cropping within one to two seasons.

GROWTH AND DEVELOPMENT

Mango trees start producing fruit 2–4 years after field planting and can continue to produce fruit for more than 100 years. Under ideal conditions, trees can grow to 2 m (6.6 ft) in the first year. Once trees start cropping, their growth rate will slow.

Phenology

Phenology is the annual cycle of growth events. In mature mangos, the phenological cycle is similar for most varieties and environments, varying only in timing and duration. The exception is seen in trees grown close to the equator, where the seasonal fluctuations are minimal and flowering and cropping can occur several times a year. The major phenological growth events are discussed below.

Dormancy

In a typical tree there are two periods of dormancy. The first is immediately after harvest or ripe fruit drop, when the tree becomes dormant for 2–8 weeks, depending on the soil moisture conditions and previous crop load. The second dormant period is after the summer flush period, when dryer conditions set in. The second dormancy period is critical for floral bud development.

Leaf flushing

The postharvest dormancy is broken by the first summer vegetative flush, which usually coincides with the wet season. Vegetative flushing usually continues throughout the wet season, slowing as the climate and soil dry out. The leaf-flushing period can have one to five flushing events, with the whole canopy flushing in synchrony or in patches. In years of poor flowering and cropping, several leaf flushes can occur during the flowering and fruiting period. Although mango is an evergreen tree, large quantities of old leaves are shed during vegetative flushing. The fallen leaves become mulch under the tree, where nutrients are recycled from old leaves to the new leaves.

Flowering

Mango flowering occurs during the coolest months of the year. Flowering requires 4–6 weeks of shoot dormancy and cool night temperatures to trigger floral induction of the terminal buds. The absolute temperature needed for floral induction varies among varieties and climates, but night temperatures between 8°C and 15°C (46–59°F) with day temperatures around 20°C (68°F) are typically needed. Better flowering is seen in trees growing in the subtropics where the seasonal temperature differences are stronger and more reliable than in the hot tropics. In Hawai'i, the main flowering is between December and April.

Pollination

Wind and insects such as wasps, ants, flies, and bees are the main pollinators in mango. Temperatures below 10°C (50°F) during flowering are not conducive to production of viable pollen, and temperatures below 15°C (59°F) during pollination can prevent effective pollen tube growth and fertilization of the ovary. Pollen is generally compatible within and between varieties.

Fruiting

Young seedling or grafted mango trees will produce fruit between 2 and 4 years after field planting. Initially, hundreds of fruits can be set on each flowering inflorescence. The tree naturally thins the crop by shedding fruit throughout the fruit-development period. At full fruit maturity on heavy bearing trees, most mango varieties will hold one fruit for every two or three inflorescences.

Root growth

The volume of feeder roots of the mango varies during the annual cycle, with most root development occurring during the wet periods of the year and declining during the dry periods. Root growth is periodical, slowing or stopping during major canopy growth events.

Mango inflorescence (flower stalk). PHOTO: I. S. E. BALLY

Fruit development

Mango fruit can take 3–6 months to mature, with temperature being the primary influence on maturity timing. Fruits grow faster and mature earlier in warmer climates. The variety of mango also has an influence on maturity timing, with varieties being classified as early, mid- or late season. The mango harvest season is generally in the hotter summer months but can be outside this period in climates close to the equator, where out-of-season flowering is common. In Hawai'i, the harvest season is between June and September, and in Fiji, between January and February.

Crop yield

Mango fruit yields are generally low compared to other tropical and subtropical fruit species. The yields often reflect irregular annual bearing patterns, and they vary greatly from season to season. The yielding capacity of a tree is dependant on variety, tree age, tree size, seasonal conditions, and previous cropping history. Typically, yields are often less that 5 mt/ha (2.2 t/ac) but can reach 20–30 mt/ha (9–13.5 t/ac) in well managed orchards. Single trees can produce between 200 and 300 kg (440–660 lb) of fruit in heavy cropping years and as low as 5 kg (11 lb) in bad years. Good irrigation and disease management can greatly improve crop yields.

PROPAGATION

Mango is propagated by seed and various vegetative methods. The genetic quality of a mango seedling depends on the embryo type of the seed. Polyembryonic seeds will usually produce three to ten seedlings from each seed, most of which will come true to type with the tree they came from. Polyembryonic seeds also contain one embryo that is genetically different from the parents; i.e., this embryo will produce an off-type seedling. In contrast to polyembryonic seeds, monoembryonic seeds produce only one seedling for each seed that is always genetically different from the parents. For this reason, most monoembryonic varieties are propagated by grafting onto polyembryonic rootstocks.

Propagating seedlings

Seed collection

Seeds are best collected from fully mature or ripe fruits before the fruits have begun to decay with postharvest diseases. Seeds from the larger fruits generally produce the most vigorous seedlings. If possible, select seeds from trees that are free of seed weevils (*Sternochetus mangiferae* [F.] Coleoptera: Curculionidae). Only polyembryonic seeds will produce seedlings that are true to type (see polyembryonic/monoembryonic discussion above).

Seed processing

The best germination results are achieved when the seed is removed from the leathery endocarp of ripe or nearly ripe fruit that has not been chilled. After removing the flesh, cut the endocarp open using hand pruners and remove the kernel. During this operation, it is important not to cut and damage the seed.

Seed storage

Mango seed does not store well, and seed viability is greatly reduced from infection by fungi if it is not removed from the fruit when the fruit begins to ripen. Once the seeds are removed from the leathery endocarp, they loose viability very rapidly due to desiccation and should be planted immediately or soaked in water for up to 24 hours before planting. Germination percentages will drop off rapidly if seeds are stored for more than a few days after opening.

Planting techniques

Seeds should be planted to a depth of 2 cm (0.8 in) and oriented on their side to facilitate a straight stem and roots. Monoembryonic seeds can be planted 1-2 cm (0.4–0.8 in) deep into 5-20 liter (1–5 gal) pots containing a loose, well drained potting medium. Polyembryonic seeds, which produce more than one seedling per seed, are commonly planted into seedling beds of sand with an impenetrable root barrier at 15 to 20 cm (6–8 in) depth. The root barrier makes it easier to lift the seedlings when potting up. This is usually done when the seedlings are approximately 30 cm (12 in) high. With healthy polyembryonic seedlings it is common to have germination rates of over 600% and potting up rates of 300–400%. When potting up, only use the three or four most vigorous seedlings from each seed, discarding the rest. Choosing only the most vigorous seedlings will avoid selecting the zygotic embryo that is often the source of off-type trees.

Growing area

Nursery seedlings are best raised in a shade house under 50–80% shade and hardened up in full sunlight prior to field planting. Avoid raising seedlings under the canopies of larger mango trees, as this practice promotes infection of the seedlings with fungal diseases.

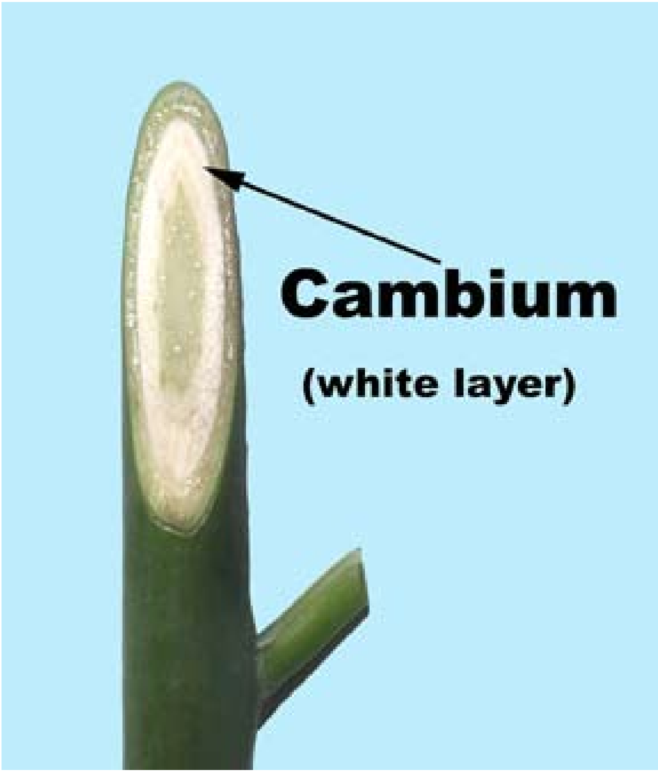
Time to outplanting

Young mango trees can be field-planted when approximately 12 months old and large enough to compete with minor weeds. At the time of planting, seedlings should be at least 1 m (3.3 ft) tall and have a stem diameter of at least 15 mm (0.6 in). If irrigation is available, the best time to field-plant is in early spring when the weather is mild; otherwise, trees should be planted at the onset of the wet season. To avoid transplant shock when field planting, trees should be hardened by holding in full sunlight for at least a week prior to field planting. If trees are excessively vigorous at the time of field planting, they can be pruned to reduce leaf area and water demand on the establishing root system.

Grafting and budding

Many of the better mango varieties have monoembryonic seeds which, when planted, will not reproduce true to type. Grafting is the preferred method of propagating mango varieties. Grafting is used to join the upper part (the scion) of a selected variety to the lower part of another (the rootstock)—the upper part is an identical clone of the desired tree. Grafting is normally done when the young seedlings are in nursery pots.

Almost all methods of grafting can be adapted for mango. Two popular methods for mangos are the cleft graft and the whip-and-tongue graft.



Prepared stock showing cambium. PHOTO: I. S. E. BALLY

To achieve a successful graft it is important to have healthy, actively growing rootstocks and select scion wood with swollen buds that are ready to burst. It is also important to match the cambium layers in both the stock and scion, as the cambium is where the cells are actively dividing and the joining of the graft takes place. This is most easily done when the stock and scion wood are the same diameter. In mango the cambium layer is the white woody layer just below the bark.

In the wedge method, the scion is prepared by making two sloping cuts that form a "V" shape. A straight cut is made on the stock to the same depth as the V shape on the scion. The V-shaped scion is then inserted in to the stock, making sure the cambium layers of both match up. The whole joint is then wrapped with grafting tape to hold it in place, and a plastic bag is used to cover the scion and union to prevent excessive moisture loss during the healing process.

The whip-and-tongue method is similar to the wedge but uses interlocking cuts that give a stronger graft and greater surface area for healing of the graft.

Scion selection

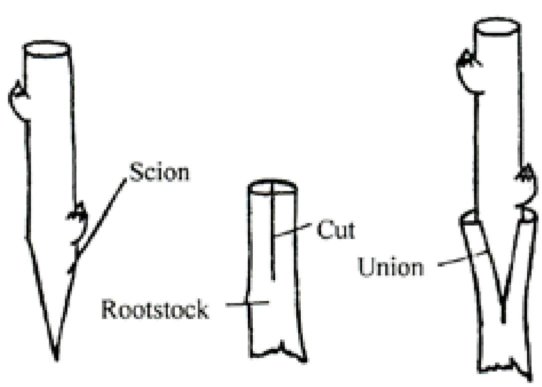
Scion wood should be only collected from actively growing trees that show no signs of disease infection. Scion wood is best taken from terminal shoots with swollen terminal buds about to burst. The scion thickness should match the stock thickness to which it is to be grafted (6–15 mm [0.25–0.6 in] diameter) and be between 100 and 200 mm (2.5–5 in) long.

Scion collection and storage

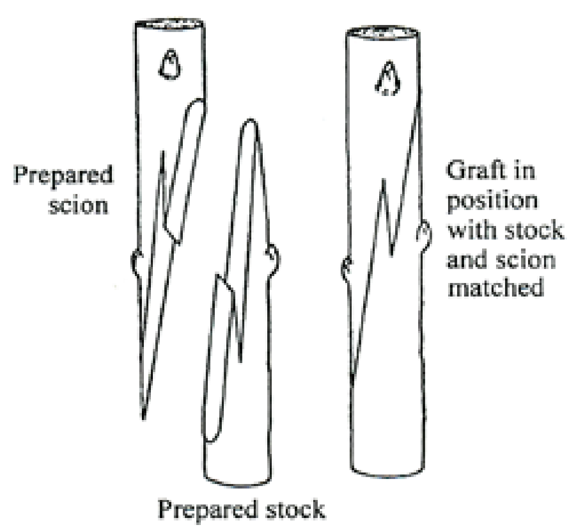
After selecting and removing an appropriate piece of scion wood from the tree, all leaves should be immediately removed to reduce moisture loss through transpiration. The scion should be placed in a plastic bag and held in a cooled box at 5–10°C (41–50°F). If the scion wood is not be used within 12 hours of collection, it should be wrapped in moist paper toweling inside a plastic bag and stored in the vegetable crisping section of a domestic refrigerator. Scion wood can be kept in this way for up to 2 weeks.

Pre-grafting

Scion budwood should be dipped in a fungicide and insecticide solution to prevent the spread of insect pests and disease.



Wedge graft



Whip and tongue graft

Left: Healed graft union 3 months after grafting. Right: Mango graft 5 days after bag removal. The wedge graft is still wrapped in white tape at bottom. PHOTOS: I. S. E. BALLY

Growing area

Grafting is usually done in the warmer months of the year when trees are actively flushing and night temperatures are between 18 and 21°C (64–70°F). Grafting of young seedlings is best carried out in a shadehouse with greater than 50% shade. When topworking established trees in the field (see below), completed grafts should be shaded with large paper bags.

Post-graft care

Remove any sucker growth below the graft. The scion should start to shoot between 10 and 14 days after grafting. When this happens, the plastic bag should be removed but not the grafting tape. The tape must be left on the graft until the tree has flushed twice from the scion and the graft union is fully healed.

Materials used

To achieve consistent successful grafting, a good grafting knife is needed. These knives differ from ordinary knives because they are beveled only on one side; the other side is flat to ensure a straight cut. You will also need some grafting tape and plastic bags. Grafting knives and tape are available from most gardening shops.

Field planting

Grafted trees are best planted out in the field after the second growth flush, when the graft has fully hardened. This is usually 1–2 years after germination. At this stage the trees are usually 60–120 cm (24–48 in) tall. If field-planted when smaller, competition from weeds can slow establishment. If the trees are left in pots for longer than 2 years, they become root-bound and will not develop healthy, spreading root systems when field-planted. Transplanting shock at the time of field planting can also hinder a tree's establishment. To avoid transplant shock, it is best to harden the trees by placing them in full sunlight for a week or more before transplanting.

Excessively vigorous trees should be pruned prior to transplanting to reduce the water demand on the establishing root system. Animals will graze on young mango leaves, so the trees should be protected from grazing animals.

Tree grafted in the field (topworked). The upper part of the trunk is painted white, and the new scion wood is grafted to the three slender shoots. PHOTO: I. S. E. BALLY

Other comments on propagation

Grafting is also used to change the variety of a tree already growing in the ground without sacrificing the established rootstock. This technique is often referred to as topworking. Topworked trees will come into production within a couple of seasons, much faster than planting new seedlings.

DISADVANTAGES

Mangos grow and produce in many tropical and subtropical climates, although fruit production is limited by wet weather during the flowering and fruiting period. Inconsistent yields and fruit quality from season to season are also limiting characteristics of many mango varieties. These variations are partly due to the vigorous nature of many mango types that tend to grow leaves and vegetation at the expense of flowers and fruit.

Fruit production, and (rarely) tree growth, can be severely affected by a range of insect pests and diseases. These, however, can usually be adequately managed in commercial orchards.

Pests

Many insects live in and feed on mango trees, but only a few of these are considered major pests.

Scale insects

Several species of scale insects are known to be pests of mango, including *Phenacaspis dilatata, P. cockerelli, Ceroplastrs rubens,* and *Aulacaspis tubercularis*. The infested areas turn pale green or yellow and eventually die. The insects attack all parts of the tree and are often a serious pest in the nursery.

Tip borers

There are two main species of tip borers, *Penicillaria jocosatrix* and *Chlumetia euthysticha*. The larvae of these species bore into and kill the young developing flushes. The pest activity is worst during hot, wet, summer seasons.

Fruit flies (*Dacus* sp., *Strumenta* sp., *Bactrocera dorsaila,* and *Pardalaspis* sp.).

Fruit fly species differ among regions. Adult flies lay eggs in near-ripe or ripe fruit, and the larvae tunnel and feed throughout the flesh, destroying and decaying it.

Seed weevil

The mango seed weevil (*Sternochetus mangiferae*, *S. gravis*) bores into the seed early in the development of the fruit, with little or no damage to the edible fruit. In the seed, the larvae destroy the cotyledons, thus reducing seed germination. The presence of seed weevils is a major quarantine barrier for the export of mango to many countries.

Other pests

Other insect and mite pests of mango include fruit spotting bugs (*Amblypelta lutescens*, *A. nitida*), seed caterpillars, planthoppers, flower-feeding caterpillars (Geometridae, Lymantriidae, Noctuidae, Pyralidae, and Torticidae families), thrips (*Selenothrips rubocinctus*), leaf miners (*Acrocercops* sp.), fruit piercing moths (*Othreis* sp.), termites (*Isopetra* sp.), mites (*Eriophyes mangifera*, *Oligonychus coffeae*), and coccids (*Coccus* sp.).

Diseases and disorders

A range of leaf, fruit, and soil diseases can affect mango, many of which can be adequately controlled with good management and judicious use of fungicides and bactericides. Detailed discussions of individual diseases can be found in the books listed in the recommended reading section. A brief description of the major diseases of concern are listed below.

Anthracnose

Anthracnose (*Colletotrichum gloeosporiodies*) is a serious fungal disease of flowers, fruit, and leaves. At flowering and early fruit development, anthracnose causes the flowers and young fruit to develop black lesions and be aborted from the inflorescence. Wet conditions during flowering promote anthracnose development. After the fruit reaches approximately 4 cm (1.6 in) in diameter, the fruit's natural defense mechanisms protect it from anthracnose by inducing the fungus into a quiescent period. When the fruit softens during the ripening process, the natural defense mechanisms break down, and latent infections of anthracnose develop into black lesions that rot the whole fruit in days. Postharvest anthracnose is the major reason for losses of mangos during storage and transport.

Mango scab

Mango scab (*Elsinoe mangiferae*) is a fungal disease that affects leaves, stems, and young fruit. On the stems and leaves, scab lesions form numerous, slightly raised, gray, oval to elliptical lesions. In young fruit, black, scabby lesions develop that in severe infections can cause the fruit to drop off. As the fruits grow, scar tissue develops around the black lesions, making them unmarketable due to blemishes. The lesions do not expand after harvest. Mango scab is more prominent in wetter regions.

Bacterial black spot

Bacterial black spot (*Xanthomonas campestris* pv. *Mangiferaeindicae*) is a bacterial disease of the leaves and fruit. The disease is worse in windy areas and in trees with low vigor. The disease is identified on the leaves by raised black lesions with greasy margins delineated by leaf veins. Fruit lesions initially appear as small, irregular, water-soaked spots around lenticels. Later, lesions become raised with a greasy appearance, cracking, and oozing bacteria-laden sap. The disease is spread in wind-driven water from lesions to natural openings and wounds on the tree.

Internal physiological disorders

Several internal physiological disorders can affect the flesh and eating quality of mangos. Some common forms of these disorders are

- "jelly seed"—premature ripening from around the seed
- "soft nose"—premature softening of the nose of the fruit
- "spongy stem end"—breakdown of the flesh and vascular tissue at the stem end
- "internal breakdown"—premature ripening and cellular breakdown of the flesh.

Symptoms vary among varieties of mango, but all of the above disorders are thought to be associated with low fruit calcium levels.

Other fruit diseases

Alternaria rot (*Alternaria alternata*)
Powdery mildew (*Oidium mangiferae* Berthet)
Stem end rot (*Lasiodiplodia theobromae, Dothiorella dominicana* or *Phomopsis mangiferae*)
Mango malformation (*Fusarium* sp.)

Other disadvantages

The sap that spurts and oozes from the fruit and peduncle when harvesting is highly caustic and toxic. Contact with human skin can cause severe dermatitis, rash, and blistering that requires medical attention. These are common ailments of mango pickers. Some people are hypersensitive ,and contact through picking, peeling, or eating a mango can cause swelling of the lips, throat, face, and other skin.

During harvesting, any sap that contacts the fruit will burn the skin, leaving dark, unattractive, sunken blemishes known as sap burn. Commercial mango farmers go to a lot of effort to prevent the sap from contacting the fruit or contaminating the wash water during the harvest and packing operations.

Potential for invasiveness

Mango is not an aggressively invasive species, but some wild trees can be found in native forest areas suited to their growth. The seeds can be carried by birds, bats, and other animals.

AGROFORESTRY/ENVIRONMENTAL PRACTICES

Crop shade/overstory

Mangos do not make a good overstory tree for cropping shade-tolerant species because their dense canopy produces 100% shade.

Livestock shelter

The dense canopy and tolerance of soil compaction make the mango an ideal tree for sheltering livestock from sun and rain. Trees must be protected from animals until the canopy is higher than grazing height.

Sap oozing from mango stem attachment is highly caustic. PHOTO: I. S. E. BALLY

Homegardens
Mangos are used as shelter and shade trees in villages and homegardens. Two or three trees make an excellent addition to tropical homegardens in areas favorable to fruit production.

Fence posts
Mango wood is soft and rots rapidly when exposed to the elements, so it is not suitable for fence posts. However, mangos have been used as living fence posts.

Windbreaks
Mangos are sometimes used in mixed-species windbreaks, but their dense canopies cause wind turbulence, reducing windbreak effectiveness. Fruit production and quality is poor on wind-exposed trees.

Silvopasture
Mangos grow well in pastures, although cattle will graze off lower leaves. It is necessary to fence off young trees for the first 3–4 years to protect them from livestock.

Native animal/bird food
Mango fruits are a food source for many birds, fruit bats, wild pigs, and rodents.

USES AND PRODUCTS
Mangos have long been recognized as more than just edible ripe fruit. The edible uses of the fruit include non-ripe fruit, seed, and processed products such as achars, chutneys, preserves, etc. The fruit is eaten for its nutritional value, its medicinal value, and for its pleasant flavor. The fruit and its by-products are used for animal fodder, and the timber is used for canoe building and making charcoal. Today mango and its flavor are added to many products, such as fruit juices, ice creams, wines, teas, breakfast cereals, muesli bars, and biscuits.

Fruit
Mangos are predominantly grown for their fruit, which is mostly eaten ripe as a dessert fruit. Mature green mangos are also eaten fresh or as pickles. Green eating varieties are distinguished from others by their sweet, non-starchy, non-astringent flavor at the green-mature stage of fruit development. Mature green eating mangos are eaten in several ways throughout the world. In Thailand they are sliced or grated in fresh salad, pickled (ma mung dong), soaked in water and sugar (ma mung chaien), salted and dried (ma mung khem), sliced in vinegar or fish sauce (ma mung pla wa arn), or eaten as a crunchy fruit. In many places, e.g., Samoa, the fruits are eaten green because someone else will eat them if one waits for ripening or because fruit fly larvae are not yet developed. Fresh mangos are processed and preserved into a wide range of products including pulps, juices, frozen slices, dried slices, pulp (fruit leather), chutneys, jams, pickles, canned in syrup, and sliced in brine.

Mangos are a highly nutritious fruit containing carbohydrates, proteins, fats, minerals, and vitamins, in particular vitamin A (beta carotene), B_1, B_2, and vitamin C (ascorbic acid). As the fruit ripens, concentrations of vitamin C decrease and glucose, fructose, and sucrose concentrations increase. Mangos make a significant seasonal contribution to diet of many Pacific islanders that primarily have a starch-based diet.

Flavoring/spice
Mango purees and essences are used to flavor many food products such as drinks, ice creams, wines, teas, breakfast cereals, muesli bars, and biscuits.

Nut/seed
In parts of India the seed is eaten as a boiled or baked vegetable or ground into a starchy flour.

Leaf vegetable
Young leaves, still rose or bronze colored, can be boiled to render them edible. Although the cooked leaves hold their shape and are attractive, their resinous flavor is an acquired taste. Some varieties are more suitable for eating in this manner (Martin et al. 1998). Young leaves of the related

species *Mangifera pajang* are eaten as vegetables in Sarawak.

Beverage/drink/tea

Alcoholic beverages made from mangos include wines and liquors made in Australia and India. Specialty teas are occasionally flavored with fragrant mango flowers.

Medicinal

In addition to mango's food value, it has also been used for its medicinal value. In Samoa, a bark infusion has been a traditional remedy for mouth infections in children (pala gutu), and in Tonga, infusions of leaves of mango, the orange (*Citrus sinensis*), and other species are used to make a potion to treat relapse sickness (kita).

In India, a drink made from unripe mango fruit is used as a remedy for exhaustion and heat stroke. Half-ripe fruit eaten with salt and honey is used for a treatment of gastro-intestinal disorders, bilious disorders, blood disorders, and scurvy. Ripe mangos are a rich source of vitamin A, and are used to treat vitamin A deficiencies such as night blindness. Diabetes has been treated with a drink made from the infusion of fresh mango leaves. Dried mango seed ground into flour is used to treat diarrhea. Diarrhea and throat disorders are treated by gargling bark extracts mixed with water. In India, fruit sap has been used to treat the pain of bee and scorpion stings. Many of the traditional Indian medicinal uses of mango involve eating unripe fruit. It should be noted that unripe fruit contains a lot of the toxic sap that when eaten in excess can cause throat irritation, indigestion, dysentery, and colic.

Animal fodder

Livestock will graze on mango leaves and eat fallen fruit. The leaves can be toxic if consumed in large quantities. Seeds and by-products of processing fruit have been used to feed cattle, poultry, and pigs.

Honey

Mango flowers are a rich source of nectar collected by honey bees.

Timber

Mango timber when properly seasoned has been used in furniture, for carving, as wall and floor paneling, and utensil manufacture. The timber is gray-brown, often with a pink tinge. It is coarse-textured hardwood that is easy to work and finishes well. The timber breaks down rapidly if exposed to the elements without preservation treatment.

Mangos make a wonderful addition to homegardens, such as here in Apia, Samoa where other popular homegarden trees include breadfruit, coconut, citrus, and vi (*Spondias dulcis*). PHOTO: C. ELEVITCH

Fuelwood

Mango wood makes excellent charcoal.

Canoe/boat/raft making

In French Oceania and the Cook Islands, mango wood is used for canoe construction.

Tannin/dye

A yellowish-brown dye used for silk is extracted from the bark.

URBAN AND COMMUNITY FORESTRY

Mangos have traditionally been grown as garden and community trees in many countries. The trees are prized primarily for their delicious fruit, but also valued for their dark green foliage with its periodic splashes of new red-brown leaves. Other aspects such as flood and drought tolerance and a dense spreading canopy that provides shade and shelter for humans and animals, make mangos valued garden trees. Traditionally, mangos have also been grown as shade trees in streets and parks, but their high maintenance and public nuisance have brought them into disfavor in many public situations in recent times.

Size

Mango can reach heights of 15–30 m (50–100 ft). In urban environments cultivated trees are usually maintained to a height of between 3 and 10 m (10–33 ft) when mature.

Rate of growth

Mangos are fast-growing trees, often growing in excess of 1.5 m (5 ft) per year when well tended in urban conditions.

Roots

Mango roots are extensive and build up around water sources such as leaking pipes and water spigots. In mature trees, major roots will come to the surface and may disrupt lawns or paved surfaces for a distance from the trunk equal to the spread of the canopy. Aside from the area under the canopy, there is little danger mango roots will raise pavement or foundations.

Household uses

The fruit from the mango can be eaten as a ripe fruit or processed into a range of products such as achars, chutneys, jams, pulps, juices, and canned or frozen. The unripe green fruit is commonly eaten throughout the Pacific, picked fresh as a snack or dipped in salt or soy sauce. The green fruit is also commonly pickled, peeled, and sliced.

Light requirements

Mangos prefer full sun. Where grown in shaded situations, the canopy becomes thin and weak. Fruiting is greatly reduced and the fruit lose their attractive blush.

Water/soil requirements

Mangos grow in most soil types from heavy clays to light sands but prefer well drained lighter soils. Mangos are generally tolerant of many harsh soil conditions. Over hard, compacted subsoil or smooth lava (such as paho'eho'e) that is impenetrable by the roots, trees may become unstable in high winds, be more subject to drought, and growth may become stunted.

Expected life span in a homegarden

Mango trees are long-lived and can be expected to survive as mature trees for over 100 years.

Varieties favored for use in a homegardens

There are many named and unnamed mango varieties grown throughout the Pacific islands. The most suitable varieties to grow in the homegarden is a matter of personal taste and how the tree is to be used. Small or dwarf mango varieties are suitable for smaller gardens where space is limited. Some of these varieties include 'Keitt', 'Fairchild', 'Rapoza', 'Willard', and 'Irwin'. Larger more vigorous varieties are suitable where the trees are to provide shade and shelter. Some of these varieties include: 'Haden', 'Kensington Pride', 'Gouviea', 'Mapulehu', and 'Ah Ping'. If there is

Nutritional value of 100 g fresh mango pulp. (Source: USDA Nutrient Database for Standard Reference, Release 14 July 2001)

Constituent	Amount in 100 g fresh pulp
Water	81.7 g
Energy	65 kcal (272 kj)
Protein	0.51 g
Fats	0.27 g
Carbohydrates	17.00 g
Total dietary fiber	1.8 g
Ash	0.50 g
Minerals	
calcium	10 mg
iron	0.13 mg
magnesium	9.0 mg
phosphorus	11 mg
potassium	156 mg
sodium	2 mg
zinc	0.04 mg
copper	0.11 mg
manganese	0.027 mg
selenium	0.6 mcg
Vitamins	
vitamin C (total ascorbic acid)	27.2 mg
thiamine	0.056 mg
riboflavin	0.57 mg
niacin	0.584 mg
pantothenic acid	0.16 mg
vitamin B_6	0.160 mg
total folate	14 mcg
vitamin A, IU	3894 IU
vitamin A, RE	389 mcg_RE
vitamin E	1.120 mg_ATE
tocopherols, alpha	1.12 mg
Lipids	
total saturated fatty acids	0.066 g
total monounsaturated fatty acids	0.101 g
total poly unsaturated fatty acids	0.051 g
cholesterol	0.00 mg
Amino acids	
Tryptophan	0.008 g
Threonine	0.019 g
Isoleucine	0.018 g
Leucine	0.031 g
Lysine	0.041 g
Methionine	0.005 g
Phenylalanine	0.017 g
Tyrosine	0.01 g
Valine	0.026 g
Arginine	0.019 g
Histidine	0.012 g
Alanine	0.051 g
Aspartic acid	0.042 g
Glutamic acid	0.06 g
Glycine	0.021 g
Proline	0.018 g
Serine	0.022 g

A quick-bearing crop such as papaya can be grown between mango seedlings for the first few years, after which the mangos start filling the open space and begin bearing a fruit crop. PHOTO: C. ELEVITCH

room for more than one mango tree, two or more varieties with different bearing seasons can be selected to extend the time ripe fruit is available.

Seasonality of leaf flush, flowering, fruiting

Mangos generally flower in the coolest and driest part of the year and the fruits develop through the spring and early summer to ripen in the hottest part of the year. Leaf flushing (periodic growth of new leaves) can occur throughout the year, but is usually concentrated in the summer months after the fruits ripen and often coincides with summer rains. Mangos shed leaves continuously throughout the year, but most of the annual leaf shedding occurs immediately after each new growth flush.

Ornamental values

Mango flower colors differ among varieties and range from green through yellow and pink to dark red. Inflorescences (flower stalks) vary in length from 12 to 50 cm (5–20 in). The inflorescences are usually abundant and provide an attractive contrast to the dark-green foliage. In many mango varieties the young expanding leaves are a dark chocolate brown or purple color that turns gradually to dark green as the leaves reach full size and harden.

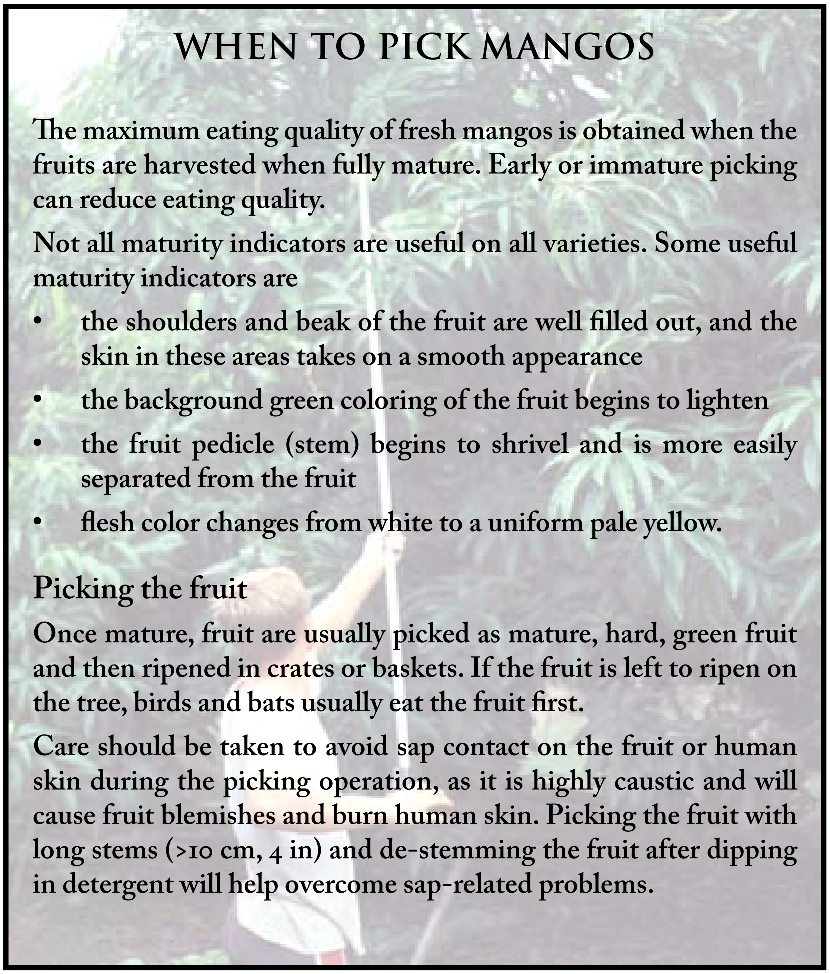
Bird/bee/wildlife

Mango trees attract a range of wildlife (birds, bats, and other fruit-eating creatures). During the fruiting season, fruit bats and fruit-eating birds are attracted to the tree. Bees visit the flowers, but most pollination is done by flies.

Maintenance requirements

Fertilizer Mangos grown in the homegarden generally do not need regular fertilizer; however, if the foliage appears light green or yellowish, it can be greened up by the application of 0.5–2 kg (1.1–4.4 lb) of a well balanced fertilizer once or twice a year.

Watering Although mangos are able to withstand periodic drought, it is best to water the trees during the dryer months. Watering mango trees when the flowers and fruit are on the tree will improve the fruit set and size of the fruit at harvest.



WHEN TO PICK MANGOS

The maximum eating quality of fresh mangos is obtained when the fruits are harvested when fully mature. Early or immature picking can reduce eating quality.

Not all maturity indicators are useful on all varieties. Some useful maturity indicators are

- **the shoulders and beak of the fruit are well filled out, and the skin in these areas takes on a smooth appearance**
- **the background green coloring of the fruit begins to lighten**
- **the fruit pedicle (stem) begins to shrivel and is more easily separated from the fruit**
- **flesh color changes from white to a uniform pale yellow.**

Picking the fruit

Once mature, fruit are usually picked as mature, hard, green fruit and then ripened in crates or baskets. If the fruit is left to ripen on the tree, birds and bats usually eat the fruit first.

Care should be taken to avoid sap contact on the fruit or human skin during the picking operation, as it is highly caustic and will cause fruit blemishes and burn human skin. Picking the fruit with long stems (>10 cm, 4 in) and de-stemming the fruit after dipping in detergent will help overcome sap-related problems.

Pruning If left unpruned, mangos can become very large trees (15–30 m [50–100 ft]). Pruning to limit tree size or provide clearance from buildings and roads is common practice and usually needs to be done every 1–2 years. Pruning may also be necessary to thin the canopy and remove any dead branches inside the canopy. Mangos are very tolerant of pruning and limbs of any size can be removed. After heavy pruning it is common for trees to flower and crop poorly the next season, with increasing harvests in following seasons.

Drawbacks

Mangos are considered a messy tree because they tend to continuously drop leaves and other material. At late flowering/early fruit set, the tree drops the aborted flowers and inflorescence branchlets, which can stain concrete or cars parked beneath. Mangos naturally thin their fruit crop, shedding aborted fruit from flowering until fruit are almost full size. These fruits have a high sap content that can stain concrete, kill grass, and strip paint from cars.

Mango branches are brittle and can break during heavy wind storms or with heavy crop loads. It is also common for branches to snap under the weight of a person climbing the tree to pick the fruit.

Nuisance issues

Fruit that is allowed to ripen and fall to the ground quickly begins to rot. Because they are smelly as they rot, ripe fruits attract vermin such as rodents and feral pigs. Decaying fruit kills grass in patches and clogs up mowing equipment.

Hazards

Mango trees in urban spaces such as car parks, sports fields, and public walkways can be a problem during the fruiting season. Ripe fruit falling from trees is not only a hazard when falling, but rotting fruits on the ground present a hazard as they are slippery if stepped on (just like banana peels). The sap that exudes from the stems of fruit is highly caustic and toxic, and contact with unprotected skin can cause severe blistering and rashes that can require medical attention. Skin and eye protection should be used when picking the fruit. In hypersensitive people, consumption of the fruit can cause swelling of the lips, throat, and face.

Common pest problems

Mangos are susceptible to a range of pests and diseases that affect the tree and fruit. In general, the pests in garden trees exist at low levels in balance with their predators and do not require any specific control measures. For severe pest infestations, see the "Pests" section above.

Other

Along with coconut and breadfruit, mango is one of the most common homegarden fruits in the Pacific. The popularity of the mango comes from the almost universally-loved fruit, which can be too costly for most households to purchase. A mature tree of a selected variety can reliably produce enough fruit for a family, with extra to preserve in various ways or share with friends and neighbors. The shade and shelter provided by the dense, spreading canopy of the mango has traditionally been a focal point for work and social gatherings in the Pacific.

COMMERCIAL PRODUCTS

Commercial mango production is carried out in several

Pacific nations including Hawai'i, Fiji, and the Solomon Islands.

Tree spacing

Tree spacing is governed by the variety and climate. Traditional spacings were wide (up to 12 x 12 m, 70 trees/ha; 40 x 40 ft, 28 trees/ac) as trees were allowed to grow to full size. In more recent times, tree spacing has been reduced and trees are maintained at smaller sizes. This facilitates pest and disease control and harvesting operations. Smaller compact varieties can be planted as close as 7 x 4 m or 375 trees/ha (23 x 13 ft, 152 trees/ac).

Pruning

Managed orchard trees require regular annual pruning to maintain an open canopy of manageable size. This allows air and sunlight to penetrate, which reduces pests and diseases and enhances internal fruit color. Mangos can be heavily pruned with little effect on tree health, although heavy pruning may stimulate excessive vegetative growth at the expense of flowering and fruiting.

Irrigation

Irrigation during the flowering and cropping period can greatly increase the number of flowers and the number and size of fruits at harvest.

Fertilizer

As a rule, mangos do not require large amounts of fertilizer. Overfertilization can be detrimental to yield, promoting excessive vegetative vigor at the expense of flowering and fruiting. Mangos are especially sensitive to nitrogen, which not only promotes vigor but also reduces fruit color at harvest and reduces the fruits' tolerance of postharvest disease. Various fertilizer schedules can be found in the publications listed in the bibliography below.

Crop manipulation

Manipulation of flowering to increase fruit set is a common commercial practice. Two popular treatments are the application of potassium nitrate (KNO_3) or paclobutrazol to promote flowering. Potassium nitrate works only on some varieties in some climates. Soil drenches with pa-

Regular annual pruning to maintain an open canopy and control the size of the tree is necessary for commercial production. Pruning by climbing into the canopy is a common method for small growers. PHOTO: C. ELEVITCH

CONTEMPLATING GROWING MANGO COMMERCIALLY?

Many issues have to be considered when embarking on commercial mango production. In addition to the obvious production-related issues such as how, where, and what to grow, there are marketing, finance, license, and regulatory issues that need to be considered. A good place to start is by reading a good growing and production handbook and getting advice from an advisory service. Some of these are listed at the end of this publication.

clobutrazol generally increase flowering, encourage early flowering, and reduce vegetative vigor (use of paclobutrazol is subject to registration requirements of the chemical, which may vary with countries). Other techniques that have been used with variable results include cincturing, which involves making a shallow saw cut around the trunk or limb to temporarily ring bark it and restrict the flow of carbohydrates down the limb. Smudging (lighting fires under the trees to smoke the canopy for several weeks) was popular in the Philippines before potassium nitrate became widely used. In some parts of India, root pruning or disruption through cultivation or exposure to the air was used as a flower-inducing treatment.

Harvesting

Fruits are usually harvested by hand or with the help of picking devices. The fruits are handled gently as they are easily damaged by abrasion and sap contamination. Care should be taken to avoid sap contacting the fruit during the harvesting and packing operations, as it is caustic and causes dark, unsightly blemishes on the fruit. Sap can also burn human skin. Mango branches are brittle and can snap without warning. This is a common cause of injury to people climbing trees during harvest.

Postharvest care

To maximize the storage life of mangos, fruits are generally dipped in hot water and fungicides to slow the development of postharvest fungal rots. Controlled cool temperatures are also essential if fruit quality is to be maintained during storage. Temperatures will vary depending on the stage of fruit ripeness and variety. Ethylene gassing is used to trigger even ripening in stored fruit.

Specific detailed information on the various aspects of commercial mango production can be found in the publications listed in the bibliography below.

INTERPLANTING/FARM APPLICATIONS

Mango is often used in a mixed cropping or interpolating situation. When mango trees are young, they can be mixed with smaller crops such as papaya, coffee, and vegetables. As the trees become larger, they cast heavy shade, and their roots out-compete smaller species. Mature mangos can be successfully mixed with other similarly vigorous species such as jackfruit, avocado, breadfruit, coconut, guava, or rambutan.

PUBLIC ASSISTANCE AND AGROFORESTRY EXTENSION

Extension offices for agroforestry and forestry in the Pacific: <http://www.traditionaltree.org/extension.html>.

GERMPLASM RESOURCES

Collections of mango varieties and related species are maintained in many tropical and subtropical countries on most continents. Because of the short storage viability of the seed, collections are held as mature growing trees, usually maintained by research organizations involved in mango improvement in the region. In the Pacific, the major collections are held in Hawai'i, Australia, and Fiji as listed below. Collections of *Mangifera* from other parts of the world are listed in the International Plant Genetic Resources Institute (IPGRI) web site <http://web.ipgri.cgiar.org/germplasm>.

Locations of major mango collections for the Pacific region

Australia

Queensland Department of Primary Industries
PO Box 1054, Mareeba QLD 4880, Australia
E-mail: ian.bally@dpi.qld.gov.au

Fiji

Botany Section, Koronivia Research Station
PO Box 77, Nausori, Fiji

Philippines

Institute of Plant Breeding, College of Agriculture, UPLB College, Laguna, Philippines
E-mail: opd@ipb.uplb.edu.ph

United States including Hawai'i

Subtropical Horticultural Research Unit, National Germplasm Repository–Miami

13601 Old Cutler Road
Miami, FL 33158 USA
E-mail: mia@ars-grin.gov

INTERNET

Queensland Department of Primary industries mango information: <http://www.dpi.qld.gov.au/thematiclists/1088.html>.

General crop information: <http://www.extento.hawaii.edu/kbase/crop/crops/I_mango.htm and http://www.crfg.org/pubs/ff/mango.html>.

The Mango: Asia's King of Fruits. (Douthett, D.G. 2000. Southern Illinois University Carbondale): <http://www.siu.edu/~ebl/leaflets/mango.html>.

Mango varieties suited for unripe eating: <http://www.dpi.qld.gov.au/horticulture/5332.html>.

Grafting mangos: <http://www.dpi.qld.gov.au/horticulture/5328.html>.

Mango crop production questions and answers: <http://www.dpi.qld.gov.au/horticulture/5240.html>.

Postharvest processing: <http://www.ba.ars.usda.gov/hb66/contents.html>.

Anthracnose: <http://www.dpi.qld.gov.au/business/7318.html>.

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Species Profiles for Pacific Island Agroforestry (www.traditionaltree.org)

Mangifera indica (mango)

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Acknowledgments: The author and publisher thank Richard Campbell, Dale Evans, Heidi Johansen, Diane Ragone, and Art Whistler for their input.

Recommended citation: Bally, I.S.E. 2006. *Mangifera indica* (mango), ver. 3.1. In: Elevitch, C.R. (ed.). Species Profiles for Pacific Island Agroforestry. Permanent Agriculture Resources (PAR), Hōlualoa, Hawai'i. <http://www.traditionaltree.org>.

Sponsors: Publication was made possible by generous support of the United States Department of Agriculture Western Region Sustainable Agriculture Research and Education (USDA-WSARE) Program; SPC/GTZ Pacific-German Regional Forestry Project; United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS); USDA Forest Service Forest Lands Enhancement Program; State of Hawai'i Department of Land & Natural Resources Division of Forestry & Wildlife; Kaulunani, an Urban Forestry Program of the DLNR Division of Forestry and Wildlife and the USDA Forest Service; and Muriel and Kent Lighter. This material is based upon work supported by the Cooperative State Research, Education, and Extension Service, U.S. Department of Agriculture, and Agricultural Experiment Station, Utah State University, under Cooperative Agreement 2002-47001-01327.

Series editor: Craig R. Elevitch

Publisher: Permanent Agriculture Resources (PAR), PO Box 428, Hōlualoa, Hawai'i 96725, USA; Tel: 808-324-4427; Fax: 808-324-4129; E-mail: par@agroforestry.net; Web: <http://www.agroforestry.net>. This institution is an equal opportunity provider.

April 2006
ver. 3.2

Metrosideros polymorpha (ʻōhiʻa lehua)

Myrtaceae (myrtle family)

ʻōhiʻa, ʻōhiʻa lehua, lehua **(Hawaiʻi)**

J. B. Friday and Darrell A. Herbert

IN BRIEF

Distribution Endemic to the six largest Hawaiian islands.

Size Greatly variable, typically reaches 20–24 m (66–79 ft) in height; may be much smaller on lava rock or boggy soils.

Habitat Wide range, 1–2500 m (1–8200 ft) elevation with rainfall of 400–10,000 mm (16–400 in). Largest component of lowland and montane wet and mesic forests, dry forests, subalpine shrublands, and new lava flows.

Vegetation Associated with dozens of other native species.

Soils Very widely adapted, occurring on medium and heavy clay uplands; tolerates rocky soils and organic soils forming on recent lava flows.

Growth rate Slow growing, 0.3–0.6 m (12–24 in) per year in height, and 1–3 mm (0.04–0.12 in) in stem diameter per year.

Main agroforestry uses Windbreak, shade, ornamental.

Main products Pole wood, fuelwood, honey source

Yields High-volume, old-growth stands may yield 70–84 m^3/ha (1000–1200 ft^3/ac or 5000–6000 bf/ac); stands on poor soils such as lava rock may yield much less.

Intercropping Used in farm cultivation only when naturally present due to very slow establishment and growth.

Invasive potential Poses a serious risk of being invasive if introduced outside of Hawaiʻi.

PHOTO: J. B. FRIDAY

Huge old ʻōhiʻa tree at Kīpuka Puaulu, Hawaiʻi Volcanoes National Park. Note the deeply fluted bole and the sparse crown.

INTRODUCTION

The native Hawaiian ʻōhiʻa (*Metrosideros polymorpha*) is the most abundant tree in the Hawaiian Islands. The name *Metrosideros* is derived from the Greek *metra*, heartwood, and *sideron*, iron, in reference to the hard wood of the genus (Dawson and Stemmermann 1999). Known locally by its Hawaiian name, ʻōhiʻa lehua, the species is found on all the major islands and in a variety of habitats. Distributed from near sea level to the tree line (2500 m [8200 ft]), the species exhibits tolerances of frost, volcanic vapors, and excesses or deficiencies in moisture. It is found across a rainfall gradient having extremes of less than 400 mm (16 in) to over 10,000 mm (400 in) on Mt. Waiʻaleʻale, Kauaʻi, one of the wettest places on earth. ʻŌhiʻa is found growing on a broad range of substrates including those as young as recent lava flows or as old as highly weathered Oxisols. Dominant in cloud forests and most rainforests above 400 m (1300 ft), often with a tree fern understory, the species is also common in seasonally wet forests, where it may be dominant or in mixtures with the native *Acacia koa* or the invasive species *Morella faya* (formerly *Myrica*) (Mueller-Dombois and Fosberg 1998).

ʻŌhiʻa is a slow-growing broad leaf evergreen whose form, foliage, and flower color can vary greatly from site to site. Representatives of the species can reach a stature as great as 30 m (100 ft) on well drained soils with sufficient moisture, while others in boggy sites can be fully mature when only a few cm tall. This phenotypic variation, affected by environment, allows the species to adjust to the extreme range of conditions listed above (St. John 1979, Stemmermann 1983, Aradhya et al. 1991). The resulting expressions of morphological variation lie at the heart of the species name *polymorpha* (meaning "many forms") and have prompted investigations into the genetic variations. The species is thought to be an example of how one ancestral species can begin to diversify and evolve into many species when isolated in an island environment (incipient speciation). It may also be that ʻōhiʻa remains a generalist with broad plasticity.

There are many modern and ancient uses for the flowers, leaves, and wood of ʻōhiʻa, but the forests are perhaps most highly valued for aesthetics, watershed protection, and as habitat for Hawaiʻi's native and endemic biota. The species itself is a critical food source to endemic nectivorous and insectivorous birds (Berger 1981, Smith et al. 1995), and critical specific habitat to endemic *Achatinella* and *Partulina* tree snail species (Hadfield and Mountain 1980, Hadfield and Miller 1989). However, past land-use practices have resulted in the reduction of ʻōhiʻa's range, largely through land-use conversion to cattle pasture and agriculture. Because mature stands may experience canopy decline and dieback of age-cohorts (Mueller-Dombois 1983, 1985, 1987), Hawaiʻi's early foresters experimented with the replacement of some forest stands with introduced species for the purposes of maintaining watershed integrity and creating a potentially renewable timber industry. In recent years there have been efforts to restore some of these lost ranges.

DISTRIBUTION

The natural distribution is limited to the six largest islands in the Hawaiian archipelago: Hawaiʻi, Maui, Molokaʻi, Lānaʻi, Oʻahu, and Kauaʻi.

Location of introductions

ʻŌhiʻa is planted as an ornamental plant in New Zealand, where there are several other native species of *Metrosideros* (Adams 1967).

BOTANICAL DESCRIPTION

Preferred scientific name

Metrosideros polymorpha Gaud.

Family

Myrtaceae (myrtle family)

Non-preferred scientific names

Metrosideros collina (not itself a synonym, but several infraspecific taxa described under it are)
M. haleakalensis
M. lutea
Nania glabrifolia
N. lutea
N. polymorpha

Common names

ʻōhiʻa, *ʻōhiʻa lehua*, *lehua* (Hawaiʻi). The common names are often written without the Hawaiian diacritical marks, i.e., ohia or ohia lehua.

Growth, form, and size

Growth form ranges from tall trees to small erect or prostrate shrubs. Crowns may be compact or open-branched. Height of crown base may be low when growing in open habitat, but branching begins at mid-stem or higher in closed canopy forest. On moist, deep soils, ʻōhiʻa grows to 20–24 m (66–79 ft) in height with a diameter at breast height (dbh) of 45–90 cm (18–36 in). Trees to 30 m (100 ft) in height and 216 cm (85 in) dbh have been recorded (Lamb 1981, Elevitch pers. obs.). The bole may be straight,




Top left: Flower buds close to opening. Top right: Ripening seed capsules; open capsules show tiny seeds within. Bottom left: Jack Jeffrey shows the common red flower, so familiar in the remaining native Hawaiian forests. Bottom right: Typical appearance of bark. PHOTOS: C. ELEVITCH

cylindrical and smooth, or twisted and deeply fluted. Forest trees may often have tall stilt roots, as these trees grow from seedlings that germinate on fallen logs or fallen hāpu'u (*Cibotium* spp., tree fern) stems, which rot away by the time the tree matures. Some trees may sprout bunches of aerial roots. Shrub growth forms predominate on poorly drained, dry or rocky soils, and at high altitude (Skolmen 1974a, Little and Skolmen 1989, Adee and Conrad 1990, Mueller-Dombois and Fosberg 1998, Dawson and Stemmermann 1999).

Flowers

Flowers are usually red but sometimes salmon, pink, yellow, or orange. Clusters of flowers are about 5–8 cm (2–3 in) wide and are on the terminal ends of the branches. The bunches of stamens extend 1–3 cm (0.4–1.2 in) out from the flower and give the blossoms a pompom, brush, or hair-like appearance. The Hawaiian name *lehua* (from *'ōhi'a lehua*) refers to the hair-like appearance of the blossoms (Rock 1974). Flowers occur in inflorescences of 2–5 pairs of cymules; peduncles 7–18 mm (0.28–0.7 in) long; pedicels 2–8 mm (0.08–0.32 in) long; bracts ovate to suborbicular, 5–10 mm (0.2–0.4 in) long; sepals rounded to triangular, 1.5–4 mm (0.06–0.16 in) long; petals obovate to orbicular, 2.5–5 mm (0.1–0.2 in) long; stamens 10–30 mm (0.4–1.2 in) long; style 13–30 mm (0.5–1.2 in) long (Dawson and Stemmermann 1999). Each cluster of flowers lasts several days. Flowers are pollinated by both birds and insects. Yellow flowers have been shown to be self-compatible, while red flowers are partially self-incompatible and require a pollinator for good seed set (Carpenter 1976).

Pink flowers. PHOTO: J. B. FRIDAY

Yellow flowers. PHOTO: J. B. FRIDAY

Salmon flowers. PHOTO: C. ELEVITCH

Leaves

Foliage varies from thick, dark greenish-gray with dense surface fuzziness, primarily on the lower surface of the leaf, to thin, bright green, and smooth. Leaves are opposite and clustered at the ends of the branches. Leaf shape is highly variable, ranging from round to oval to egg-shaped, 1–8 cm (0.4–3.1 in) long, 1–5.5 cm (0.4–2.2 in) wide. Several pairs of raised veins radiate from the base. Upper surface is smooth, lower surface smooth or woolly or fuzzy. Margins are flat to turned under, apex rounded or sometimes pointed, base wedge-shaped or heart-shaped. Petioles are 1–16 mm (0.04–0.63 in) long, 1–3 mm (0.04–0.1 in) wide, but can be sessile, especially at high elevation (Dawson and Stemmermann 1999).

Fruit

Fruiting capsules are 3–10 mm (0.1–0.4 in) long and wide, smooth or fuzzy (Dawson and Stemmermann 1999).

Seeds

The seed capsules contain many minute seeds. There are approximately 1750 seeds per gram (50,000 seeds/oz).

Similar or look-alike species

There are about 50 species in the genus *Metrosideros* in Southeast Asia and the Pacific (Wagner et al. 1999). *Metrosideros kermadecensis*, from the Kermadec Islands off of New Zealand, has escaped from cultivation on Maui and may be considered a pest species (Evenhuis and Eldredge 2004). The pohutukawa tree of New Zealand, *Metrosideros excelsa* (syn. *M. tomentosa*), is sometimes planted as an ornamental in Hawai'i but is not reported to have escaped from cultivation (Kinsey, undated). Several cultivars of *M. excelsa* are grown. 'Ōhi'a was originally classified as a variety of *Metrosideros collina,* a related tree of Tahiti, Rarotonga, and other islands in the South Pacific, but now is seen as a species endemic to Hawai'i (Little and Skolmen 1989).

How to distinguish from similar species/look-alikes

The flowers of *Metrosideros excelsa* and *M. kermadecensis* are dark crimson in color, as opposed to the more orange-red of *M. polymorpha,* and the young buds and undersides of leaves are covered in a silvery-white felt. *Metrosideros kermadecensis* is a smaller tree with brighter red flowers than *M. excelsa*. A variegated leaf variety of *M. kermadecensis* is also cultivated. *Metrosideros polymorpha* has not been reported to naturalize elsewhere in the Pacific, although it has been introduced to New Zealand as an ornamental plant. The Hawaiian species of *Metrosideros* are characterized by the presence of bud scales and a frequently forking branching pattern.

***Metrosideros kermadecensis*, an exotic to Hawai'i not recommended for planting, has darker crimson leaves than 'ōhi'a, and a silvery-white felt on the underside of the leaves.** PHOTO: FOREST AND KIM STARR, USGS

GENETICS

Eight varieties of the Hawaiian *Metrosideros polymorpha* complex are recognized on the basis of classical taxonomy (Wagner et al. 1999). In addition to the *M. polymorpha* varieties, four distinct species are also recognized: *M. macropus, M. rugosa*, *M. tremuloides*, and *M. waialealae*. Genetic distinctions between varieties are not clear, but isozyme analyses suggest variability between populations are a likely case of incipient speciation (Aradhya et al. 1991). Altitudinal, soil-based, and successional ecotypes have been proposed on the basis of morphological variations, especially in leaves (Corn and Hiesey 1973, Stemmermann 1983, Stemmermann and Ihsle 1993, Adee and Conrad 1990, Mueller-Dombois 1994, Kitayama et al. 1997). Intraspecific hybridization has been demonstrated (Corn 1979). Genetic differences correlate with environmental differences, although in some cases differences within phenotypic varieties may be greater than between varieties, and many intermediate phenotypes exist (James et al. 2004).

Variability of species

The species occurs in a range of forms from prostrate shrubs to tall trees. Leaves range greatly in both size and shape and may be smooth to fuzzy or woolly. Flowers may be red, pink, salmon, orange, yellow, and many shades in between.

Known varieties

There are eight known varieties (see table), some of which are restricted in geographic distribution across the main Hawaiian islands.

Table. ***Metrosideros polymorpha*** **varieties**

dieteri	Middle to high elevations on Kaua'i. Small trees. Leaves with raised veins.
glaberrima	Middle to high elevations on O'ahu, Moloka'i, Lāna'i, Maui, Kaua'i, and Hawai'i. Shrubs to tall trees.
incana	Low to middle elevations on O'ahu, Moloka'i, Lāna'i, Maui, and Hawai'i. Shrubs to tall trees.
macrophylla	Middle elevations on Hawai'i. Small to tall trees. Relatively large leaves.
newelli	Low to middle elevations on Hawai'i, usually along watercourses. Small to large trees.
polymorpha	Middle to high elevations on O'ahu, Moloka'i, Lāna'i, Maui, and Hawai'i. Small to large trees. Leaves usually with dense woolly pubescence on lower surface.
pumila	Middle to higher elevation swamps on Kaua'i, Moloka'i, and Maui. Prostrate shrubs.
pseudorugosa	Higher elevation bogs on West Maui. Prostrate shrubs.

ASSOCIATED PLANT SPECIES

'Ōhi'a is by far the dominant forest tree in Hawai'i and makes up most of the biomass in most lowland and montane wet and mesic forests. 'Ōhi'a also occurs as a major component of the vegetation in dry forests, subalpine shrublands, and on new lava flows. 'Ōhi'a forests in wet areas with deep soil are tall in stature with a continuous canopy, whereas scattered 'ōhi'a trees occur on new or little-weathered lava flows and in dry areas. Small 'ōhi'a trees grow with other shrub species at high-elevation sites above 2000 m (6500 ft). Open stands occupy young lava flows in wet areas on Hawai'i island, while swampy areas may be occupied by dwarf 'ōhi'a trees, especially on the island of Kaua'i (Adee and Conrad 1990, Wagner et al. 1999).

Associated species commonly found in native habitats

ʻŌhiʻa forms almost pure stands on new lava flows. In older forests it grows as huge old specimens along with up to 40 other tree species (Lamb 1981). In wet and mesic areas above 800 m (2600 ft), where most remaining native forests occur, the next most common tree after ʻōhiʻa is koa (*Acacia koa*). ʻŌhiʻa and koa share the montane forests with smaller tree species such as naio (*Myoporum sandwicense*), kōlea (*Myrsine lessertiana*), ʻōlapa (*Cheirodendron* spp.), pilo (*Coprosma* spp.), kāwaʻu (*Ilex anomala*), manono (*Hedyotis* spp.), alani (*Melicope* spp.), kōpiko (*Psychotria* spp.), and ʻōhiʻa hā (*Syzygium sandwicensis*). The understory is dominated by ferns, including the tree ferns hāpuʻu (*Cibotium* spp.) and ʻamaʻu (*Sadleria* spp.), and shrubs such the native Hawaiian raspberry or ʻākala (*Rubus hawaiensis*) and ʻōhelo (*Vaccinium* spp.). Dryland ʻōhiʻa forests are interspersed with native trees such as lama (*Diospyros sandwicensis*), alaheʻe (*Psydrax odorata*), kauila (*Colubrina oppositifolia*), olopua (*Nestegis sandwicensis*), wiliwili (*Erythrina sandwicensis*), and naio. Lama, alaheʻe, and hala (*Pandanus tectorius*) are also common in the few remaining lowland wet ʻōhiʻa forests, where the understory is frequently the uluhe fern (*Dicranopteris linearis*). At high elevations, above about 2000 m (6500 ft), ʻōhiʻa forms scattered stands and shrublands with māmane (*Sophora chrysophylla*), koa, and naio (Adee and Conrad 1990, Wagner et al. 1999).

Heidi Johansen stands next to a centuries-old ʻōhiʻa lehua tree that has a circumference at breast height of 6.8 m (22.3 ft) and diameter of 2.16 m (7.08 ft). Manukā, South Kona, Hawaiʻi. PHOTO: C. ELEVITCH

Species commonly associated as aboriginal introductions in Pacific islands

Few coastal ʻōhiʻa forests remain, and ʻōhiʻa is rarely seen in cultivated areas in Hawaiʻi, which were originally cleared for agriculture and now support the Polynesian-introduced trees such as coconut, breadfruit (*Artocarpus altilis*), and milo (*Thespesia populnea*).

Species commonly associated in modern times or as recent introductions

Native ʻōhiʻa forests in Hawaiʻi suffer from an onslaught of invasive alien species. Chief among these in the wet forests are strawberry guava (*Psidium cattleianum*), albizia (*Falcataria moluccana*), and various melastomes (for example, *Melastoma* spp., *Clidemia hirta*, and *Miconia calvescens*). ʻŌhiʻa forests in mesic areas suffer invasions from *Morella faya* (formerly *Myrica*), *M. cerifera*, and Christmas berry (*Schinus terebinthifolius*). The understory of ʻōhiʻa forests is often composed of alien grasses, in particular meadow rice grass (*Ehrharta stipoides*), which inhibits regeneration of the trees. Dryland ʻōhiʻa forests are invaded by silk oak (*Grevillea robusta*) and threatened by fires encouraged by invasion of the introduced fountain grass (*Pennisetum setaceum*).

LEGENDARY ʻŌHIʻA LEHUA

Many Hawaiians believe that ʻōhiʻa forests are sacred to Pele, the goddess of volcanoes. When angry, Pele destroys the ʻōhiʻa with streams of lava. It is one of five plants sacred to Laka, the goddess of hula. Many Hawaiian legends include ʻōhiʻa.

In one legend Ka-ehu, the yellow shark of Pearl Harbor, homesick for the beauty of Puna, chanted:

O my land of rustling lehua-trees!
Rain is treading on your budding flowers,
It carries them to the sea.
They meet the fish in the sea.
This is the day when love meets love,
My longings are stirring within me
For the spirit friends of my land.
They call me back to my home, I must return.

(Westervelt 1916)

ENVIRONMENTAL PREFERENCES AND TOLERANCES

Climate

ʻŌhiʻa has a wide environmental amplitude. The species occurs from just above sea level to the tree line (above 2500 m [8200 ft]), where such high-altitude forests are exposed to frost and ephemeral snows. Along moisture gradients ʻōhiʻa can be found distributed between sites as extreme as dry forests with less than 400 mm (16 in) annual rainfall to wet forests and bogs with more than 10,000 mm (33 ft) annual rainfall (Stemmermann and Ihsle 1993, Dawson and Stemmermann 1999). Maximum biomass and optimal growth form occur at mean annual temperatures between 16°C (61°F) and 21°C (70°F) and rainfall between 1000 (40 in) and 3000 mm (120 in) annually (Stemmermann 1983; Stemmermann and Ihsle 1993; Mueller-Dombois 1987, 1994; Adee and Conrad 1990).

Elevation range

1–2500 m (3–8200 ft)

Mean annual rainfall

400–10,000 mm (16–400 in); 1000–3000 mm (40–120 in) preferred

Rainfall pattern

Prefers year-round rainfall, although it grows in areas with seasonal precipitation.

Dry season duration (consecutive months with <40 mm [1.6 in] rainfall)

4 months

Mean annual temperature

10–24°C (50–75°F); 16–21°C (61–70°F) preferred

Mean maximum temperature of hottest month

29°C (84°F)

Mean minimum temperature of coldest month

0°C (32°F)

Minimum temperature tolerated

-4°C (25°F)

Soils

The range of soil types tolerated includes Histosols, Mollisols, Spodosols, Oxisols, Ultisols, and Alfisols (Adee and Conrad 1990, Crews et al. 1995). ʻŌhiʻa is the dominant tree on new, excessively drained lava flows as well as on ancient and water-saturated soils surrounding the Alakaʻi bogs on Kauaʻi (Mueller-Dombois 1994, Herbert and Fownes 1995). ʻŌhiʻa is also dominant on both nutrient-rich and nutrient-depleted soils (Crews et al. 1995, Herbert and Fownes 1999), as well as soils suffering from aluminum toxicity problems (Moomaw et al. 1959, Mueller-Dombois 1994). On exposed ridges, steep slopes, or poorly drained sites ʻōhiʻa does not reach large size and may be reduced to dwarf shrub stature (Adee and Conrad 1990).

Soil texture

ʻŌhiʻa usually grows on medium and heavy clay soils of the Hawaiian uplands. It also tolerates rocky soils and organic soils forming on new lava flows.

Soil drainage

The species develops best on relatively level well drained sites. ʻŌhiʻa does not tolerate poor drainage well and may die out on very poorly drained pāhoehoe (sheet) lava.

Soil acidity

pH 3.6–7.4. ʻŌhiʻa generally grows in acid, weathered soils where the pH may reach as low as 3.6 (Crews et al. 1995). In drier areas ʻōhiʻa may grow in soils that are neutral to mildly alkaline.

Special soil tolerances

ʻŌhiʻa tolerates shallow, rocky soils, and young trees may be found on all but the very freshest lava flows. In other sites, ʻōhiʻa will grow in extremely acid, infertile soils.

ʻŌhiʻa is often one of the first plants to colonize new lava flows. PHOTO: C. ELEVITCH

Dwarf ʻōhiʻa near the Alakaʻi swamp, Kauaʻi, Hawaiʻi. In harsh conditions, or on poorly drained sites, ʻōhiʻa is dwarfed. PHOTO: D. HERBERT

Tolerances

Drought

Well established ʻōhiʻa with deep root systems can persist in extremely dry areas receiving less than 400 mm (16 in) of rain annually. On older substrates in dry areas, ʻōhiʻa forests are replaced by other native dryland species such as lama (*Diospyros sandwicensis*) and alaheʻe (*Psydrax odorata*) (Stemmermann and Ihsle 1993). Droughts in these areas commonly last for 4 months. However, trees growing on shallow lava soils in wetter areas can be killed by droughts of a few weeks.

Full sun

ʻŌhiʻa prefers to grow in full sun.

Shade

The tree tolerates only light shade. It can grow underneath a koa canopy but does not regenerate in its own shade or under other understory trees, relying on treefall gaps in the mature forest.

Fire

ʻŌhiʻa is killed by intense fires, although it may resprout after light fires. Dryland ʻōhiʻa forests are threatened by alien invasive grasses, which allow fires to spread and kill the native trees (Smith and Tunison 1992).

Frost

ʻŌhiʻa tolerates light frosts, but temperatures below –8°C (18°F) permanently damage tissue (Scowcroft et al. 2000, Cordell et al. 2000).

Waterlogging

It does not tolerate waterlogging. Forest dieback is common in high-rainfall areas with underlying heavy clay soils or pāhoehoe (sheet) lava (Hodges et al. 1986).

Salt spray

The species has low salt tolerance and is seldom found where exposed to salt spray, although it is found in sheltered areas down to sea level (Rauch and Hensley 1997).

Wind

ʻŌhiʻa has good wind tolerance and is wind-firm in hurricanes (Herbert et al. 1999), although strong winds may snap isolated trees.

Other

The tree is tolerant of volcanic fumes.

Abilities

Regenerate rapidly

ʻŌhiʻa regenerates prolifically from windblown seeds after disturbances, if the site is not taken over by alien vegetation. ʻŌhiʻa is the only native tree to regenerate on recent lava flows for the first few years or even decades.

Self-prune

The tree self-prunes only slowly. Tall trees may retain scraggly lower branches for years.

Coppice

Sometimes ʻōhiʻa coppices thickly, but at other times the tree is killed by coppicing or pollarding. New growth after trees are coppiced is fragile and easily broken. Fallen trees

ʻŌhiʻa trees often start out growing on nurse logs on the forest floor (left)… leaving a cavity under the tree after the substrate decays (right). Pictured: co-author J.B. Friday. PHOTOS: J. B. FRIDAY, T. MCEVOY

in the forest, however, may send up new vertical shoots that in time develop into trees.

GROWTH AND DEVELOPMENT

ʻŌhiʻa trees seed prolifically but grow slowly. They survive by colonizing lava flows or fallen logs in forest gaps where other vegetation cannot compete. Growth of mature forest trees may be imperceptibly slow.

Growth rate

In optimal conditions, seedlings 60–70 cm (24–28 in) tall can be grown from seed in a year. This relatively fast rate of growth may continue through the pole stage, after which growth is typically slow.

Stem diameter growth rates are especially slow, in the range of 1–3 mm (0.04–0.12 in) per year. Saplings and poles may have relatively fast growth rates (Bornhorst 2005), but forest trees rarely grow more than 2 mm (0.08 in) in diameter per year (Adee and Conrad 1990, Herbert and Fownes 1995, 1999, Raich et al. 1997, Vitousek and Farrington 1997, Gerrish and Mueller-Dombois 1999). Annual height growth is up to 0.3–0.6 m (12–24 in).

Flowering and fruiting

The earliest flowering is 2 years after germination (Bornhorst 2003). Flowering occurs throughout the year but may be most abundant after seasonal rains, generally during and after the winter months and on into summer. The seed capsules may not release their seed for up to a year after flowering (Carpenter 1976).

Some trees form air roots that trap moisture droplets in the air. PHOTO: C. ELEVITCH

Timber yields

Timber volumes per unit area for mature forest are low in comparison for related trees such as *Eucalyptus* species because of ʻōhiʻa's tendency to grow in dense, pole-sized stands and the trees' irregularly shaped stems, which yield little lumber. Higher-volume stands may only yield 70–84 m^3/ha (1000–1200 ft^3/ac or 5000–6000 bf/ac) (Skolmen 1974a), whereas the average stands yield only half that. Basal area of ʻōhiʻa forests may be up to 40 m^2/ha (175 ft^2/ac), although again this may be composed of many small trees (Adee and Conrad 1990). A forest survey in 1970 estimated that stands on deep soils on the wetter parts of the island, which were described as "commercial" ʻōhiʻa stands, were increasing volume at a rate of 0.47 m^3/ha/yr (6.7 ft^3/ac/yr or 34 bf/ac/yr). Many other stands were composed of pole-sized timbers that were not increasing in volume at all (Metcalf et al. 1970).

Rooting habit

ʻŌhiʻa is shallow-rooted on pāhoehoe (sheet) lava or in poorly-drained areas but deeply rooted in dry sites and on ʻaʻā (rough) lava. Even on pāhoehoe lava, roots may find cracks and penetrate deeply.

Reaction to competition

ʻŌhiʻa does not tolerate shading from overstory trees and can easily be smothered or shaded out by exotic weedy grasses, vines, and trees.

PROPAGATION

ʻŌhiʻa is propagated by cuttings, air-layering, or by seeds. While seeds germinate readily and are true to type (Stemmermann 1983), cuttings or air-layers are perhaps the best way to achieve specific flower color for ornamentals (Rauch and Hensley 1997). The National Tropical Botanical Garden recommends that care be taken to select plants or seeds to be propagated from a nearby locale with similar environmental conditions to the outplanting site, because ʻōhiʻa exhibits a variety of growth patterns that are influenced by environment (NTBG 1993).

Propagation by seed

Seeds are easily collected and germinate readily. In natural settings seeds commonly germinate as epiphytes on tree ferns or moss-covered logs (Little and Skolmen 1989).

Seed collection

Whole fruit capsules are collected. Fruits mature 70–90 days after flowering and should be collected after maturity but before capsules open (Allen 2002). The mature capsules will be swollen, and lines will appear where the capsule will dehisce (Allen 2002). Capsules should be air-dried in a paper bag or cardboard box to prevent loss of seeds (NTBG 1993, Herring 2002). Viability ranges from less than 10% to more than 75% (Dawson 1970, Burton 1982, Drake 1993, Allen 2002).

ʻŌhiʻa can flower throughout the year but flowering generally peaks in spring or summer after vegetative flushing. Some varieties or populations peak in fall or winter. Individual trees or branches may produce flowers at any time during the year (Adee and Conrad 1990). Drake (1993) noted that on the island of Hawaiʻi (wet forests at 700 m [2300 ft] elevation), 75% of seeds were dispersed in December and January.

Capsules must be collected before they open, as shown here, or the seeds disappear into the wind. PHOTO: J. B. FRIDAY

Seed storage

For greatest viability, seeds should be sown as quickly as possible after collection (NTBG 1993). Seeds may be stored in a dry, cool location or under refrigeration (Allen 2002), but for greatest viability seeds should be sown within a month of capsule dehiscence. Viability may drop to less than 10% after a year of storage (Allen 2002) and may be near 0% within 3 years (Corn 1979).

Pre-planting treatments

No pretreatment of seeds is necessary.

Germination, media, and containers

Seeds should be spread onto germination trays filled with a moist, sterile potting medium, sterile compost, or cinder and left uncovered or covered by a very thin layer of soil (NTBG 1993, Bornhorst 2005). Fresh seeds germinate in 5–10 days, whereas stored seeds may take as long as 6 weeks

(Corn 1979). Seedlings should be transplanted into 5 cm (2 in) diameter containers with a well drained, loose substrate when 4–6 true leaves have formed (NTBG 1993, Bornhorst and Rauch 2003). The National Tropical Botanical Garden recommended a small amount of slow-release NPK 8–8–8 fertilizer with micronutrients be mixed with the media upon planting, and once-per-month applications of a liquid foliar fertilizer at half strength be applied thereafter (NTBG 1993). Bornhorst (2003) recommended daily watering of potted seedlings.

Time to outplanting

With good nursery practices, seedlings can be ready for outplanting in 6–12 months at a size of 25–30 cm (10–12 in) tall.

Outplanting

Seedlings are vulnerable to drought and should be well established before planting out (NTBG 1993, Bornhorst 2005, Allen 2002). Full sun, frequent watering, and avoidance of strong wind are recommended.

Other comments on propagation

Transplanting of wild seedlings seldom succeeds. If transplanting is attempted, plants should be as small as possible, not more than a few cm tall.

Potted seedlings have a tendency to send roots down into the ground through the bottom of their containers. Care should be taken that they do not form taproots into the ground while in the nursery. This is a particular problem in warm, humid environments.

Propagation by cuttings

Collecting vegetative material

Cuttings can be taken from the tips of vigorous and recently matured growth and should be 1 cm (0.4 in) diameter and 10–15 cm (4–6 in) long (Criley 1998, Bornhorst and Rauch 2003). Success can vary with material selected. Near 100% success is reported from some parent material, while other material is nearly impossible to propagate (Bornhorst and Rauch 2003).

Treatment

Bornhorst (2005) recommended cutting leaves

Top: A container that prevents root spiraling is recommended. Pictured: Baron Horiuchi. Bottom: For certain situations where early field maintenance is impractical, trees can be grown out in large containers and successfully transplanted. Pictured: Anya Tagawa. PHOTOS: C. ELEVITCH in half, removing leaves from the lower 2.5 cm (1 in) of the stem, and dipping cuttings in a strong rooting hormone for ten seconds. Rauch and Hensley (1997) had 100% success with a 2000 ppm concentration indolbutyric acid (IBA) at a ratio of 2:1 with naphthaleneacetic acid (NAA). Criley (1998) reported success with rooting hormones having 2:1 IBA to NAA at concentrations of 2000–4000 ppm IBA. To grow ʻōhiʻa from cuttings, a misting system is strongly recommended.

Media

Sterile potting media such as pure perlite or vermiculite, 1:1 perlite to vermiculite, or 2:1 mixture of perlite to peat moss have been used (Bornhorst 2005, Rauch and Hensley 1997, Criley 1998, Herring 2002). Choice depends on climate and grower's preference.

Propagation by air-layers

Vegetative material

Some individuals may air-layer easier than others (Herring 2002). Bornhorst (2005) suggested that the presence of aerial roots might indicate a plant that will air-layer easily.

Treatment

Herring (2002) recommended using a standard air-layering technique, while Bornhorst (2005) recommended using a strong rooting hormone. Tanabe and Frazier (1984) had good success with the ring-girdle technique and a range of indolbutyric acid IBA concentrations.

Air-layering is frequently used to clone a desirable tree, such as this one with yellow blossoms. PHOTO: C. ELEVITCH

DISADVANTAGES

Potential for invasiveness

Because of its prolific, windblown seeds and ability to survive on harsh sites, ʻōhiʻa has the potential to become a serious pest if planted outside the Hawaiian islands. On other Pacific islands, there is the danger that ʻōhiʻa would hybridize with native populations of other species of *Metrosideros.*

Diseases and pests

The National Tropical Botanical Garden (NTBG) notes problems with thrips and ants, which can transfer other pests such as scale and aphids to ʻōhiʻa (NTBG 1993). These pests mainly affect young, planted trees. Leaves on young trees are frequently affected by psyllid insects that cause galls. Mealybugs and sooty mold may affect seedlings in wet areas. A previously undescribed rust was found on ʻōhiʻa nursery seedlings in early 2005 (D. Ogata, pers. com.). The endemic cerambycid borer *Plagithmysus bilineatus* has the greatest potential for negative impact on ʻōhiʻa. It may become epidemic to weakened trees in cases of canopy dieback (Papp et al. 1979, Mueller-Dombois 1985, Adee and Conrad 1990). Other potentially damaging borers include *Ceresium unicolor*, *Xyleborus saxesensi*, and *X. simillimus* (Adee and Conrad 1990). ʻŌhiʻa is attacked by the two spotted leafhopper (*Sophonia rufofascia*), an exotic pest only discovered in Hawaiʻi in 1987 (Alyokhin et al. 2004). Forest trees are host to several species of native Hawaiian mistletoe (*Korthalsella* spp.) (Wagner et al. 1999). Root rots *Phytophthora cinnamomi*, *Pythium vexans,* and *Armillaria mellea* can also be damaging and are most often associated with weakened stands experiencing canopy decline (Corn 1972, Papp et al. 1979). ʻŌhiʻa forests on the windward side of the island of Hawaiʻi were observed to be undergoing massive canopy dieback in the 1960s and 70s. Five to seven types of decline have been identified, and no single uniform cause has been determined. Most of the area affected by ʻōhiʻa decline is wet and poorly drained, and the so-called "wetland dieback" and "bog formation dieback" make up more than 80% of the affected decline area (Hodges et al. 1986). While the fungal rots *Phytophthora cinnamomi* and *Armillaria mellea* and the borer

A NEW DISEASE OF ʻŌHIʻA

A new rust disease was discovered on potted ʻōhiʻa plants in a nursery on Oʻahu in April 2005. No previous rusts had been reported for ʻōhiʻa, thus this discovery was a cause for concern. The rust has been identified as *Puccinia psidii* and causes a common disease of eucalyptus, guava, allspice (*Pimenta dioica*), paperbark (*Melaleuca quinquenervia*), and other plants in the Myrtaceae in South and Central America to Florida, where it is called eucalyptus rust or guava rust. The rust quickly spread to all the major islands and on Oʻahu has been found infecting rose apple (*Syzygium jambos*) and common guava as well as the native trees *Eugenia koolauensis* and *E. reinwardtiana.*

The rust most commonly affects young shoots. Initial symptoms are yellow powdery spots growing individually or in a circular pattern on the leaf and shoot. Infected young tissue does not expand and leaves and shoots become deformed as normal tissue continues to expand. As this is a new disease in Hawaiʻi, it is unknown how severe the problem will be in natural forests or whether the rust can kill mature ʻōhiʻa trees. *Puccinia psidii* is considered a serious disease in the eucalyptus industry in Brazil. The Hawaiʻi Department of Agriculture is asking that growers avoid transporting ʻōhiʻa, eucalyptus, paperbark, guava, rose apple, or other seedlings in the family Myrtaceae inter-island to reduce the spread of the disease, although the rust spores are wind-borne and naturally spread rapidly within a community. For ornamental trees, cutting and destroying infected foliage and shoots may help reduce the infection. In nurseries, keeping the foliage dry may also help prevent infection (Killgore and Heu 2005).

Rust symptoms on new shoot. PHOTO: D. OGATA

Plagithmysus bilineatus have all been found attacking trees in areas affected by dieback, all probably only affect trees already stressed by poor soil drainage or other environmental factors. The most likely explanation of the ʻōhiʻa dieback phenomenon is that ʻōhiʻa stands are predisposed to decline because of age and cohort senescence (Mueller-Dombois et al. 1980, Mueller-Dombois 1983). Mature ʻōhiʻa stands are even-aged in nature, having been regenerated after a disturbance, and therefore reach senescence at the same time and are then vulnerable to attacks of pests and diseases. Prolific ʻōhiʻa regeneration under most dieback stands lends credence to the theory that ʻōhiʻa decline is age-related. In some areas, however, bogs are formed after the dieback of the ʻōhiʻa forest.

Other disadvantages or design considerations

ʻŌhiʻa's chief limitation is its slow growth. Timber plantations of ʻōhiʻa are unknown and would probably not be financially viable.

AGROFORESTRY/ENVIRONMENTAL PRACTICES

Soil stabilization

ʻŌhiʻa forests protect the upper reaches of most of Hawaiʻi's critical watersheds. On new lava flows, ʻōhiʻa forests help break down the rock and develop organic soils as well as providing sites for litter accumulation.

Crop shade/overstory

If some ʻōhiʻa trees are left when a forest is cleared for agricultural use, these can provide light shade for coffee, cacao, or other shade-loving understory crops. Alternatively, tree crops such as noni (*Morinda citrifolia*) may be planted in alleys cut in the ʻōhiʻa forest.

Shade or street tree

ʻŌhiʻa saplings and poles will grow quickly given an adequate water supply (Bornhorst 2005) but will not develop a significant canopy for many years. Trees are susceptible to dieback if the sites are badly compacted and often flooded and are susceptible to physical damage by people or careless weeding and maintenance.

Homegardens

Because of improved propagation success, ʻōhiʻa has in recent years become a popular garden ornamental. The flowers are most often red but are also found in yellow, orange, and salmon. Many garden shops and nurseries now carry ʻōhiʻa lehua (Bornhorst 2003, 2005). Unfortunately, some growers sell exotic species of *Metrosideros* as a type of ʻōhiʻa (e.g., "New Zealand ʻōhiʻa") when they are aliens such as pohutukawa (*M. excelsa*) and *M. kermadecensis.* Alien species in the same genus as ʻōhiʻa may pose a threat to the genetic pool of the native Hawaiian species if they escape from cultivation.

ʻŌhiʻa can survive in pasture but will not regenerate. PHOTO: C. ELEVITCH

Windbreaks

Natural stands of ʻōhiʻa make fine windbreaks for moderately windy areas. Single trees or single rows of trees, if left after the surrounding forest is cut, are susceptible to wind breakage, so bands several meters wide should be left. Planted ʻōhiʻa trees could be part of a windbreak if planted along with other, faster growing trees.

Silvopasture

Isolated ʻōhiʻa trees are often found in high-elevation pastures in Hawaiʻi, remnants of the forests that were originally cleared. These trees are seldom healthy and suffer from soil compaction and root damage from grazing livestock. Eventually, if an area is grazed long enough, all the ʻōhiʻa trees except for individuals growing in protected locations die off. ʻŌhiʻa cannot regenerate through thick pasture grasses such as kikuyu grass (*Pennisetum clandestinum*), and cattle damage any young trees that get started.

Dispersed ʻōhiʻa trees can provide light shade for crops such as coffee, as shown here, without interfering with most farm operations. PHOTO: C. ELEVITCH

Watershed and habitat for native species

ʻŌhiʻa is more valuable for its environmental services than for products. ʻŌhiʻa forests are important habitat for Hawaiʻi's native and endemic species of birds, arthropods, mollusks, and plants, many of which have co-evolved with the ʻōhiʻa and endangered (Zimmerman 1948, Hadfield and Mountain 1980, Berger 1981, Hadfield and Miller 1989, Smith et al. 1995). The honeycreeper family of birds, in particular, has evolved into many endemic species in Hawaiʻi. Most of these, such as the common, bright red ʻapapane (*Himatione sanguinea*), the scarlet ʻiʻiwi (*Vestiaria coccinea*), and the yellow ʻamakihi (*Loxops virens*) inhabit the ʻōhiʻa forest and feed on the nectar of the ʻōhiʻa blossoms and insects in the trees (Carlquist 1980). ʻŌhiʻa and koa forests also provide habitat for Hawaiʻi's most endangered birds, such as the Hawaiʻi ʻākepa (*Loxops coccinea*), which nests in the cavities of the largest ʻōhiʻa trees (Freed 2001), and the Hawaiʻi creeper (*Oreomystis mana*). The endangered ʻakiapōlāʻau (*Hemignathus munroi*) has evolved a woodpecker-like lower bill and the ability to drill holes and suck sap directly from certain individual ʻōhiʻa trees (Pejchar, pers. com.). ʻŌhiʻa also provides critical specific habitat for endemic *Achatinella* and *Partulina* tree snail species (Hadfield and Mountain 1980, Hadfield and Miller 1989). Understory plants in the forest germinate on fallen ʻōhiʻa logs or even on still-living ʻōhiʻa trees. The trees provide a growing surface above the alien grasses, which cover the forest floor and protect young plants against damage by feral pigs.

ʻŌhiʻa provides valuable watershed protection in Hawaiʻi because of its abundance and especially broad environmental amplitude. Most of the upper-elevation forests above Hawaiʻi's important agricultural and urban areas are covered with ʻōhiʻa forests.

The native Hawaiian honeycreeper ʻapapane on an ʻōhiʻa lehua blossom. PHOTO: J. JEFFREY

Ornamental

ʻŌhiʻa trees, with their brightly colored flowers and silvery or reddish young foliage, make beautiful ornamental specimen plants.

USES AND PRODUCTS

Honey

ʻŌhiʻa is an excellent honey plant, and ʻōhiʻa honey is one of the only truly native Hawaiian honeys. It is commonly sold in markets throughout Hawaiʻi.

Medicinal

In ancient times extracts of ʻōhiʻa blossoms mixed with other herbs were used to treat childbirth pains and thrush (a fungal disease). In modern times flowers are still given to mothers for childbirth pains (Krauss 2001). New leaf shoots with a reddish color were chewed for numbing sore throats.

Although ʻōhiʻa is not considered feasible for commercial plantation forestry, existing ʻōhiʻa stands can be interplanted with other timber species such as koa. PHOTO: C. ELEVITCH

Wood

The wood is very hard and dense. A set of tests at the USDA Forest Service Forest Products Laboratory on wood from eleven trees from Kona and Puna found an average specific gravity of 0.81 (oven dry weight over green volume) (Youngs 1960). Weight averaged 0.91 g/cm^3 (57 lb/ft^3) for oven-dry wood and 1.17 g/cm^3 (73 lb/ft^3) for green wood. Shrinkage was 6.9% radial, 12.1% tangential, and 19.1% in volume. In color ʻōhiʻa has pale brown sapwood that merges indistinctly to the reddish to purplish brown heartwood, often streaked, and can develop a long curl. The interlocked grain and growth bands sometimes give the wood an attractive figure; at other times the wood is very plain. The texture is medium and the vessels are very fine and scattered throughout (Lamb 1981). The wood is not as strong as its density would suggest, though, probably because of its spiral grain (Youngs 1960). ʻŌhiʻa's hardness

Left: ʻŌhiʻa seedling that volunteered on fence post, showing how opportunistic the tree can be. Right: A mature ʻōhiʻa tree in upper Puna supporting epiphytic growth of paʻinu (*Astelia menziesiana*) and *Trematolobelia grandifolia*. PHOTOS: A. YEH

makes it difficult to work, and the wood is notorious for shrinking, warping, splitting, and checking during drying. Because of the wood's tendency to warp, boards should be air-dried before kiln-drying (Youngs 1960). The common spiral grain weakens the wood if sawn into timbers. Severe spiral grain and shrinkage during drying leads to instability of the wood and limits ʻōhiʻa's use in furniture making, cabinetry, and construction (Skolmen 1974a, Little and Skolmen 1989). Today the most common uses of the wood include wood strip flooring, decking, decorative posts, and round wood construction (Skolmen 1974a, Little and Skolmen 1989). While floors made of ʻōhiʻa in Hawaiʻi are generally stable, shrinking and swelling of the wood might cause problems in highly seasonal climates. Round posts are varnished to preserve the golden brown color of the sapwood; otherwise they weather to grey as does all exposed wood.

Heartwood is not resistant to attack by fungi when in contact with the ground. In tests in a wet area on Oʻahu, stakes cut from ʻōhiʻa heartwood lasted only about a third as long as redwood stakes and about half as long as stakes cut from *Eucalyptus robusta*. ʻŌhiʻa posts and rails exposed to the weather but not in contact with the soil were resistant to decay over the 9½ year test (Skolmen 1974a, 1974b). ʻŌhiʻa is only slightly resistant to termite attack (Grace et al. 1996).

Historically, ʻōhiʻa wood has been used as fence posts, furniture, veneer, ukulele keys, ship blocking in dry-docks, bracing stakes in agriculture and irrigation ditch construction, wharf fenders and marine construction, pallets, pile-driver cushions, and biofuel (Skolmen 1974a, Little and Skolmen 1989, Grossman 1992). A mill in Pāhoa on the island of Hawaiʻi sold millions of railroad ties made of ʻōhiʻa to the Santa Fe Railroad company in the early 1900s, until it was found that the ties were not durable in the desert climate.

Ancient Hawaiians used the wood in carving sacred images (kiʻi or tikis), spears, and mallets, and household items such as poi boards. Construction uses included structural poles, rafters, and temple walls (Abbott 1992, Gon and Pang 1998, Kirch 1985, Little and Skolmen 1989).

Fence posts

ʻŌhiʻa poles are traditionally used as fence posts in Hawaiʻi, although they are only moderately durable when in contact with the soil, and longer lasting woods such as kauila (*Colubrina oppositifolia* or *Alphitonia ponderosa*) were preferred before they became rare.

Fuelwood

ʻŌhiʻa has always been a favorite firewood, continuing to today. It burns with a hot, clean flame. The only disadvantage is the difficulty in splitting the cross-grained logs.

Craft wood

Jewelry, jewelry boxes, turned bowls, furniture, and cabinetry are among the many modern craft uses. ʻŌhiʻa was not used for carved wooden calabashes (ʻumeke lāʻau) in ancient times in Hawaiʻi due to its tendency to warp and crack (Abbott 1992).

Canoe/boat/raft making

Despite the large size of ʻōhiʻa trees, they were not used to build hulls for canoes (waʻa) in ancient times. Once a canoe's hull was carved from a koa tree, ʻōhiʻa wood was often used for the decking, gunwales, and seats (Abbott 1992). Spreaders for canoe hulls were carved from naturally curved ʻōhiʻa stilt roots (Krauss 1993). ʻŌhiʻa wood was also sometimes used for paddles and for the booms that connected the hulls of the great double-hulled voyaging canoes (waʻa kaulua).

Body ornamentation/garlands

The flowers are used in garlands and leis and in the traditional Hawaiian religion are considered sacred to the goddess Pele (Kirch 1985, Little and Skolmen 1989, Bornhorst 2005). The tips of young shoots known as liko are also commonly incorporated into leis.

Top: ʻŌhiʻa wood flooring. PHOTO: J. B. FRIDAY **Bottom: Hawaiians frequently use the wood for sacred images (kiʻi), which turn light gray when exposed to the elements. Puʻuhonua o Hōnaunau, Kona, Hawaiʻi.** PHOTO: C. ELEVITCH

Ceremonial/religious importance

The majority of the large carved wooden sacred images (kiʻi) in old Hawaiʻi were made from the wood of ʻōhiʻa. Along with lama (*Diospyros sandwicensis*), ʻieʻie (*Freycinetia arborea*), halapepe (*Pleomele aurea*), maile (*Alyxia oliviformis*), and the palapalai fern (*Microlepia strigosa*), ʻōhiʻa was one of the ritual plants associated with the hula. ʻŌhiʻa represented the god Kūkāʻōhiʻa Laka, who was named for a legendary ʻōhiʻa tree that bore both red and white flowers (Abbott 1992). In the traditional Hawaiian religion, the fire-red flowers are considered sacred to Pele, the volcano goddess.

Other

The red flowers are the official symbol of the island of

Liko (the new leaf tips) are found in a rainbow of colors and are a favorite component of leis. PHOTOS: C. ELEVITCH

Hawaiʻi. Some people believe that picking ʻōhiʻa flowers will cause it to rain.

URBAN AND COMMUNITY FORESTRY

ʻŌhiʻa can be a splendid ornamental tree in cooler, wetter areas such as the Hilo and Puna districts on Hawaiʻi or in Mānoa or Wahiawā on Oʻahu. Planting an ʻōhiʻa tree in a yard or garden brings a bit of the forest home. A good example of this can be seen in Waimea on Hawaiʻi, where ʻōhiʻa was planted along the roads and in many public landscapes. The tree grows slowly and needs to be well cared for. It cannot tolerate abuse as other popular landscape trees can. If forest areas are cleared for development, specimen ʻōhiʻa trees can be left as a reminder of the forest that once was there.

Size

ʻŌhiʻa trees in landscape settings usually reach 3–12 m (10–40 ft) in height, smaller than trees in the forest. Some trees grow vertically and may only have a canopy spread of 1–2 m (3.3–6.6 ft); others may fork and spread their canopy over 10 m (33 ft).

Rate of growth in a landscape

In well watered areas, ʻōhiʻa grows about 60 cm (2 ft) in height per year.

Roots

When grown on lava soils, ʻōhiʻa has spreading surface roots. The tree may be killed if these roots are cut, and traffic and machinery can also damage roots. In deep soils or in porous lava, roots go deep and enable the tree to survive dry periods.

Products commonly used in a Hawaiian household

The red, yellow, and orange ʻōhiʻa flowers are made into intricate leis in Hawaiʻi. The silvery, green, or reddish new shoots are also used. ʻŌhiʻa wood was once used for housing and carving sacred images (kiʻi) in old Hawaiʻi. Today ʻōhiʻa wood is mostly used as round posts (unsawn) for architectural elements and for flooring.

Light requirements

ʻŌhiʻa trees prefer full sunlight but tolerate slight shading from surrounding plants.

Water/soil requirements

ʻŌhiʻa prefers wetter and cooler areas in Hawaiʻi. The tree can grow on various textures of soil and on organic soils formed over lava rock. ʻŌhiʻa is killed by drying out and must be kept well watered, especially when first planted (Bornhorst 2005). ʻŌhiʻa trees planted in shallow depressions in pāhoehoe (sheet) lava may flourish for several years but die from drying out when the trees grow larger and the thin soil is no longer able to hold enough water to support them during dry spells. ʻŌhiʻa growing on pāhoehoe may also die from constant flooding, especially if water is diverted to the site because of nearby construction or development.

Expected life span in a homegarden

Huge old ʻōhiʻa trees in the forest are many centuries old, and even moderate-size trees may be a couple of hundred years old. However, trees grown near places where people live often succumb to injury, root damage, flooding, or soil compaction if care is not taken.

Varieties favored for use in a homegardens or for street trees

Many people favor the mamo (yellow-flowered) variety of ʻōhiʻa. Pink, orange, and red are also planted in landscaping. All colors may be propagated by air-layering.

Seasonality of leaf flush, flowering, fruiting

ʻŌhiʻa may flower at any time of year. Individual trees flower once or twice per year, and some individuals may flower almost continuously.

Exceptional ornamental values

ʻŌhiʻa is a favorite ornamental tree because of its showy blossoms. Trees with blossoms of exceptional color may be propagated by cutting or air-layer to ensure that the colors remain true.

Use as living fence, hedge, or visual/noise barrier

ʻŌhiʻa does not tolerate lopping or pollarding well, and this limits its use as a hedge. However, closely planted trees can form a thick barrier in open spaces.

Bird/bee/wildlife

ʻŌhiʻa trees attract bees and other insects. While they are important nectar trees for native forest birds, few of these survive near inhabited areas, and ʻōhiʻa trees are more likely to attract alien bird species.

Maintenance requirements

Trees should be mulched heavily and fertilized only sparingly. ʻŌhiʻa trees have evolved to survive in infertile soils; heavy fertilization causes sappy growth that may not be strong enough to bear its own weight and is prone to insect attack. Slow-release fertilizers or natural compost works best.

Drawbacks

In a landscape setting, ʻōhiʻa is limited by its slow growth. Trees over 22–30 cm (10–12 in) tall are not easily transplanted, and larger potted specimens may not survive. ʻŌhiʻa is also easily barked and damaged by machinery such as mowers and weed cutters. ʻŌhiʻa generally does not tolerate topping or pollarding. A drawback to using ʻōhiʻa in

Left: ʻŌhiʻa trunk and roots are easily de-barked by careless use of grass trimmers or other machinery. PHOTO: J. B. FRIDAY **Center and right: Plastic guards can help protect bark from damage during maintenance, although damage can still occur, as here above and below guard.** PHOTOS: C. ELEVITCH

Left: Stand of ʻōhiʻa serving as a windbreak for the Hawaiʻi Belt Road on the Hāmākua coast. PHOTOS: J. B. FRIDAY **Right: Gall insects commonly affect young trees, but the trees usually outgrow these pests.** PHOTO: C. ELEVITCH

agroforestry systems is that it is a host for the black twig borer (*Xylosandrus compactus*), a serious pest of coffee, cacao, and other tree crops.

Nuisance issues

None.

Common pest problems

Young ʻōhiʻa foliage may be attacked by Chinese rose beetles and gall insects. Usually the trees outgrow these pests without treatment. Aphids and their associated ants and sooty mold may be problems in wet areas. A rust disease probably caused by the fungus *Puccinia psidii* was discovered in Hawaiʻi in 2005 (see text box above).

Other

Developers in Hawaiʻi often leave a few token ʻōhiʻa when clearing native forest for building sites. Unfortunately, these usually die after a few months or years from having their root system damaged by bulldozers and other machinery. If ʻōhiʻa are desired as part of the landscape, an area at least as wide as the trees are tall must be left undisturbed. Since many building sites on Hawaiʻi are on relatively new lava flows with shallow soils, the trees' root systems are spreading and shallow. Cutting or trampling the roots will usually kill the trees. Compromised trees can become a hazard, especially in high winds, as the whole tree can come crashing down.

COMMERCIAL PRODUCTS

ʻŌhiʻa lehua has become a popular garden ornamental, and many nurseries and garden shops now carry the tree (Bornhorst 2003, 2005). For production of ornamental flowers it is recommended to start plants from cutting or air-layer because vegetative propagation ensures that the plants will be true to type (Rauch and Hensley 1997).

ʻŌhiʻa posts are sold in Hawaiʻi today for approximately US$1.00 per inch (2.5 cm) of diameter per lineal foot (30 cm). For example, a ten-foot long post of eight inches in diameter would sell for $80.00. Air-dried, rough-sawn lumber suitable for milling into flooring sells for $1.25/bf, while lumber of firsts and seconds grade sells for $3.50–$5.00 per board foot. Finished ʻōhiʻa flooring sells for $7.00–$9.00 per square foot.

Spacing

Because of its slow growth rate, ʻōhiʻa is not grown in timber plantations.

Management techniques

Timber management is seldom if ever undertaken in ʻōhiʻa forests because of the tree's perceived low value and slow rate of growth. Faster-growing pole stands might be managed for pole production for architectural elements. At a growth rate of 3 mm (0.12 in) diameter per year, it would take 50 years to grow a 15 cm (6 in) diameter pole. Natural forests might be extensively managed for a small return. However, continued pressure to clear lowland forests for agricultural crops makes the prospect of such sustainable, long-term silviculture unlikely.

Design considerations

While ʻōhiʻa itself is slow growing and unlikely to yield much return, ʻōhiʻa trees can be managed as part of a koa silvicultural system, as occurs in the native forests. The faster-growing koa does not shade out the ʻōhiʻa, but the ʻōhiʻa can provide side shade for the koa and possibly reduce branchiness and encourage straight growth (Patrick Baker, pers. com.). ʻŌhiʻa could also provide habitat for native birds in such a mixed system. Koa trees may be planted into an existing scattered ʻōhiʻa forest, or ʻōhiʻa may be planted along with koa. ʻŌhiʻa is not shade tolerant and cannot be regenerated under its own canopy or in dense shade, although it does grow well under a light koa canopy.

On-farm processing methods required to access market

ʻŌhiʻa is often logged and milled using portable mills brought to the forest sites. Most ʻōhiʻa harvesting today occurs in conjunction with land clearing for coffee, papaya, pasture, or other agriculture or residential uses. Almost all ʻōhiʻa harvested is cut on the island of Hawaiʻi.

On-farm processing

ʻŌhiʻa logs often check badly at the ends. Brackets hammered into the ends of logs may help decrease losses due to splitting. Drying lumber should be done very slowly to minimize checking and splitting (Forest Products Laboratory, undated). Poles should be debarked when freshly cut.

Markets

ʻŌhiʻa flooring is produced locally on Oʻahu and Hawaiʻi. ʻŌhiʻa architectural elements are favored by builders on Hawaiʻi and upcountry areas on Maui and Kauaʻi.

INTERPLANTING/FARM APPLICATIONS

Example 1

Location

Hakalau National Wildlife Refuge, Hawaiʻi island. The refuge is located on the upper slopes on the windward side of Mauna Kea, in a cool, mesic area. Rainfall is 2000 mm (80 in) annually. The deep, acid soils are derived from volcanic ash and classified as Typic Hydrudands (USDA classification). Soils are silty clay loams and silt loams which contain high amounts of organic material but also fix available phosphorus. Temperatures at the higher elevations can dip below freezing during the winter months (Scowcroft and Jeffrey 1999). While originally forested, the upper parts of the refuge had been gradually converted by logging, burning, and grazing to pasture dominated by kikuyu grass (*Pennisetum clandestinum*), meadow rice grass (*Ehrharta stipoides*), and other alien grasses over the past century.

Description

The U.S. Department of the Interior's Fish and Wildlife Service has been restoring a native koa-ʻōhiʻa forest to the higher elevations (above 1800 m [6000 ft]) of the refuge since 1989. Their goal is to restore the habitat for the native bird life, including eight endangered species such as the ʻākepa (*Loxops coccinea*), the ʻakiapōlāʻau (*Hemignathus munroi*), and the Hawaiʻi creeper (*Oreomystis mana*). ʻŌhiʻa trees are grown from locally-collected seed in a nursery at the site. The seedlings, which are grown in dibble tubes

ʻŌhiʻa seedlings planted under 8- to 10-year-old koa trees at Hakalau National Wildlife Refuge are protected from frost damage. PHOTO: C. ELEVITCH or root trainers, take 18–24 months to reach plantable height of 15–20 cm (6–8 in) tall. Planting sites are scalped to remove competing grasses, and trees are initially fertilized with 10–30–10 granular fertilizer. Older trees at the site are growing at a rate of approximately 1 mm (0.05 in) per year in diameter. Early reforestation efforts indicated that a major cause of mortality in young outplanted ʻōhiʻa seedlings was frost damage. Currently ʻōhiʻa seedlings are outplanted underneath the canopies of 8–10-year-old koa trees established on the site. The koa overstory decreases radiative cooling at ground level and keeps the ʻōhiʻa seedlings from being damaged (Scowcroft et al. 2000). Koa, being a nitrogen-fixing tree, also increases nitrogen availability in the soil. When planted under koa, ʻōhiʻa trees have shown close to 100% survival, whereas they showed almost no survival when planted on bare ground in the open.

An alternative successful planting technique is to plant seedlings onto fallen logs in the pastures, or even onto artificial planters made from wood and potting material. Elevating the seedlings above the ground by even 0.5 m (20 in) seems to help avoid frost damage.

Spacing

The ʻōhiʻa seedlings are planted at wide spacings, about 4 m (13 ft) apart, in a mixture of other native forest and understory trees including kōlea (*Myrsine lessertiana*), ʻōlapa (*Cheirodendron* spp.), and pilo (*Coprosma* spp.), and the shrubs ʻākala (*Rubus hawaiensis*), pūkiawe (*Leptecophylla tameiameiae*), and ʻōhelo (*Vaccinium* spp.).

Example 2

Location

Puna, Hawaiʻi.

Description

ʻŌhiʻa forests on lava rock soils in lower Puna are often cleared for planting horticultural crops such as papaya, noni, or ʻawa (kava). These crops all benefit from windbreaks. While planting ʻōhiʻa trees is not practical because of their slow growth, some landowners carefully lay out their fields so as to leave remnants of the ʻōhiʻa forest to serve as windbreaks.

Crop/tree interaction

The crops benefit from decreased moisture stress in dry periods and avoid physical damage from the wind. Windbreaks of ʻōhiʻa also serve as honey plants for nearby beekeepers and as forage for any native birds that remain in the area.

Spacing

Windbreaks generally protect areas ten times their height. ʻŌhiʻa forests in the lava rock lands of Puna may only be 10 m (40 ft) tall. To protect 3 m (10 ft) tall papaya or other tree crops, windbreaks should be left every 100 m (330 ft). Since ʻawa and noni tolerate some shade, windbreaks may be spaced even closer for better protection, or plantings may be done in alleys cleared in the native forest. Since a single row of ʻōhiʻa may not be windfirm, especially on shallow substrates, enough land needs to be left so that the trees can grow several rows deep.

Example 3 (Contributed by Craig Elevitch)

Location

Kona, Hawaiʻi.

Description

Coffee is traditionally grown in full sun in Kona, but it can also be grown under light shade. Some landowners choose to leave some of the native forest trees such as ʻōhiʻa and lama (*Diospyros sandwicensis*) as shade trees in coffee farms. While both these trees are slow growing and it would not be practical to plant them along with the coffee, it is sometimes possible to leave some trees in place when the farm is cleared. These trees may provide habitat for native birds and serve as a reminder of the history of the farm. One disadvantage is that old ʻōhiʻa trees, as any nearby trees, may serve as a host for the black twig borer (*Xylosandrus compactus*), a serious pest of coffee.

Windbreak of ʻōhiʻa forest protecting a noni plantation in Puna, Hawaiʻi.
PHOTO: S. NELSON

Crop/tree interactions

Although coffee is a shade-tolerant plant, shading decreases the amount of the coffee produced. Light overstory shade is generally used in tropical countries to decrease overbearing and consequent nutrient stress (Bittenbender and Smith 2004). While growers in Hawai‘i generally have avoided nutrient stress by fertilizing sufficiently and growing coffee in full sun, there may be a marketing premium or niche for "shade-grown" coffee.

Spacing

‘Ōhi‘a and other native overstory trees are left as they grow, scattered across the landscape.

PUBLIC ASSISTANCE

The Cooperative Extension Service (CES) of the University of Hawai‘i can assist landowners with questions relating to ‘ōhi‘a. Their forestry web site includes many valuable publications, forestry news, and an extensive list of forestry links for Hawai‘i.

Extension Forester
College of Tropical Agriculture and Human Resources
University of Hawai‘i at Mānoa
Komohana Agricultural Complex
875 Komohana St., Hilo, HI 96720
Tel: 808-959-9155; Fax: 808-959-3101
Web: http://www.ctahr.hawaii.edu/forestry

INTERNET

Hardwood Drying Schedules, Forest Products Laboratory, USDA Forest Service: <http://www1.fpl.fs.fed.us/drying.html>.

Hawaiian Native Plant Propagation Database–*Metrosideros polymorpha*: <http://www2.hawaii.edu/~eherring/hawnprop/met-poly.htm>.

Native Plant Network Propagation Protocol Database: <http://www.nativeplantnetwork.org/network/search.asp>.

The Flora of the Hawaiian Islands, a web site of the Smithsonian Institution, is a database of flowering plants and ferns in Hawai‘i: <http://ravenel.si.edu/botany/pacificislandbiodiversity/hawaiianflora/index.htm>.

Coffee planted in the understory of native ‘ōhi‘a-lama-kolea forest, ‘Ōhi‘a Forest Farm, South Kona, Hawai‘i. PHOTO: C. ELEVITCH

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Species Profiles for Pacific Island Agroforestry (www.traditionaltree.org)

Metrosideros polymorpha (ʻōhiʻa)

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Acknowledgments: The authors and publisher thank Susan Cordell, Dale Evans, Clyde Imada, Heidi Johansen, Mark Kimball, Lyman Perry, Forest and Kim Starr, Janice Uchida, and Aileen Yeh for their input. The authors thank Craig Elevitch for contribution of the example of ohia on a coffee farm. Photo contributions from Craig Elevitch, Tom McEvoy, Jack Jeffrey, Scot Nelson, Desmond Ogata, Forest and Kim Starr, and Aileen Yeh are greatly appreciated.

Recommended citation: Friday, J.B., and D.A. Herbert. 2006. *Metrosideros polymorpha* (ʻōhiʻa), ver. 3.2. In: Elevitch, C.R. (ed.). Species Profiles for Pacific Island Agroforestry. Permanent Agriculture Resources (PAR), Hōlualoa, Hawaiʻi. <http://www.traditionaltree.org>.

Sponsors: Publication was made possible by generous support of the United States Department of Agriculture Western Region Sustainable Agriculture Research and Education (USDA-WSARE) Program; SPC/GTZ Pacific-German Regional Forestry Project; USDA Natural Resources Conservation Service (USDA NRCS); Kaulunani, an Urban Forestry Program of the DLNR Division of Forestry and Wildlife and the USDA Forest Service; State of Hawaiʻi Department of Land & Natural Resources Division of Forestry & Wildlife; USDA Forest Service Forest Lands Enhancement Program; and Muriel and Kent Lighter. This material is based upon work supported by the Cooperative State Research, Education, and Extension Service, U.S. Department of Agriculture, and Agricultural Experiment Station, Utah State University, under Cooperative Agreement 2002-47001-01327.

Series editor: Craig R. Elevitch

Publisher: Permanent Agriculture Resources (PAR), PO Box 428, Hōlualoa, Hawaiʻi 96725, USA; Tel: 808-324-4427; Fax: 808-324-4129; E-mail: par@agroforestry.net; <http://www.agroforestry.net>. This institution is an equal opportunity provider.

Species Profiles for Pacific Island Agroforestry
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April 2006
ver. 2.1

Metroxylon amicarum, *M. paulcoxii*, *M. sagu*, *M. salomonense*, *M. vitiense*, and *M. warburgii* (sago palm)

Arecaceae (palm family)

Will McClatchey, Harley I. Manner, and Craig R. Elevitch

IN BRIEF

Distribution Southeast Asia, Melanesia, and some islands in Micronesia and Polynesia.

Size Depending on species, 9–33 m (30–108 ft).

Habitat Tropical lowland forest and freshwater swamps, usually found near sea level but can be found 1–700 m (3–2300 ft) with rainfall of 2000–5000 mm (80–200 in).

Vegetation Grow with a wide range of species found in lowland freshwater swamps and in traditional swidden gardens in lowland rain forests.

Soils Can grow on a wide variety of soils, including well drained, poor quality sand, clay, or ʻaʻā lava.

Growth rate The growth rate is rapid, exceeding 1.5 m (5 ft) per year in optimal conditions.

Main agroforestry uses Coastal protection, improved fallow, homegardens.

Main products Staple food, thatch.

Yields Under good conditions, *M. sagu* can yield 15–25 mt of air-dried starch per ha (6.7–11.1 t/ac) at the end of an 8-year growth cycle. Other species are somewhat less productive.

Intercropping Interplanting for its non-food products is practiced extensively on many Pacific islands.

Invasive potential It has little potential to become invasive.

M. warburgii **growing among breadfruit (*Artocarpus altilis*) and poumuli (*Flueggea flexuosa*) in American Samoa.**

INTRODUCTION

The genus *Metroxylon* is found from 17°S to 15–16°N latitude ranging from Thailand, peninsular Malaysia and Indonesia, to Micronesia, Fiji, and Samoa. The palms are generally found at low elevations in swamps. The genus is of significant economic importance in traditional societies and is of ever increasing importance in Malaysia, Indonesia, the Philippines, and Papua New Guinea. Because of their value, *Metroxylon* species have been moved from place to place by aboriginal peoples, with much of the present distribution probably due to multiple ancient introductions.

Metroxylon species stand between 9 and 33 m (30–108 ft) in height. Generally, the species tolerate salinity and prolonged flooding and acidic and wet soils. Observations of *M. warburgii* in Samoa suggest that the species does well in polycultural complexes.

Metroxylon palms are used throughout the Indo-Pacific region by lowland-, marsh-, and near-marsh-dwelling peoples. *Metroxylon* is of extreme importance to over a million people who use the palms as their primary dietary starch source. The palms are of secondary importance to thousands of other people who use them as a source of superior house thatch with limited use as a food supplement.

DISTRIBUTION

Native range

Metroxylon species are found in moist localities in tropical rainforests, moist upland rainforest, and freshwater swamps of Southeast Asia, Melanesia, and some high volcanic islands in Micronesia and Polynesia. They are also present on a few low islands and atolls of the Pacific, (e.g., Futuna and Nukuoro).

The natural habitat of *Metroxylon* is tropical lowland forest and freshwater swamps. The palms are often found growing in the freshwater margin at the back of mangrove swamps, extending inland as far as slow moving freshwater flows.

They are found in swamps from southern Thailand, peninsular Malaysia, Indonesia, and the Philippines through Pohnpei, Samoa, and Fiji. Distribution is extensive in New Guinea, but they are not found in swamps in Northern Australia. Much of the distribution outside of Melanesia is probably of ancient anthropogenic origin.

M. amicarum is native to the Caroline Islands (Federated States of Micronesia, states of Pohnpei and Chuuk), the Marshall Islands, and formerly in Guam and Palau.

M. paulcoxii is found in Western Samoa on 'Upolu and Savai'i islands.

M. sagu is believed to be endemic to Papua New Guinea, New Britain, and the Molucca Islands. Flach (1997) considers Papua New Guinea to be the center of diversity. *M. sagu* is present in Aimelik, Palau, at the old Japanese introduction station.

M. salomonense is endemic to the Solomon Islands including Bougainville Island (Papua New Guinea).

M. vitiense is endemic to Fiji on the islands of Viti Levu, Ovalau, and Vanua Levu.

M. warburgii is found in Futuna, Fiji, Rotuma, Solomon Islands, Vanuatu, Western Samoa, American Samoa, and possibly in Tahiti, Tokelau, and Tonga.

Current distribution

In Papua New Guinea and most Pacific islands, *Metroxylon* spp. are found mainly in wild stands. As it is difficult to distinguish between wild and feral, many so-called wild stands may stem from ancient plantations. Various species are grown throughout the tropics in experimental and commercial plantations.

M. amicarum in Pohnpei is found in freshwater wetlands, either coastal or moist upland rainforest. A few were reported by Stone (1970) to be planted in Guam. There is no local name for this species in Guam, suggesting that it is an introduced species there. *M. amicarum* is possibly an aboriginal introduction to Pohnpei from the Santa Cruz Islands as a cultivar of *M. warburgii* (McClatchey 1998, 2002).

M. paulcoxii is possibly an aboriginal introduction from the Santa Cruz Islands via Rotuma as a cultivar of *M. warburgii*.

M. sagu is by far the most important economic species and is now grown commercially in Malaysia, Indonesia, the Philippines, and New Guinea for production of sago starch and/or conversion to animal food or fuel ethanol. In many countries of SE Asia, except Irian Jaya, *M. sagu* is mainly found in semi-cultivated stands. Irian Jaya has about 6 million ha of *M. sagu*. The stands of good quality *M. sagu* can be quite large. Papua New Guinea has an estimated 1 million ha of wild and 20,000 ha (49,400 ac) of semi-cultivated *M. sagu*. *M. sagu* is also found in Guam, Palau, Nukuoro, Kosrae, and Jaluit, Marshall Islands (Fosberg et al. 1987), most likely the result of human introduction.

M. warburgii has been distributed from Northern Vanuatu and the Santa Cruz Islands to many other adjacent island groups, such as Banks, Tikopia, Anuta, and Rotuma, and a bit further to Fiji, Samoa, and Futuna. It is expected that further research will find that *M. warburgii* is a widely

Distribution of *Metroxylon* species.

dispersed and highly varied species.

BOTANICAL DESCRIPTION

Preferred scientific names

Metroxylon amicarum (H. Wendland) Beccari
M. paulcoxii McClatchey
M. sagu Rottboell
M. salomonense (Warburg) Beccari
M. vitiense (H. Wendland) H. Wendland ex Bentham & Hooker f.
M. warburgii (Heim) Beccari

Family

Arecaceae (palm family)

Subfamily

Calamoideae

Non-preferred scientific names

Many species of *Metroxylon* have previously been classified under the genera *Coelococcus* and *Sagus*.

M. amicarum *Sagus amicarum* Wendl., *Coelococcus amicarum* (Wendl.) Warb., *C. carolinensis* Dingl., *M. carolinense* (Dingl.) Becc., *M. amicarum* var. *commune* Becc., and *M. amicarum* var. *majus* Becc. are not preferred names (Fosberg et al. 1987).

M. paulcoxii No valid non-preferred scientific names known. *M. upoluense* is often used, although it is an invalid name.

M. sagu *Sagus inermis* Roxb. and *Sagus spinosus* Roxb. are not preferred names. In Rauwerdink's classification, *M. rumphii* and *M. squarrosum* are given as synonyms (Flach 1997).

M. salomonense *Coelococcus salomonensis* Warburg, Ber. and *Metroxylon bougainvillense* Beccari are not preferred names.

M. vitiense *Coelococcus vitiensis* H. Wendl. ex Seem. and *Sagus vitiensis* H. Wendl. ex Seem. are not preferred names

M. warburgii *Coelococcus warburgii* Heim. *M. upoluense* is often used, although it is an invalid name.

Common names

M. amicarum

Caroline ivory nut, Caroline ivory nut palm, Polynesian ivory nut palm, Polynesian ivory palm (English)
oahs (Pohnpei)
oj (Marshall Islands)
rupang, *rúpwúng* (Chuuk)

M. paulcoxii

niu Lotuma (Western Samoa)

M. sagu

ambasao (Kwara'ae, Solomon Islands)

balau (Melanau, Sarawak)
chr aè saku (Cambodian)
lumbiya (Philippines)
pohon sagu, pohon rumbia (Bahasa Indonesia)
rumbia (Malaysia)
sago palm, true sago palm, sago (English)
sakhu (Thai)
sa:khu'u, *tônz* (Laos)
saksak (Pidgin English, Papua New Guinea)
sagu (Vietnamese)
tha-gu-bin (Myanmar)

M. salomonense

ao (San Cristobal)
atava, *endeve*, *karamava*, *katuva*, *karama*, *katua*, *karmo*, *nive* (Choiseul)
ato (Bougainville, Florida Islands)
ato, *hapiri*, *naota*, *natho*, *tete-na* (Santa Isabel)
ato, *rao*, *sao* (Guadalcanal)
atovo, *endeve*, *kinenda*, *nggoe*, *pina* (New Georgia)
kalovo (Savosavo)
lao, *rao*, *sao*, *wanda* (Malaita)
name (Shortland Islands)
nat (Russell Islands)
pina (Vella Lavella)

***M. paulcoxii*, 'Upolu, Samoa.** PHOTO: W. MCCLATCHEY

***M. amicarum*, Chuuk Atoll.** PHOTO: W. MCCLATCHEY

***M. sagu*, Aimelik, Palau.** PHOTO: W. MCCLATCHEY

***M. salomonense*, Kolobaqara, Solomon Islands.** PHOTO: W. MCCLATCHEY

***M. warburgii*, American Samoa.** PHOTO: W. MCCLATCHEY

***M. vitiense*, Nasavusavu, Vanua Levu, Fiji.** PHOTO: W. MCCLATCHEY

M. vitiense

songo, *songa*, *niu soria*, *seko* (near Nadi) (Fiji)

M. warburgii

enkul, *natakra*, *natalawa*, *natangura*, *netato*, *nindru ambih*, *notah*, *nuwauriet*, *sokora*, *tangula*, *tenebee*, *tsuku*, *wataghor* (Vanuatu)

lnkoko, *noeroe*, *lovnete*, *nete*, *nokwo*, *otovo*, *ole*, *oe*, *koko*, *laukoko* (Santa Cruz group)

niu Lotuma (Western Samoa)

ota (Anuta, Futuna, Rotuma, Tikopia)

Size

Note that for the leaf and petiole lengths the lower numbers apply to juvenile palms, while the higher numbers apply to mature palms.

M. amicarum reaches a height of 12–33 m (39–108 ft) tall, with a stem 30–36 cm (12–14 in) in diameter. Leaves 4–7 m (13–23 ft) long, petiole 1–3 m (3.3–10 ft) long.

M. paulcoxii is small to moderate size; petiole 1–3 m (3.3–10 ft) long, rachis 1.5–2.9 m (5–9.5 ft) long.

M. sagu reaches 15 m (49 ft) in height with bole diameter (without leaf sheaths) of 35–60 cm (14–24 in).

M. salomonense attains 8–20 m (26–66 ft) tall, with stems 25–55 cm (10–22 in) in diameter. Leaf petiole 1.3–7 m (4–23 ft) long, rachis 2.9–7.5 m (9.5–25 ft) long.

M. vitiense grows to 5–16 m (16–52 ft) tall, with stem 36–50 cm (14–20 in) diameter. Leaf petiole 1.8–8 m (6–26 ft) long, rachis 4–6 m (13–20 ft) long

M. warburgii reaches a height of less than 9 m (30 ft) when mature. Six to 9 m (20–30 ft) tall, with stem 31–43 cm diameter (12–17 in), leaves 0.3–1.5 m (1–5 ft) long

Flowers

The inflorescence is large, paniculate, and mainly terminal for most species. The palms are monoecious, having both male and female flowers on the same plant. Flowers differ little between species other than in length of the parts. The palms are monocarpic; i.e., they fruit and flower once and then die. An exception is *M. amicarum*, which flowers for a number of years (pleonanthic) instead of flowering once and dying. Flowers are borne on crowded spikes, spirally in pairs (of male and hermaphrodite, functional female) flowers.

Leaves

Like most palms, *Metroxylon* species have an erect crown of large, pinnate arching leaves. Leaves moderate to large, pinnate; petiole 0.33–7 m (1–23 ft) long, unarmed or armed with single to multiple spines 1–46 cm (0.4–18 in) long, occurring as clusters, combs, or upon collars of short lateral vascular bundles, sometimes with wide, thin, and papery flattened spines up to 50–60 cm (20–24 in) long and 1–2 cm (0.4–0.8 in) wide; rachis 2.3–7.7 m (7.5–25.3 ft) long, unarmed or armed like the petiole or much less so, particularly in leaves emerging higher on the stem, the surface often adorned with transverse spineless combs; leaflet number proportional to leaf length, usually 160–340, 72–203 cm (28–80 in) long and 4–17.8 cm (1.6–7 in) wide, with a single large, hard, sometimes yellow midrib, frequently glossy green above and dull-pale green below, unarmed or armed with short spines, 1–29 mm (0.04–1.14 in) long, along the margins and main vein.

Fruit

Mature fruits are globose, ovoid or pyriform, 1.5–8.3 cm (0.6–3.3 in) wide, and 2.3–10.6 cm (0.9–4.2 in) long. The epicarp is covered in 7–40 regular ordered, alternating vertical rows of green to golden yellow, to dark brown, to grey-margined, reflexed scales, with mid-fruit scales 4–19 mm (1.6–7.5 in) long.

M. amicarum

Fruit rounded to pyriform, (5.3)7.2–8.3(13) cm ((2.1)2.8–3.3(5.1) in) in diameter, 5.6–13 cm (1.7–5.1 in) long; epicarp covered in 26–38(40) rows of golden to chocolate brown and grey margined, reflexed scales, with mid-fruit scales 7–14 mm (2.7–5.4 in) long. *M. amicarum* seeds are disseminated by gravity or water. Fruits are often found on shores of the Caroline Islands, having been carried by ocean waves and currents from one island to another or one part of an island to another.

M. paulcoxii

Fruit obpyriform, 5.4–6 cm (2.1–2.4 in) in diameter, 6.5–7 cm (2.6–2.7 in) long, with emergent apical stigmatic remains; epicarp covered in 24–26 rows of green to golden yellow-brown to grey margined, reflexed scales, with the mid-fruit scales 13 mm (5.1 in) long.

M. salomonense

Fruit rounded, globular, 5.9–8 cm (2.3–3.1 in) in diameter, 5.2–7 cm (2.0–2.7 in) long; epicarp covered in 25–38 regular ordered alternating vertical rows of green to golden yellow, sometimes tinged with red, to brown, with grey margined, reflexed scales, with mid-fruit scales 11–19 mm (4.3–7.5 in) long.

***M. vitiense*, showing spines on leaf base and petiole, Viti Levu, Fiji.** PHOTO: W. MCCLATCHEY

M. sagu

Fruit depressed-globose to obconical, 3–5(7) cm (1.2–2(2.7) in) in diameter, covered with 18 vertical rows of rhomboid greenish-yellow scales. *M. sagu* produces both pollinated (seeded) and parthenocarpic (non-pollinated) fruit. Seeded fruits contain a stony (hard), white endosperm and brown testa. Parthenocarpic fruit are smaller and contain a spongy mesocarp. *M. sagu* fruits take about 24 months to mature.

M. vitiense

Fruit rounded to elliptic/ovular, 4.1–5.8 cm (1.6–2.3 in) wide, 4.9–6.4 cm (1.9–2.5 in) long; epicarp covered in 25–27 rows of green to golden yellow to dark brown to grey margined, reflexed scales, with mid-fruit scales 9–12 mm (3.5–4.7 in) long.

M. warburgii

Fruit obpyriform, (3.5)5.4–7 cm ((1.4)2.1–2.7 in) wide, (4.4)6.4–8.5 cm ((1.7)2.0–3.3 in) long, with emergent apical stigmatic remains; epicarp covered in 23–31 rows of green to golden yellow-brown, grey margined, reflexed scales, with mid-fruit scales 9–13 mm (3.5–5.1 in) long.

Bark

The bark of mature palms is gray, rough, and fissured in long plates or corky ridges. The stem is frequently surrounded by deteriorating, partially attached leaf-sheaths. The lower internodes frequently have suckers and/or sharp to blunted adventitious roots. On younger trees the bark is smoother and paler gray to brownish in color. The inner bark is light colored and bitter.

How to distinguish from similar species/look-alikes

Metroxylon species may be confused with other palms, although not with any that are found in the native range. Palms in Samoa have often been incorrectly reported as *Metroxylon vitiense*, when only *M. warburgii* and *M. paulcoxii* have been reported in Samoa.

M. amicarum has inflorescences that are axillary; most of the other *Metroxylon* species are monocarpic (the terminal bud develops into a large inflorescence). *M. amicarum* palms are also the tallest, reaching 33 m (108 ft) or possibly taller.

M. sagu has 18 rows of scales on the fruit. The other *Metroxylon* species have between 24 and 40 rows of scales.

M. sagu commonly reproduces by suckers and rarely by seed, while the other species are not reported to reproduce by suckers and normally reproduce by seed. *M. sagu* is eas-

Young inflorescences cut from *M. salomonense*, Guadalcanal, Solomon Islands. PHOTO: W. MCCLATCHEY

Fruits maturing on *M. amicarum*. PHOTO: D. WARD

Developing inflorescence of *M. salomonense* over a period of 2 years and 4 months. The tree shown was planted in 1985 as a juvenile. From left to right: first-order branches forming (11 Dec 2000), flowers forming (6 Sept 2001), and fruit forming (26 Apr 2003). LEFT AND CENTER PHOTOS: E. BURSON, RIGHT PHOTO: R. BAKER

***M. amicarum* fruits, Nett, Pohnpei. Note the wide variation in shape from fruits collected from one stand of trees.** PHOTO: W. MCCLATCHEY

***M. amicarum* fruit.** PHOTO: R. BAKER

ily distinguished by the robust size of the inflorescence branches, which are massive compared with other species.

M. warburgii, along with *M. paulcoxii* and some *M. amicarum*, is easily recognized by its pear-shaped fruits. *M. warburgii* is found over a very wide range of islands and is unstudied throughout much of that range. It is very likely that the species is more variable than currently realized.

GENETICS

While *M. sagu* is mainly propagated vegetatively, the other species reproduce by seed. Of these, *M. amicarum* and some individuals of *M. warburgii* stand out because they do not die upon reaching a reproductive age, instead persisting to become quite tall.

Known varieties

The number of locally identified and named varieties of *M. sagu* is very large. In the Western Sepik basin of Papua New Guinea, Rauwerdink (1986) noted that local sago growers distinguished 20 local cultivars.

Varietal differences have been noted for a number of characteristics including degree of spininess; color of starch; width, length, and thickness of leaflets; number of years until inflorescence initiation, to name a few.

M. sagu has many selected varieties that are thornless and reach maturity in less than 6 years. Rauwerdink (1986) has reviewed the range of varieties and characteristics of preferred types.

Selected varieties are not known for the other species covered here.

Culturally important related species in the genus

All of the species are of major importance to local cultures, except for *M. vitiense*, when was of marginal importance in Fijian society except for a few communities where it was considered to be a source of superior thatch and edible heart of palm.

ASSOCIATED PLANT SPECIES

The less commercially important species are found both in lowland tropical freshwater swamps as well as in traditional swidden gardens in higher altitude lowland rain forests.

In Pohnpei, *M. amicarum* is an occasional component of the montane (upland) rainforest. Plants common to this rainforest are *Clinostigma*, *Glochidion*, *Myrsine*, *Elaeocarpus*, *Syzygium*, *Psychotria*, *Timonius*, *Astronidium*, *Cyathea* tree ferns, and many lianas (*Ipomoea*, *Merremia*, *Freycinetia*, *Hypserpa*, and *Pachygone*). *M. amicarum* is also found in freshwater swamps where common components are species of *Terminalia*, *Campnosperma*, *Barringtonia*, *Erythrina*, *Ficus*, *Hibiscus*, *Phragmites*, *Acrostichum*, and *Scirpodendron* (Mueller-Dombois and Fosberg 1998).

In Papua New Guinea freshwater swamps, *M. sagu* is found in association with *Campnosperma brevipetiolata*, *Terminalia brassii*, *Pandanus*, and several other species. (Mueller-Dombois and Fosberg, 1998).

In the Solomon Islands, *M. salomonense* forms a distinctive freshwater forest type (Mueller-Dombois and Fosberg 1998).

M. vitiense commonly grows in forests in swampy places (Smith 1979). Formerly, it was common near Navua, Viti Levu, but is now found in the more inaccessible swampy valleys.

In Samoa, *M. warburgii* is found in a number of villages on Upolu and Savai'i islands growing as a cultivated species in polycultural agroforests. Here *M. warburgii* has been found growing in traditional agroforests in association with *Citrus* spp., breadfruit (*Artocarpus altilis*), screwpine (*Pandanus* spp.), coconut (*Cocos nucifera*), and *Alocasia macrorhiza*, to name a few common cultivated species.

Massive inflorescence branches of *M. sagu*. PHOTO: W. MCCLATCHEY

ENVIRONMENTAL PREFERENCES AND TOLERANCES

Climate

The suitable climate for *Metroxylon* species is the humid tropical rainforest of SE Asia and the equatorial Pacific. The relative humidity should be at least 70%, but the plant can tolerate lower humidity for short periods without damage, and incidental light should be above 800 k/cm^2/day (Flach 1997).

Metroxylon species do not tolerate water shortage well. In rainfall-dependent sago palm growing localities, rainfall should be uniform and ample. Flooding for prolonged periods and stagnant water are detrimental to growth.

As long as sufficient water is present, there does not seem to be an upper temperature limit for growth of sago. The palms cannot tolerate frost and grow more slowly in cooler climates such as Hawai'i or areas with seasonally cooler weather such as Florida and Queensland.

Metroxylon species can be found in areas where the rainfall is high throughout the year or where there is a summer maximum of rainfall. Soil moisture is probably more important than rainfall pattern or amount, if groundwater and surface water sources are adequate. Flach (1997) noted that if there are short dry spells, the water table should be at most 40–50 cm (16–20 in) below the soil surface.

Elevation range

1–700 m (3.3–2300 ft). Although certain *Metroxylon* species grow well in inland and upland areas, all *Metroxylon* palms growing away from lowland regions are the result of human cultivation.

Mean annual rainfall

2000–5000 mm (80–200 in)

Rainfall pattern

Metroxylon grows in areas with summer or winter peaks or uniform rainfall without pronounced dry spells.

Dry season duration (consecutive months with <40 mm [1.6 in] rainfall)

The plant does not tolerate drought (unless there is ample groundwater).

Mean annual temperature

25°C (77°F)

Mean maximum temperature of hottest month

Greater than 30°C (86°F)

Mean minimum temperature of coldest month

17°C (63°F)

Minimum temperature tolerated

17°C (63°F) (Flach 1997)

Soils

Metroxylon species can grow on a wide variety of soils. They can persist on well drained, poor quality materials including sand, clay, or ʻaʻā lava. The palms will grow in soil that is periodically inundated by salt water as long as fresh water flow is more prevalent.

Soil texture

They prefer medium and heavy soils.

Soil drainage

Metroxylon species grow best in soils with impeded drainage or with seasonal waterlogging. Waterlogging for long periods impedes growth and productivity.

Soil acidity

The palms thrive in acidic to neutral pH (4.0–7.4) soils. One reference indicates tolerance of very acid soils (Flach 1997).

Special soil tolerances

All of the species seem to tolerate salinity for short periods without apparent damage, with some populations growing in regular salt spray, periodic tidal flux, and at the edges of brackish mangrove swamps. Salinity should not exceed 10 S/m (equivalent to 1/8 the salt concentration of sea water) (Flach 1997).

Tolerances

Drought

Drought is detrimental to the growth and productivity of all *Metroxylon* species.

Full sun

The palms do best when there is an adequate amount of sunlight, which is needed to complete their life cycle. With sunlight, the trunks will elongate and begin to produce and store starch.

Shade

Trees grow well in moderately open forest canopies under up to 50% shade. Where growing in mixed stands, the palms can be shaded out by dense shade cast by taller dicotyledonous trees. *M. sagu* produces suckers even when shaded.

Fire

The palms do not tolerate fire.

Frost

The plants do not tolerate frost.

Waterlogging

Metroxylon species tolerate waterlogging, although *M. sagu* is not found where the groundwater depth is too deep. In permanently wet situations, *M. sagu* will develop pneumatophores (modified roots for gaseous exchange). In permanently wet or flooded localities many specimens will remain in the rosette stage and not complete their life cycle and reach maturation (Flach 1997). *M. sagu* is one of the few species that can be grown in swamps without extensively modifying the swamp habitat. However, even though modification is unnecessary, cultivation within the swamp habitat may have detrimental effects on the swamp ecosystem.

Salt spray

Salt spray as well as mild soil salinity are tolerated.

Wind

They are tolerant of windy conditions including bad storms and are rarely observed with sheared tops.

GROWTH AND DEVELOPMENT

Cultivated varieties in well established plantations (particularly of *M. sagu*) grow to a height of 12–18 m (40–60 ft) in 6–14 years. At maturity the trees convert stored stem starch into a large, terminal inflorescence; therefore, farmers watch for early development of the inflorescence as an indication of harvest time. At that time, hormones in the tree convert stored starch into simpler sugars for mobilization.

M. sagu undergoes four stages during its life cycle. Flach's (1997) model has an 11–12 year life cycle from seed to seed under optimum ecological conditions. These stages are:

1. Rosette stage of 45 months from seeding; during this period the plant forms a total of about 90 leaves. This is a period characterized by relatively little growth.
2. Bole formation stage of 54 months; during this period, the bole elongates to maximum height and produces one leaf per month. Plants during this stage have a total of a bout 24 leaves and 54 leaf scars on the bole and are producing a high amount of starch.
3. Inflorescence stage of 12 months. The plant forms two leaves per month, the rate of starch accumulation starts to decrease, and the starch moves from the lower to the upper bole. Palms are harvested for starch during this and the next period. In the semi-cultivated *M. sagu* stands of Papua New Guinea and Irian Jaya, local collectors say that for high production per unit time and area, starch should be harvested at flower initiation (Flach 1997).
4. Fruit ripening stage of 24 months.

Some varieties of *M. sagu* develop an inflorescence at 6–7 years. While this species forms dense stands in freshwater swamps, it produces its highest yield of starch and completes it life cycle when the soil is drier and not flooded.

***M. amicarum,* growing in broad, flat valley with numerous freshwater seeps and small streams, just above sea level. Kitti, Pohnpei.** PHOTO: W. MCCLATCHEY

Other *Metroxylon* species typically require 12–15 years to reach maturation but under ideal circumstances may flower in 10 years.

Growth rate

The growth rate is rapid. Assuming a life cycle of 12 years, growth to a height of 20 m (66 ft), and optimal ecological conditions, this gives a growth rate of 1.67 m/yr (5.5 ft/yr).

Flowering and fruiting

These palms are monocarpic, meaning they flower once, then die. *M. amicarum* is an exception; it flowers repeatedly over many years. Most of the time, *M. warburgii* flowers only once; however, some individuals exhibit growth that is between hapaxanthic and pleonanthic, with an extended but still terminal growth period with large leaves in the inflorescence.

Yields

In Papua New Guinea and Southeast Asia, *M. sagu* is harvested for its large starch grains. Barrau (1959) gave the average yield per trunk as 110–136 kg (242–299 lb) of starch, and up to 400 kg (880 lb) for sterile cultivars. Purseglove (1968) stated that in a New Guinea swamp forest there are about 60 palms per hectare (24 palms/ac) worth felling for their starch, yielding 7000 to 9000 kg (15,400–19,800 lb) of starch per year, with a water content of 35–40%.

In the subsistence economy of the Oriomo Papuans, 150–160 hours of work are required to produce enough sago starch for one person per year (1 kg [2.2 lb] air dried starch/day) (Ohtsuka 1983). In Salawati Island, West Irian, an average wild sago palm trunk weighing 1000 kg (2200 lb) yields 150 kg (330 lb) of dry starch (Flach 1997). Sarawak smallholders produce about 50,000 mt (55,000 t) of air-dried sago flour per year for export (Singapore Zoological Gardens Docents 2000).

Leaf production rates are uncertain. However, growers indicate that it is critical that at least three mature leaves be left when harvesting leaves for thatch, or else the palm is likely to die. Often palms harvested for thatch have impeded growth and the appearance of stress. As an indication of this stress, Haska (1995) noted that for *M. sagu* in West Java, average starch production "is only 55 kg/trunk" from palms grown for leaves, while it is "175 kg/trunk for the same variety grown for starch only."

Rooting habit

M. sagu has heavy aerial and spongy roots with a tough central vascular strand that penetrate only about 1 m (3.3 ft) deep into the soil (ARCBC 2004). It is likely that the rooting system is fairly shallow, similar to coconut's. In wet areas, the palm produces pneumatophores (roots which aid in respiration).

Reaction to competition

When growing in mixed forests, *Metroxylon* can be shaded out by faster growing species. It does not compete well against dicotyledonous trees (Flach 1997). However, it readily grows as a living fence on the sunny side of gardens and in agroforestry plantations of mixed, shorter stature trees and shrubs.

PROPAGATION

All *Metroxylon* species are propagated by seed. An exception to this is *M. sagu*, which for the most part is sterile, reproducing via vegetative suckers emerging from roots or lower trunks of parent plants. The species also reproduces by stolons, often meters in length. For more information on propagating *M. sagu*, see Schuiling and Jong 1996.

Propagation by seed

Seed collection

With the exception of *M. amicarum*, *Metroxylon* species reproduce only once, at the end of their life cycle. The flowering stage occurs at an age of 6–20 years. Seeds only germinate when fully mature (signified by large fruit size and the husk turning color from green to straw or brownish). Fruits take 24–36 months to reach maturity. Because of the height of the fruit at the apex of the palm, and the difficulty of assessing maturity, it's best to collect fruit immediately after it has fallen to the ground.

Seed processing

The seeds are large and can easily be cleaned of loose debris or soil after falling.

Seed storage

The seeds lose their viability rapidly when stored and do not tolerate dry conditions. Successful germination occurs within 1–2 months after maturity, and it is best to sow seeds immediately after harvest. Seeds may germinate while still attached to the infructescence (vivipary) and grow to heights of 0.9–1.2 m (3–4 ft) tall before breaking off and falling to the ground. This is particularly common in *M. warburgii*.

The short life span of the seeds and the long reproductive cycle means that *Metroxylon* is best maintained and conserved in field gene banks (Flach 1997). In a sago swamp, seeds germinate readily when they are laying on moist soils.

Pre-planting seed treatments

Flach (1997) noted that germination can be speeded up if the seed husk is removed and the covering over the embryo (operculum) is loosened. Care should be taken not to damage the embryo.

Growing area

Due to the large seed size and rapid early growth, *Metroxylon* is well suited for direct-seeding in the field, assuming conditions are consistently moist. Seedlings can also be germinated in a nursery and transplanted bareroot at a young age, or grown to a larger size in a container. Seedlings transplant well as long as roots are not bound.

Germination

The seeds germinate best when exposed to a temperature of 30°C (86°F) and high humidity for prolonged periods (Ehara et al. 1998). Under such conditions, freshly harvested *Metroxylon* seeds have a high germination rate in 1–2 months. Such conditions can be achieved in a closed nursery, which heats up quickly in the sun. Artificial heat such as a climate-controlled cabinet or temperature-regulated bottom heat can also work. Prolonged exposure to temperatures above 38°C (100°F) can harm the seeds.

Media

A standard well drained nursery medium containing peat moss, coir, sand, etc., can be used, as long as the medium is free of pathogenic organisms.

Time to outplanting

Plants should be outplanted as soon as possible. Plants can have roots up to 30 cm (12 in) long and 2–3 eophils (first leaves) and still survive transplantation.

Approximate size at time of outplanting

Although it is best to outplant before the second eophil emerges, plants with several sub-mature leaves (1–2 m [3.3–6.6 ft] long) and a well developed root system have been successfully planted out.


Transplanting volunteer seedlings collected from under mature palms may be the easiest propagation method. This is a *M. warburgii* seedling collected in American Samoa. PHOTO: C. ELEVITCH

DISADVANTAGES

Metroxylon species, aside from *M. sagu*, are not very productive as starch plants. Their importance as a source of thatch is gradually decreasing as more durable man-made materials become available. Other minor products such as vegetable ivory are of limited economic importance. The spiny leaves may be considered a drawback, especially in urban environments. Expansion of the species into freshwater swamps may have serious ecological implications for the fauna and flora and is not recommended.

Potential for invasiveness

Metroxylon species are not considered to be an invasive.

Diseases and pests

The Pacific island species have few notable pests or diseases. The problems of diseases and pests are greater with intensive cultivation of *M. sagu*. In Sarawak, the main pests are the hispid beetle larvae (*Botronyopa grandis*) that feed on young tissue of the unopened spear at the central base of the crown; termites (*Coptotermes* spp.), which can be a pest on peat soils containing undecayed vegetative material; and red striped palm weevil larvae (*Rhynchophorus* spp.), which burrow into injured plant tissue (Gumbek and Jong 1991, cited by Flach 1997). Wild boars and monkeys may uproot newly planted suckers. Sudden drainage of a swamp can lead to a loss of leaves associated with a physiological disease (Flach 1997).

Other disadvantages or design considerations

More research information is needed on the fertility requirements of *Metroxylon* in order to raise yields above subsistence levels.

AGROFORESTRY/ENVIRONMENTAL PRACTICES

Soil stabilization

The root systems are able to trap silt.

Crop shade/overstory

In the Western Province of Papua New Guinea, farmers plant kava (*Piper methysticum*) in beds under a cover of *M. sagu* (Lebot 1991).

Improved fallow

Throughout the Pacific, *Metroxylon* species are planted or protected in fallow land.

Homegardens

Metroxylon species are frequently incorporated in mixed homegardens on many Pacific islands.

Living fences

Young palms, with their numerous spines, act as fences for pigs and deterrents to trespassers. As the palms mature and develop above-ground stems, new palms may be planted adjacent to the juveniles to maintain the spininess of the fence.

Boundary markers

The seeds are planted along rock walls and other property boundaries.

Windbreaks

Although *Metroxylon* species are not recommended for use as windbreaks, they are tolerant of windy conditions and are rarely observed with sheared tops.

Animal fodder

After removing most of the starch, the pith of *M. sagu* is fed to pigs in Papua New Guinea and many SE Asian countries. It is used as a basis for commercial animal feed in SE Asia.

Wildlife habitat

The palms provide nesting sites for birds.

Coastal protection

As the species is somewhat tolerant of salinity, it may offer some protection to low-lying coastal areas from extensive saltwater inundation by storm surges.

Ornamental

Considered to be a desirable ornamental plant in Pohnpei and other Pacific islands.

USES AND PRODUCTS

The various species of *Metroxylon* have important cultural values throughout many parts of the Pacific and SE Asia.

Top: Living fence of *M. warburgii* and pandanus in Samoa. Bottom: *M. warburgii* in a Samoan homegarden together with coconut, breadfruit, papaya, citrus, and other trees. PHOTOS: C. ELEVITCH

The two primary uses are for the production of edible starch and durable leaf thatch. Several secondary uses have also been recorded, but these are not comparable in economic importance to the primary uses. *M. sagu* is a staple food crop in the Sepik and Gulf provinces of lowland Papua New Guinea, where most of the sago grows in wild, uncultivated stands. Among the Asmat of Papua New Guinea, felling of the palm and harvesting of the sago starch is accompanied by ritual. In house construction, the leaves of sago are used for roof thatch and wall siding, and the wood is also used for floorboards and rafters. In the Solomon Islands, the thatch is known to last 5 years or longer. The decaying trunks of the sago palm are a source of sago palm beetle grubs (*Rhynchophorous ferrugineus/ bilineatus*), an excellent source of protein. In the other parts of the Pacific, *M. warburgii* and *M. amicarum* are viewed as emergency food and are rarely or no longer eaten by people, although they are used for thatch and animal feed. Various parts of the plant are used for traditional medicines, toys, and other miscellaneous items.

PREPARING SAGO STARCH

1. Preparatory processing
   - Possible homage (monetary, spiritual, or familial) paid for access to a *Metroxylon* tree.
   - Selection of a tree containing usable starch.
   - Felling of the tree.
   - Possible transport of the log.
   - Splitting the tree open, lengthwise.
   - Removal of the pith.
2. Extraction of starch.
   - Crushing, threshing, and/or hand kneading of the pith to release the starch.
   - Washing and straining to extract the starch from the fibrous residue.
   - Collection of raw starch suspension in a settling container.
   - Decanting the water layer in order to collect the residual semi-solid pan of starch.
3. Storage of starch product.
   - Drying to form flour.
   - Cooking to form a bread or pudding.
   - Distribution of the dried/cooked end product.

(Barrau 1958, Henderson and Hancock 1988, McClatchey and Cox 1992).

Staple food

Metroxylon starch may be eaten as raw chunks of pith or as baked pieces of pith. Whole logs have been baked and taken as sea-provisions on long canoe voyages (Codrington 1891).

Each of the species is presently or has been formerly used as a source of edible starch, with the possible exception of *M. vitiense*. The most intensive use as a food source has been in the western Solomon Islands and Bougainville. Throughout the rest of the range of distribution, it was eaten as a famine food, although this is questionable in Fiji (Seemann 1865–1873) and in at least one culture in the eastern Solomon Islands (Woodford 1890).

Production and use of sago starch varies somewhat from location to location but can generally be summarized in the stages as indicated in the text box above.

Guppy's (1987) description of sago processing is typical:

"In the extraction and preparation of the sago, the natives of Bougainville Straits employ the following method. After the palm has been felled and all the pith removed, either by scooping it out or splitting the trunk, the pith is then torn up into small pieces and placed in a trough extemporized from the broad sheathing base of one of the branches of the felled tree. The trough is then tilted up and is kept filled with water, which running away at the lower end passes through a kind of strainer, made of a fold of the vegetable matting that invests the bases of the branches of the cocoa-nut tree, and is then received in another trough of similar material. The fibrous portion of the pith is thus left behind, and the sago is deposited as sediment in the lower trough. When this trough is full of sago, the superfluous water is poured off, and the whole is placed over a fire so as to get rid of the remaining moisture.... The sago is now fit for consumption, and is wrapped up in the leaves in the form of cylindrical packages 1½ to 2 feet in length."

As discussed above, production of sago from *M. paulcoxii* and *M. warburgii* is probably a recently introduced concept in Samoa. No one was observed producing starch from *M. paulcoxii*. Although starch production from *M. amicarum* is known, it is very rare, the trees being much too highly valued for thatch. Presently, many cultures have virtually abandoned the production of sago starch, in favor of other starch crops such as sweetpotato, taro, cassava (manihot), or imported rice.

Throughout SE Asia there are many traditional ways of preparing sago for consumption. (See Flach (1997) for many details about the starch, etc.). In Indonesia and many of the SE Asian countries, sago starch is produced commercially for use as food. In Cirebon, Indonesia, the starch is used in making noodles. The starch is also used in making white bread.

Sago pearls are made in West Malaysia and Sarawak. In West Malaysia the pearls are used in the preparation of three-palm pudding (sago pearls in coconut milk, and sugar from *Arenga pinnata*). In Sarawak the pearls are mixed with rice bran.

Fruit

Immature fruits (seeds) are occasionally reported as being eaten, particularly by children.

Nut/seed

In Chuuk, buttons were made from the hard, white, ivory like nut (endosperm) of *M. amicarum* during the Japanese mandate years. The nut is eaten by pigs in Chuuk and Pohnpei (Merlin et al. 1992, Merlin and Juvik 1996).

Leaf vegetable

The apical meristems or palm hearts are large and soft. The trees may be harvested prior to maturation exclusively for this purpose, with the meristem and several feet of the immature leaves being used. These palm hearts are used locally or are sold in local markets. They are eaten raw as a vegetable or cooked with other foods (now common in curries).

Secondary food products

Indirect traditional uses of *Metroxylon* include collection of mushrooms and beetle larvae that feed upon fallen trees. These are then eaten by local peoples. Naturally fallen palms may be checked periodically for growth of mushrooms and larvae, and in some areas palms are felled with the intention of collecting larvae or fungus at later times. The practice of intentionally felling *Metroxylon* to induce production of secondary products may represent one of the earliest forms of agriculture.

POHNPEI LORE

In Pohnpei, *M. amicarum* is the tallest of three native palms. Of those born of chiefly status (*Nanmwarki*), the maternal lineage, or "blood," is known as *Neinneinioahs Soupeidi*. The phrase is an honorific, with symbolic reference to this tall palm (Merlin et al. 1992). The implication is that the child will grow to be as tall, or as high in rank, as his forbears (as tall as an *M. amicarum* palm).

One legend says that before Pohnpei was vegetated, people lived in houses of rock without any roofs. A lady with magical powers visited the island and took pity on the people there. She then sent them the *oahs* plant, which the people used for thatching and other significant purposes (Elias 1998).

Top: The starch can be eaten raw. Bottom: The starch is usually harvested and refined into pure starch using a water process. Both photos: *M. warburgii*, American Samoa. PHOTOS: W. MCCLATCHEY

Appliances

The smooth inner surface of the sheaths also may be used as temporary containers or troughs for animal feed and as kneading boards for bread made from sago. *Metroxylon* leaflets may be used to line cooking pits. Woven leaflets are used as temporary baskets. Whole leaves are used to cover and protect dry-stored canoes (Feinberg 1988). The stiff, hard midribs may be used to make brooms, may serve as temporary sewing needles or pins, or may be used as thatch sheet skewers (Firth 1950). Guppy (1887) reported that gourd bottle-corks/stoppers are made from lightly rolled discs of sago leaves. The leaf sheaths are commonly covered externally with rough spines and/or rib-like protuberances. These rough sheaths have served as rasps in the preparation of sago and other food products that must be grated.

Toys

Bats, balls, and rafts are made by children from the leaf base.

Beverage/drink/tea

Starch of *M. sagu* is used in the manufacture of fructose syrup for non-alcoholic drinks. Perhaps the starch can also be used for making starch pearls similar to tapioca pearls used in fruit drinks.

Medicinal

The roots, young leaves, and stem cork of *M. amicarum* are used for traditional medicine in Pohnpei.

Timber

The wood (outer cortex) of *Metroxylon* stems is used as flooring and as planking for crossing short streams or swampy areas. The wood is not reported as being long lasting or durable, but is employed as a by-product by those who extract starch. Wood has also been used as house rafters (e.g., in Chuuk) and as wall material, although this is an infrequent usage. The woody leaf petioles of *M. sagu* are used to make walls, ceilings, and fences (Schuiling and Jong 1996).

Fuelwood

The bark can be used as a factory fuel.

Canoe/boat/raft making

The leaf rachis, without leaflets, may be used as a "raft" (Firth 1950). Children sometimes make surfboards from the petiole base (leaf sheath) that can be up to one meter wide.

Fiber/cordage

The fibrous outer layers of *M. sagu* leaf petioles are used for cordage and mat weaving (Schuiling and Jong 1996). Pith and leaf fibers have been studied for use in paper production (Kasim et al. 1995).

Fodder

The raw starch is used as pig feed on a local level. The starch has also been used on an industrial scale to feed pigs and chickens (Dunsmore and Ong 1970, Jalaludin et

Left: The leaf sheath covered with spiny ribs can be used as a grater in preparing sago starch. Right: *M. warburgii* with fronds pruned for thatch, Samoa. PHOTOS: C. ELEVITCH al. 1970, Müller 1977, Ong 1973, Springhall and Ross 1965).

Thatch/roofing/mats

Leaves are highly valued for thatch for roofs and house walls in many islands of the Pacific. In Pohnpei, roofs are called oahs, the Pohnpeian word for *M. amicarum*, as the leaves are used for thatch (Merlin et al. 1992).

The leaves are made into thatch in two different ways, with slight variations of these patterns in different cultures. Leaves may be woven into thatch sheets using the following procedure:

1. Mature leaves are split down the middle of the rachis.
2. The halves of the leaf are woven and matched with the distal apex of one half attached to the proximal petiole base of the other, and vice versa.
3. The pair of leaves is allowed to dry in the sun, thus curing it into a dry thatch.
4. Drying may take from half a day to a week or more depending on the temperature and weather.

The thatch sheets may also be used green and allowed to dry on the house (Gardiner 1898). A slightly different weaving pattern is used for sets of leaves used to thatch the apex of the roof. Rather than using pairs of leaf halves, two entire leaves are woven facing one another, then one of the two leaves is split in half (down the rachis) leaving two leaf halves and one entire leaf all woven together. After weaving, the entire leaf is at the center of the thatching strip and the leaf halves are attached to each side. These unique apical thatch leaves are commonly called fakatafiti (or a cognate) throughout their usage in western Polynesia.

Alternatively, leaves may be manufactured into sewn thatch sheets through the following procedure:

1. Leaflets are removed from the rachis.
2. Each leaflet is folded over a supporting spine of wood (e.g., *Areca macrocalyx*), bamboo (e.g., *Bambusa* or *Schizostachyum* spp.), or rattan (*Calamus* spp.).
3. The leaflets are sewn or pinned to the spine using coconut sennit, thin lengths of split *Calamus*, or *Flagellaria* stems or other suitable materials.
4. The lengths of the leaflets may be trimmed to produce a uniform-size sheet or may be left in uneven lengths.
5. The resulting thatch sheets are dried in the sun as the woven sheets.

The thatch is applied in layers, with each sheet being tied to the rafters with coconut sennit or vines. Walls may also be constructed from the same thatch sheets.

M. warburgii **thatch, Rotuma.** PHOTO: W. MCCLATCHEY

In northern Vanuatu, where both *M. warburgii* and *M. salomonense* are present, thatch from each species is used for different constructions. *Metroxylon warburgii* sheets are used for roofing, whereas *M. salomonense* sheets are used for wall siding (Zona, pers. comm.). In Samoa, older informants indicated that the leaves of *M. paulcoxii* were not useful for thatch but that *M. warburgii* is considered to be a superior thatch. Younger Samoan informants did not seem to be aware of the difference between species and seemed to harvest the leaves indiscriminately.

The leaflets (basic thatch materials) of *M. amicarum* and *M. warburgii* contain highly modified and enlarged subhypodermal bundles of fibers. These fibers explain the enduring quality of thatch made from these species. As humans have selected these species, they have probably also selected for increased fiber production and have selectively planted cultivated trees with better leaf qualities.

Resin/gum/glue/latex

In Indonesia, the starch is used as an extender in plywood adhesives.

Body ornamentation/garlands

Metroxylon fruits, particularly those of *M. salomonense* and *M. amicarum*, have been (and are still) used as sources of vegetable ivory. Formerly European industries imported quantities of *Metroxylon* seeds, i.e., "ivory nuts," which were cut into buttons for clothing. The seeds, which are quite hard and ivory-like, are carved to produce cultural items of trade in local economies and for sale to tourists. The Solomon Islands presently exports *M. salomonense* seeds to Alaska, where they are carved and sold by traditional peoples in place of sea-mammal ivory. *Metroxylon amicarum* seeds carved and sold locally in the Federated States of Micronesia are also shipped to Japan. Some of

At Buma Village (North of Auki) in Malaita Province, Solomon Islands, leaves of *M. salomonense* are used in traditional houses for wall sidings and roof thatch. These materials are reputed to last for about 7 years. Other palms in this photo include coconut and betel nut. PHOTO: H. MANNER

***M. warburgii* thatch and walls, Rotuma.** PHOTO: W. MCCLATCHEY

these "ivory nuts" that were brought to Europe by sailors eventually became labeled as collections of "petrified apples" in the Berlin Museum herbarium. The vegetable ivory is distinguished from that of other palm seeds in that *Metroxylon* often has a greenish hue and a grain that is spiraled.

Ceremonial/religious importance

Among the Asmat of Papua New Guinea, a palm that is about to bear fruit is selected, then dressed with a woman's skirt of leaves. After a honorific recitation of brave deeds by the men, the palm is felled and attacked as an enemy. Holes are bored into the trunk. The sago palm beetle (*Rynchophorus ferrugineous/bilineatus*) then lays its eggs there, and 6 weeks later the grubs are harvested, carried triumphantly as a slain enemy to the village on a tray of sago leaves, and then consumed (Singapore Zoological Gardens Docents 2000).

Other

Other uses of *Metroxylon* that are either being studied or are presently in use include alternative uses (non-food) of sago starch and uses of by-products of sago production. Sago starch is a useful substrate for commercial fuel ethanol production (Haska 1995, Holmes and Newcombe 1980, Ishizaki and Tripetchkul 1995, Lee et al. 1987, Newcombe et al. 1980, 1982, Rhee et al. 1984).

By-products of commercial sago production include reclaimed fibers and waste pith used as fertilizer. Sago pith residue as a diluent and supplement to green manures has been studied (Bintoro 1995). This use is of particular economic interest, because *Metroxylon* frequently grows in swampy areas with poor soils. Suitable fertilizers developed from local inputs, such as pith residue, could provide efficient low cost agricultural improvements for the peoples who farm in and adjacent to commercial sago growing areas.

COMMERCIAL PRODUCTS

Starch

In contrast to other sources of starch, sago yields are exceptionally high. Under good conditions the range is from 15 to possibly 25 mt of air-dried starch/ha (6.7–11.1 t/ac) of *M. sagu* at the end of an 8-year growth cycle (Flach 1997). One source notes that this industry earns RM620/mt of air-dried starch (Flach 1997). *M. sagu* is considerably more productive for starch production compared with other *Metroxylon* species. Although the starch yields of other species have not been measured, the starch from each species (including *M. amicarum*) is similar in taste and consistency to that of *M. sagu*. It seems likely that because traditional selection in species other than *M. sagu* (and possibly some populations of *M. warburgii* in Vanuatu and Rotuma, Fiji) has probably focused on leaf qualities rather than starch, that starch production has not been maximized and therefore will be of lower quality and quantity.

Thatch

Thatch made of *Metroxylon* leaves is of considerable value to local peoples. On Guadalcanal in the Solomon Islands, sewn thatch sheets sell for SI$1.50 each, or about one third to one fifth of a day's wages. Thatch sheets of *M. amicarum* sell for US$0.50 to US$2.00 each in Pohnpei, with higher prices charged after storms and for large projects such as hotels. *Metroxylon* thatch lasts for up to 10 years, whereas the alternative thatches of coconut leaves, sugarcane leaves, and pandanus must be replaced every 1–4 years. Some well thatched *Metroxylon* roofs are said to have lasted as long as 50 years. The value of this thatch to traditional peoples cannot be underestimated.

The economic value of *Metroxylon* leaf was demonstrated following Cyclone Namu (May 1986) in the Solomon Islands, when for a long period many destroyed homes could not be rebuilt because of a lack of roofing and walling material (Henderson and Hancock 1988).

INTERPLANTING/FARM APPLICATIONS

For highest yields of starch, *M. sagu* should probably be grown as a monocrop, as few other plant food species do well in the peat swamp. Except for Papua New Guinea, there are few extensive stands of *Metroxylon* throughout the Pacific islands. As a food staple, sago is not a preferred starch in the Pacific. However, interplanting *Metroxylon* for its other products is practiced extensively on many Pacific islands.

Example 1

Location

Aopo Village, Savai'i Island, Samoa

Description

This is a backyard pig-foraging area and agroforest. The most prominent species found in this backyard kitchen garden was *M. warburgii*. The palms stand about 10 m (33 ft) in height and have large inflorescences, indicating maturity. Other trees in the vicinity are citrus species, coconut, etc.

Example 1: Pig-forage area and agroforest, Aopo Village, Savai'i Island, Samoa. PHOTO: H. MANNER

Example 2

Location

Taga Village, Savai'i Island, upland garden, and agroforest area.

Description

This area has young *M. warburgii* trees with old fronds trimmed off, standing about 4 m (13 ft) high in association with screwpine (*Pandanus* spp.), coconut, banana, breadfruit (*Artocarpus altilis*), and taro (*Alocasia macrorrhiza*).

PUBLIC ASSISTANCE AND AGROFORESTRY EXTENSION

Extension offices for agroforestry and forestry in the Pacific: http://www.traditionaltree.org/extension.html.

GERMPLASM RESOURCES

Collections of most species are found at the Bogor Botanical Garden, Fairchild Botanical Garden, University of the South Pacific, Laucala campus, and the Lyon Arboretum, Honolulu.

Major collections of *M. sagu* varieties are held by the University of Malaysia, Sarawak, and the Ministry of Agriculture, Lae, Papua New Guinea.

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Example 2. Top: Agroforestry system Taga Village, Savai'i Island, Samoa. Bottom: Older *M. warburgii* trees at Tafua-tai, Savai'i Island, Samoa, spaced about 8 m (26 ft) apart. PHOTOS: H. MANNER

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Metroxylon amicarum, *M. paulcoxii*, *M. sagu*, *M. salomonense*, *M. vitiense*, and *M. warburgii* (sago palm)

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Acknowledgments: The authors and publisher thank Ray Baker, Hiro Ehara, Dale Evans, and Bill Raynor for their input. Photo contributions from Ray Baker, Eleanore Burson, and Deborah Ward are greatly appreciated.

Recommended citation: McClatchey, W., H.I. Manner, and C.R. Elevitch. 2006. *Metroxylon amicarum*, *M. paulcoxii*, *M. sagu*, *M. salomonense*, *M. vitiense*, and *M. warburgii* (sago palm), ver. 2.1. In: Elevitch, C.R. (ed.). Species Profiles for Pacific Island Agroforestry. Permanent Agriculture Resources (PAR), Hōlualoa, Hawai‘i. <http://www.traditionaltree.org>.

Sponsors: Publication was made possible by generous support of the United States Department of Agriculture Western Region Sustainable Agriculture Research and Education (USDA-WSARE) Program; SPC/GTZ Pacific-German Regional Forestry Project; USDA Natural Resources Conservation Service (USDA NRCS); State of Hawai‘i Department of Land & Natural Resources Division of Forestry & Wildlife; and the USDA Forest Service Forest Lands Enhancement Program. This material is based upon work supported by the Cooperative State Research, Education, and Extension Service, U.S. Department of Agriculture, and Agricultural Experiment Station, Utah State University, under Cooperative Agreement 2002-47001-01327.

Series editor: Craig R. Elevitch

Publisher: Permanent Agriculture Resources (PAR), PO Box 428, Hōlualoa, Hawai‘i 96725, USA; Tel: 808-324-4427; Fax: 808-324-4129; E-mail: par@agroforestry.net; Web: <http://www.agroforestry.net>. This institution is an equal opportunity provider.

Species Profiles for Pacific Island Agroforestry
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April 2006
ver. 4

Morinda citrifolia (noni)

Rubiaceae (coffee family)

canary wood (Australia); *fromager*, *murier indien* (French); *i* (Kosrae); Indian mulberry (English); *lada* (Guam, N. Mariana Islands); *kesengel*, *lel*, *ngel* (Palau); *kikiri* (Solomon Islands); *kura* (Fiji); *mangal'wag* (Yap); *mora de la India* (Spanish); *nen*, *nin* (Marshall Islands, Chuuk); *non* (Kiribati); *noni* (Hawai'i); *nono* (Cook Islands, Tahiti); *nonu*, *nonu atoni*, *gogu atoni* (Niue, Samoa, Tonga, Wallace, Futuna); *weipwul* (Pohnpei)

Scot C. Nelson

IN BRIEF

Distribution Native to Southeast Asia (Indonesia) and Australia, it now is found throughout the tropics.

Size Typically 3–6 m (10–20 ft) tall at maturity.

Habitat Widely adapted to the tropics, 1–800 m (0–2600 ft) depending on latitude, mean annual temperatures of 20–35°C (68–95°F), annual rainfall of 250–4000 mm (10–160 in).

Vegetation Associated with a wide range of common coastal and littoral forest shrubs, as well as numerous cultivated plants.

Soils Grows in an extremely wide range of soils.

Growth rate Moderate, generally 0.75–1.5 m/yr (2.5–5 ft/yr).

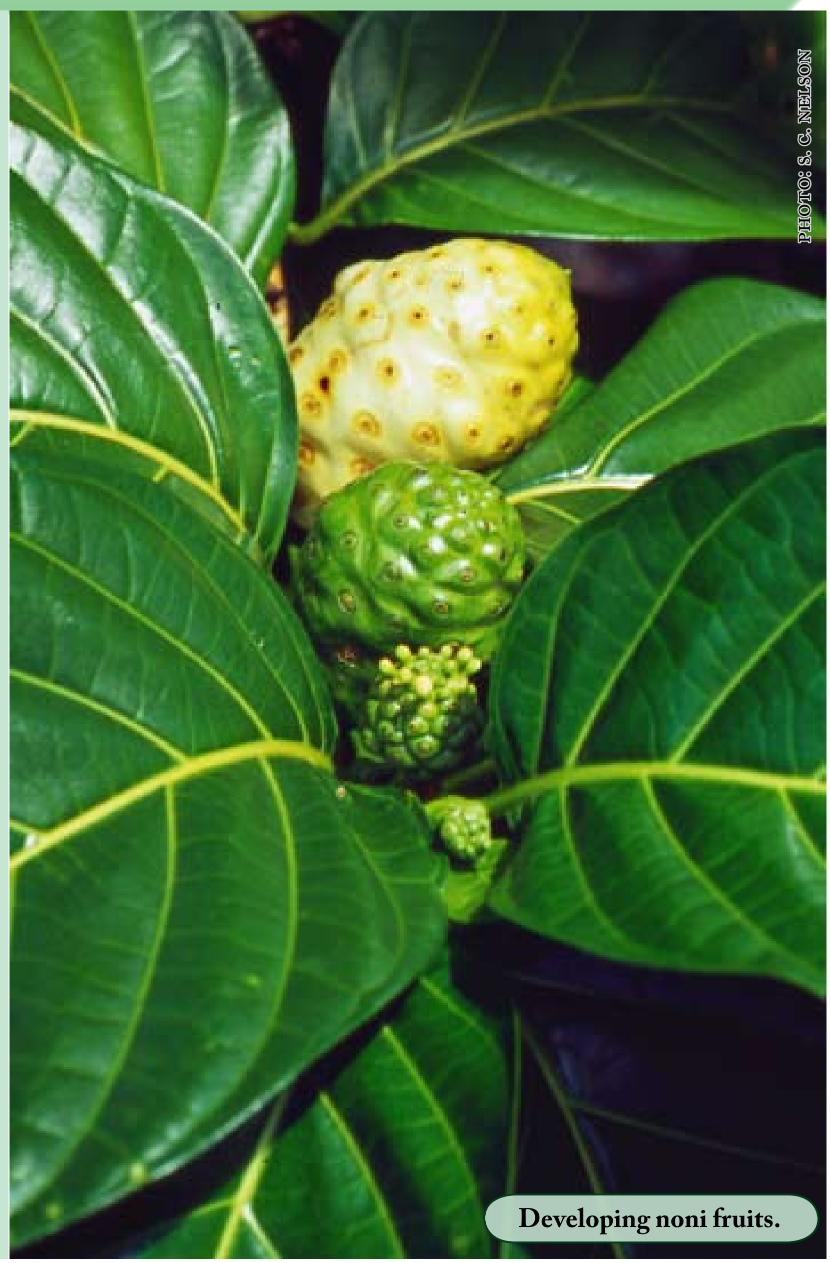
Main agroforestry uses Coastal protection, homegardens.

Main products Medicinal.

Yields Up to 80,000 kg of fruit per hectare (71,000 lb/ac) annually.

Intercropping Traditionally grown in mixed cropping systems throughout the Pacific.

Invasive potential Has naturalized outside its native range in many locations throughout the Pacific and the tropics, although it is rarely considered a pest.



Developing noni fruits.

INTRODUCTION

Noni can grow from elevations of 500 m (1640 ft) down to near sea level; here seen at Apia Bay, Samoa. PHOTO: C. ELEVITCH

Morinda citrifolia, known commercially as noni, grows widely throughout the Pacific and is one of the most significant sources of traditional medicines among Pacific island societies. This small evergreen tree or shrub is native from Southeastern Asia (Indonesia) to Australia, and now has a pantropical distribution. Noni is noted for its extremely wide range of environmental tolerances. It can grow in infertile, acidic, and alkaline soils and is at home in very dry to very wet areas. It is found naturally in relatively dry to mesic sites or lowland areas in close proximity to shorelines, or as an important forest understory species in low-elevation Pacific island forests and rainforests. Noni's extensive range of environmental tolerances also includes exposure to wind, fire, flooding, and saline conditions. Although not considered to be invasive to a degree that threatens ecosystems, noni is treated as a weed in some settings, is very persistent and difficult to kill, and is one of the first plants to colonize harsh waste areas or lava flows. All parts of the plant have traditional and/or modern uses, including roots and bark (dyes, medicine), trunks (firewood, tools), and leaves and fruits (food, medicine). The medicinal applications, both traditional and modern, span a vast array of conditions and illnesses, although most of these have yet to be scientifically supported. Noni is well suited for intercropping within traditional agroforestry subsistence farming systems or as a monocrop in full sun. The tree has attained significant economic importance worldwide in recent years through a variety of health and cosmetic products made from its leaves and fruits. These include fruit juices as well as powders made from the fruit or leaves.

DISTRIBUTION

Native range

Noni is native to Southeast Asia (Indonesia) and Australia. It can be found in disturbed forests, dry to mesic forests, alien grasslands, open areas near the shoreline, pastures and coconut plantations, in littoral forest understories, fallow areas, waste places, and around villages.

Current distribution

The distribution of noni is pantropical at latitudes of 19° N or S. The Indo-Pacific distribution includes Eastern Polynesia (e.g., Hawai'i, Line Islands, Marquesas, Society Islands, Australs, Tuamotus, Pitcairn, and Cook Islands), Melanesia (e.g., Fiji, Vanuatu, New Guinea, New Caledonia, and the Solomon Islands), Western Polynesia (e.g., Samoa, Tonga, Niue, 'Uvea/Futuna, Rotuma, and Tuvalu) and Micronesia (e.g., Pohnpei, Guam, Chuuk, Palau, the Marshall Islands, and the Northern Marianas), Indonesia, Australia, and Southeast Asia. Noni has also become naturalized on the open shores of Central and South America (from Mexico to Panama, Venezuela, and Surinam) and on many islands of the West Indies, the Bahamas, Bermuda, the Florida Keys, and parts of Africa.

BOTANICAL DESCRIPTION

Preferred scientific name

Morinda citrifolia L.

The botanical name for the genus was derived from the two Latin words *morus*, mulberry, and *indicus*, Indian, in reference to the similarity of the fruit of noni to that of true mulberry (*Morus alba*). The species name indicates the resemblance of the plant foliage to that of some citrus species.

Family

Rubiaceae (coffee family), subfamily Rubioideae

Common names

canary wood (Australia)
fromager, murier indien (French)
i (Kosrae)

Indian mulberry (English)
lada (Guam, Northern Mariana Islands)
mangal'wag (Yap)
kesengel, lel, ngel (Palau)
kikiri (Solomon Islands)
kura (Fiji)
mora de la India (Spanish)
nen, nin (Marshall Islands, Chuuk)
non (Kiribati)
noni (Hawai'i, Marquesas)
nono (Cook Islands, Tahiti)
non, nonu atogi, gogu atogi (Niue, Samoa, Tonga, 'Uvea/ Futuna)
weipwul (Pohnpei)

Size and form

Noni is a small evergreen tree or shrub 3–10 m in height at maturity. The plant sometimes supports itself on other plants as a liana. There is much variation in overall plant form, fruit size, leaf size and morphology, palatability, odor of ripe fruit, and number of seeds per fruit.

Flowers

Flowers are perfect, with about 75–90 in ovoid to globose heads. Peduncles are 10–30 mm (0.4–1.2 in) long, the calyx a truncated rim. The corolla is white, 5–lobed, the tube greenish white, 7–9 mm (0.28–0.35 in) long, the lobes oblong-deltate, approximately 7 mm (0.28 in) long. There are five stamens, scarcely exserted; the style is about 15 mm (0.7 in) long.

Leaves

Leaves are opposite, pinnately veined, and glossy. Blades are membraneous, elliptic to elliptic-ovate, 20–45 cm (8–18 in) long, 7–25 cm (3.5–10 in) wide, and glabrous. Petioles are stout, 1.5–2 cm (0.6–0.8 in) long. Stipules are connate or distinct, 1–1.2 cm (0.4–0.5 in) long, the apex entire or 2–3-lobed.

Fruit

The fruit (technically known as a syncarp) is yellowish white, fleshy, 5–10 cm (2–4 in) long, about 3–4 cm (1.2–1.6 in) in diameter, and soft and fetid when ripe.

Seeds

Seeds have a distinct air chamber, and can retain viability even after floating in water for months.

Rooting habit

Noni has a rooting habit similar to that of citrus and coffee, with an extensive lateral root system and a deep taproot.

How to distinguish from similar species

The wood of noni is a yellowish color and the fruits have a unique and distinct disagreeable odor when ripe.

GENETICS

There is a relatively high degree of genetic (e.g., morphological) variability of the fruit and leaf within the species. Known varieties include the following:

Morinda citrifolia* var. *citrifolia, the primary focus of this profile, is of greatest cultural, economic, and medicinal value, and is in greatest abundance in the Pacific region. This is a morphologically diverse species and with no clear

Left: *Morinda citrifolia* var. *bracteata* fruit and leaves. PHOTO: W. MCCLATCHEY **Right: *Morinda citrifolia* cultivar 'Potteri' with its variegated leaves.** PHOTO: S. C. NELSON sub-populations bearing unique characteristics; there exist large-fruited and small-fruited members of this group.

Morinda citrifolia* var. *bracteata is a small-fruited variety with conspicuous bracts. Found in Indonesia and other parts of the region between the Indian and Pacific Oceans.

***Morinda citrifolia* cultivar 'Potteri'** is an ornamental type, with green and white leaf variegation, distributed throughout the Pacific.

Associated plant species

Noni is associated with a wide range of common coastal and littoral forest shrubs and tree species in its native habitat. It grows as an introduced plant in agroecosystems near the shoreline of Pacific islands in open areas or as a cultivated component of agroforestry and subsistence agriculture, and is therefore associated with such plants as breadfruit (*Artocarpus altilis*), banana (*Musa* spp.), papaya (*Carica papaya*), palms (e.g., betel nut palm, *Areca catechu* and coconut, *Cocos nucifera*), pandanus (*Pandanus* spp.), beach hibiscus (*Hibiscus tiliaceus*), ti (*Cordyline fruticosa*), and *Piper* species (e.g., kava, *Piper methysticum*). Some of these associated species are understory and some are overstory for noni. Noni grows as a recent introduction around villages or in homegardens, in back yards, and along streams and gulches.

ENVIRONMENTAL PREFERENCES AND TOLERANCES

Climate

Elevation range

1–800 m (3.3–2600 ft), depending on latitude and environment.

Mean annual rainfall

250–4000 mm (10–160 in)

Rainfall pattern

Noni can tolerate a wide range of precipitation patterns, including summer, winter, bimodal, and uniform.

Dry season duration (consecutive months with <40 mm [1.6 in] rainfall)

At least 3–4 months depending on age, size of tree, temperature, relative humidity, and soils.

Mean annual temperature

20–35°C (68–95°F)

Mean maximum temperature of hottest month

32–38°C (90–100°F)

Mean minimum temperature of coldest month

5–18°C (40–64°F)

Minimum temperature tolerated

12°C (54°F)

Soils

Noni grows in a very wide range of soils and environments, with a notable ability to survive in harsh environments, such as those found on coral atolls or basaltic lava flows. It can also be found in solution pits or brackish tide pools near the coast, in limestone soils or outcroppings, on coral atolls, as a colonizing species of basaltic lava flows, as well as in native forests.

Soil drainage

Noni tolerates a wide range of drainage conditions including seasonal waterlogging, but it prefers free, well drained soils.

Soil acidity

It can grow in a wide range of acidity levels, from acidic to alkaline.

Special soil tolerances

Noni tolerates shallow, saline, sodic, and infertile soils.

Tolerances

Drought

Mature, cultivated noni can easily withstand drought for 6 months or more. Wild noni plants growing in arid conditions can spend their entire lives in conditions of perpetual drought.

Full sun

The plant grows well in full sun.

Shade

Noni can grow in a wide range of light intensities, from full sun to over 80% shade.

Fire

It can regenerate after fire by sprouting new foliage from roots or stems.

Waterlogging

Noni withstands and even thrives in brackish tide pools.

Growing in a crack in lava rock, noni is tenacious in this hot, windy, and dry area of Kona, Hawai'i. PHOTO: C. ELEVITCH

It can also tolerate flooded conditions for long periods of time.

Salt spray

It is very salt-resistant and tolerant of ocean salt spray. Noni is tolerant of extreme salinity in general and is thought to possibly gain nutritional benefit from the minerals contained in seawater.

Wind

Although windy areas are not advised for commercial production, noni can grow in windswept locations. However, yields and overall plant growth of noni in such areas are diminished.

Abilities

Regenerate rapidly

It has the ability to regenerate from shoots or root suckers rather than from seed, producing small thickets or groves.

Self-prune

Noni is not considered to be self-pruning, although the woody branches of this plant are brittle and may be relatively easily broken during overly heavy fruiting loads or during high winds.

Coppice

Noni plants regenerate well, even after severe pruning. Noni may be cut back to the trunk ("stumping") to promote the growth of a dense head of foliage.

GROWTH AND DEVELOPMENT

Growth rate

The growth rate is moderate, generally 0.75–1.5 m/yr (2.5–5 ft/yr), slowing as the tree reaches maturity.

Flowering and fruiting

Noni flowering and fruiting is continuous throughout year. Fluctuations in flowering and fruiting may occur due to seasonal effects (temperature, rainfall, sunlight intensity and duration).

Reaction to competition

Noni does not compete well with grasses or with grassy weeds in deep soils as an agricultural monocrop. However, it is a good forest understory plant that can tolerate very harsh conditions and plant competition from forest trees, including allelopathic species. In fact, noni is one of the few plants that can thrive beneath the canopy of ironwood (*Casuarina equisetifolia*) trees.

PROPAGATION

Noni is relatively easy to propagate from seeds, stem or root cuttings, and air-layering. The preferred methods of propagation are by seed and by cuttings made from stem verticals.

Propagation from seed

Seed collection

Noni flowers and fruits year-round. Fruits are harvested when they start turning white, or even when they have become fully ripe, i.e., turned soft, translucent, and characteristically odorous. For seed production, the riper the fruit, the better. Collect fruit from plants that have desirable characteristics, such as large fruit for fruit production, vigorous leaf growth for hedges, etc.

Seed processing

After picking, let the fruit ripen fully until it all turns soft (almost mushy) and translucent. This may take 3–5 days if only semi-ripe fruits were collected. Once the fruits have fully softened, press them against a screen or colander with holes slightly smaller that the seeds. The soft, fibrous pulp will slowly be removed from the seeds as they are rubbed

Noni seeds can remain viable floating in water for months. PHOTO: S. C. NELSON

against the screen. It may take 15 minutes to completely remove the clinging flesh. Rinsing in water periodically helps float off the pulp. The seeds have an air bubble trapped inside, so unlike most other seeds, healthy noni seeds float in water.

If the seeds are to be used immediately, soft fruits can be suspended in water and subjected to short pulses in a blender, very sparingly, to remove most of the flesh while slightly scarifying the seeds (see next section). If the seeds are to be stored, the flesh should be removed completely, then the seeds air-dried and stored in a paper bag in a cool room with low humidity. It is unknown how long seeds remain viable; however, 1 year is thought to be a reasonable storage time.

Germination is high for fresh seeds, often over 90%. There are approximately 40,000 seeds/kg (18,000 seeds/lb) for Hawaiian noni.

Pre-planting seed treatment

Without pretreatment, noni seeds germinate sporadically over 6–12 months. Scarification of the tough seed coat, although not a requirement, can shorten the time required for seed germination and increase the overall germination percentage. Scarification can be achieved by any physical method that abrades, damages, penetrates, or cuts open the seed coat. A simple method is to place ripe fruits in a blender and pulse the blending mechanism a few times to cut open the noni seeds before separating them from the pulp. A more time-consuming method that results in higher germination percentage consists of clipping off the tip of noni seeds near the embryo to allow water to penetrate the seed coat.

Germination time for scarified noni seeds is 20–120 days, depending upon temperature, environment, and variety or genotype. Seed germination can be rapid and uniform (20 days) in full sun to partial shade and mean temperature of approximately 38°C (100°F).

Potting media

Weed and nematode-free natural or local forest soil mixed with sand, volcanic cinder and/or composted organic matter are excellent for seedling production. A preferred pot-

A very reliable—but time-consuming—way to scarify noni seeds is to clip the pointed end of the seeds with a fingernail clipper, which allows water to quickly enter the seed coat. Left: Unclipped seed. Middle: Properly clipped seed. Right: Seed clipped too much, exposing embryo (visible as white spot at lower right). PHOTOS: S. C. NELSON

Rooted cutting (left) and seedling (right) ready for outplanting. PHOTOS: S. C. NELSON

ting medium for noni seeds is light and well drained but inherently moisture-retaining, slightly acidic to slightly alkaline (depending on locally available source material), aerobic, and high in organic matter derived from compost or peat. Nematode-infested soils or media should be avoided or treated with heat (at least 50°C [122°F] for 15 minutes) prior to using. Most nurseries prefer natural potting media rather than commercial media for noni production. Mulch (e.g., cinder, sawdust, leaf litter, or sand) may be placed over the seeds for weed control and moisture retention.

Growing area

A rain- and wind-protected but sunlit area (such as a coldframe with a clear film roof) is recommended for germination in trays. Germinate the seeds in trays filled with one part peat to one part perlite or vermiculite only. Warm, moist, and light conditions are beneficial for optimal germination. Noni seeds can germinate in conditions ranging from deep shade to full sun. Most uniform germination is achieved in light partial shade (20–30%). After the germination and early establishment phases, partial shade (20–30%) is used for growing out the individual seedlings in containers.

Establishment phase

Sow the scarified seeds evenly in germination trays or pots filled with a moisture-retaining, sterile or pathogen-free growth medium, perhaps a mixture consisting of one part perlite to one part peat. Cover lightly with 5–10 mm (0.2–0.4 in) of potting media. Keep moist with a fine sprayer so as not to disturb the seeds or the medium. The seedling trays or pots may be kept in shade or in full sun. An even temperature of 38°C (105°F) is recommended, which can be achieved with bottom heat.

Active growth phase

When the seedlings reach the four-leaf stage, carefully transplant them to individual containers for the growth phase. Root-training pots approximately 6 cm (2.5 in) square by 12 cm (5 in) deep or larger work well. Four-liter (1 gal) root-training containers can also be used.

Seedlings should be grown in partial shade and moved into full sun after 1–2 months. Keep seedlings spaced well apart to allow maximum penetration of sunlight and air circulation. In some cases, amending with additional fertilizer such as a light top-dressing of slow-release or organic 8-8-8 will aid in growth and development.

The size of noni plants at time of outplanting depends on the seedling age, fertility of the medium, pot size, noni variety, and the shade level used for seedling cultivation. A hardened seedling having at least 20–25 cm (8–10 in) of woody stem tissue (being at least 150–180 days old) has excellent performance after outplanting.

Time to outplanting

Noni seedlings (if not direct-seeded into the ground) may be outplanted about 2–12 months after germination. Young noni seedlings (8–12 weeks old; 10–15 cm (4–6 in) tall) may require more care and may be more vulnerable to environmental fluctuations and pest attack than older seedlings. Older seedlings, grown in full sun in 2- or 3-liter (2–3 quart) pots for 24–36 weeks, are preferred for their vigor and ability to establish quickly. Even older seedlings (1–3 years old) may be outplanted if they are healthy and not significantly root-bound. For older seedlings, loosen root systems gently by hand after removing them from their pots or containers.

Seedling development

After outplanting, the first year of seedling development is slow due to transplant shock and the establishment of a root system. Afterward, seedling growth is much more rapid as the crown gains size and photosynthetic mass.

Using volunteer seedlings

As an alternative to sowing noni seeds in seed-germination beds, young noni seedlings can be collected carefully from forest areas and transplanted into pots. Noni may also be sown onto raised mounds and outplanted as bare-root seedlings, although this is not a preferred method of seedling production.

Propagation from stem cuttings

Varying sizes of stem cuttings can be used, but 20–40 cm (8–16 in) cuttings are manageable and effective. Stem cuttings may root in 3 weeks and be ready for outplanting in 6–9 weeks. As with plants derived from seeds, rooted stem cuttings may be grown in pots for up to 26 weeks or more with excellent results when outplanted.

DISADVANTAGES

Potential for invasiveness

Noni has naturalized outside its native range in many locations throughout the Pacific and the tropics. Although not considered invasive to the degree that it threatens ecosystems, noni is recognized for its ability to persist and to disperse and colonize without a specific biological dispersal agent, such as humans, rodents, and birds. For example, noni seeds float for long periods of time in ocean water or streams and rivers and can remain viable for months during their journey until their deposition on a suitable substrate. Noni is considered to be a weed in some locations (e.g., in some agroforestry or diversified farming settings in Micronesia).

Susceptibility to pests/pathogens

Noni is susceptible to attack by a wide range of pests and disease-causing pathogens. However, the damage depends upon the pest or pathogen and upon the environment. When grown in a diverse, forested ecosystem, noni usually suffers from few significant pest and disease problems or damage. Conversely, when grown in a modern monocultural farming system, noni is much more susceptible to attack by many more pests and diseases and with greater intensity than in natural ecosystems. In addition, noni grown in monocultures on lands previously used for fruit or vegetable crops tends to be exposed to new pests and pathogens that may not be abundant or even present in forest or natural ecosystems.

Insect pests

Noni is susceptible to attack and damage by a range of insects, such as aphids (e.g., the melon aphid, *Aphis gosypii*), scales (e.g., the green scale, *Coccus viridis*), weevils (unidentified species), leaf miners (unidentified species), whiteflies (e.g., the Kirkaldy whitefly, *Dialuerodes kirkaldyi*), caterpillars (e.g., croton caterpillar, *Achaea janata*), thrips (e.g., the greenhouse thrips, *Heliothrips haemorroidalis*), and an unidentified species of eriophyid mite. Overuse of fertilizer can attract sap-feeding insects (e.g., aphids, whiteflies, scales) that cause a buildup of sooty mold on noni leaves. Stress from lack of nutrients or root problems may also lead to infestations of whiteflies or scales. Insect damage may be more severe in relatively dry or low-rainfall locations or in full-sun plantings as an expansive monocrop. Of the insect pests, whiteflies and scales are perhaps the most destructive. They can be controlled with sprays of insecticidal soaps and oils. In some locations, leaf miners periodically cause severe damage to noni leaves.

Pathogens and biotic diseases

In damp, high-rainfall or flooded areas, noni is prone to certain plant diseases caused by fungi or fungus-like organisms: leaf spots (*Colletotrichum* sp. and others) and stem, leaf, and fruit blights (*Phytophthora* sp. and *Sclerotium rolfsii*). The fungal leaf spot diseases are relatively minor but can be a nuisance in some locations. They can be minimized by sanitation (picking up or removing severely diseased leaves) or by periodic application of approved fungicides. Some foliar diseases caused by fungi (fungal leaf spots, or "black flag disease" caused by the fungus-like *Phytophthora*) may significantly inhibit leaf growth and fruit development.

The most common and severe pest problem for noni is root-knot disease caused by root-knot nematodes (*Meloidogyne* spp.). These soil-dwelling, root-parasitic roundworms are very destructive to noni and must be kept out of the nursery. The disease can cause farm failure. To keep nematodes out of nurseries, use soil-less media or only heat-treated soil for seedlings. Once established in a field, root-knot nematodes are virtually impossible to eradicate and can eventually result in plant death. Therefore, it is recommended that seedlings infected with nematodes never be planted (they should be destroyed). Avoid planting noni where it does not grow naturally, and avoid fields where other crops have been planted. Rocky soils are best for noni cultivation. Proper use of irrigation, fertilizer, and composts can help minimize damage caused by root-knot nematodes (for more information, see "the Noni Website" listed under "Internet" below).

Nutritional deficiencies and abiotic diseases

Noni can display a wide range of abnormal foliar symptoms due to deficiencies in fertility elements (e.g., nitrogen, iron, and phosphorous). Deficiencies in iron or other minor elements are expressed as interveinal chlorosis or scorching of leaf margins. Deficiencies in phosphorous are expressed as leaf curling, purpling, and marginal necrosis. Symptom development and expression for nutrient deficiencies on noni depend on the setting (natural vs. agricultural), overall plant stress factors (water, disease, root health, and fertilizer practices) and overall demand for nutrition and/or production (low to high).

Parasitic weeds

Noni is susceptible to infection by some coastline parasitic seed plants, including dodder (*Cuscuta* spp.) and *Cassytha filiformis*.

Host to crop pests/pathogens

Several significant pests and pathogens of general agricultural concern are also problematic for noni (e.g., ants, sap-feeding insects, and root-knot nematodes). These pests have wide host ranges and may initiate or cause significant damage to some crops (e.g., vegetables). Because noni attracts ants, some sap-feeding insects such as aphids may be a concern for certain vegetable intercropping designs with noni. Farm management plans should take into consideration the common pests and diseases that may attack the components of an interplanted system. Issues regarding pesticide spray drift and potential contamination of products and phytotoxicity must also be considered.

Noni growing under coconuts in pāhoehoe lava flow at 10 m (33 ft) elevation at Pu'uhonua o Hōnaunau, island of Hawai'i. PHOTO: C. ELEVITCH

AGROFORESTRY/ENVIRONMENTAL PRACTICES

Mulch/organic matter

Although noni regrows well after pruning, noni plants are generally are not managed for mulch production in agroforestry situations.

Homegardens

It is well suited for homegardens; a single plant is sufficient to meet the needs of one or more families.

Boundary markers

Noni can be used for boundary markers due to its persistence and ability to survive harsh conditions and extended periods of drought.

Animal fodder

The fruits and leaves are useful as animal feed or fodder (pets and livestock).

Woodlot

Noni is very compatible with lowland forest or woodlot plant species throughout the Pacific. Noni itself is not managed for wood production.

Native animal/bird food

Ripe fruits are a natural source of food for birds, rodents, and insects.

Bee forage

The flower nectaries are very attractive to honey bees.

Coastal protection

Noni is tenacious enough help to stabilize lands in harsh or unstable coastal environments.

Ornamental

Although the naturalized *M. citrifolia* (the wild and cultivated noni types) is considered by many to be a beautiful plant with shiny green foliage, some object to its use as an ornamental plant due to the strong and sometimes offensive odor of ripened fruits and because the fallen fruits attract many flies and other insects. The cultivated *M. citrifolia* variety 'Potteri' is a beautiful and functional ornamental plant with small fruits and green and white variegated leaves.

USES AND PRODUCTS

Fruit

Used in local medicines (juice, poultice) and as a famine food (e.g., by Hawaiians, Australian aborigines). Unripe fruits are cooked in curries and ripe fruits are consumed raw with salt (e.g., Burma). Fruit is cooked and mixed with coconut and eaten as stimulant on long sea voyages (e.g., Nauru).

Leaf vegetable

Very young leaves are cooked as vegetables and eaten with rice in Java and Thailand; mature leaves are wrapped around fish before cooking and then eaten with the cooked fish. The terminal bud is used as food (e.g., Kiribati).

Beverage/drink/tea

Dried leaves or fruits are used to make infusions and teas for medicinal use.

Medicinal

Leaves, fruits, stems, and roots are used in various medicinal preparations, healing protocols, and treatment methods throughout the Pacific region.

Medicinal uses (traditional) Treatment for malaria, general febrifuge, and analgesic (leaf tea); laxative (all parts of the plant); jaundice (decoctions of stem bark); hypertension (extract of leaves, fruit, or bark); boils and carbuncles (fruit poultice); stomach ulcers (oils from the fruit); scalp insecticide (seed oil); tuberculosis, sprains, deep bruising, rheumatism (leaf or fruit poultices); sore throat (gargling a mash of the ripe fruit); body or intestinal worms (whole fresh fruits); laxative (seeds); fever (leaf poultice); cuts and wounds, abscesses, mouth and gum infections, toothaches (fruit); sties (flowers or vapor from broken leaves); stomach ache, fractures, diabetes, loss of appetite, urinary tract ailments, abdominal swelling, hernias, stings from stonefish, and human vitamin A deficiency (leaves). The leaves are also used as a medicinal poultice or body wrap (e.g., Micronesia). The terminal bud has medicinal uses (e.g., Northern Marianas).

Ripe noni fruit. PHOTO: S. C. NELSON

Medicinal uses or purported applications (contemporary, worldwide) Purported value of noni for treatment of ailments including attention deficit disorder, addictions, allergies, arthritis, asthma, brain problems, burns, cancer, cardiovascular disease, chemical sensitivity, chronic fatigue, diabetes, digestive problems, endometriosis, fibromyalgia, gout, hypertension, immune deficiency, infection, inflammation, jet lag, multiple sclerosis, muscle and joint pain, polio, rheumatism, severed fingers, sinus, and veterinary medicine have yet to be validated.

Flavoring/spice

The leaves are used to wrap fish or other meats and foods during cooking.

Masticant/stimulant

Fruits are believed to be as an appetite and brain stimulant.

Timber

The wood can be used in light construction, canoe parts and paddles, axe and adze handles, and digging sticks.

Fuelwood

The trunk is used for firewood (e.g., in Kiribati).

Craft wood

Roots are used for carving (e.g., Niue).

Wrapping/parcelization

The leaves are used to wrap and flavor food for cooking (e.g., Cook Islands).

Dye

The bark contains a red pigment and the roots contain a yellow pigment, both used in making dyes. Dyes from noni were traditionally and are still used to color clothing and fabrics.

Food for animals

Leaves are used for livestock fodder (e.g., Niue, India) and to feed silkworms (e.g., India). The fruit is used as pig food (e.g., Puerto Rico).

Repellent

A fetid oil obtained from seeds is used as scalp insecticide or insect repellent (e.g., Hawai'i).

Ceremonial/religious importance

Traditionally used as a "ghost medicine," based on the religious belief that ghosts are repelled by the odor of the fruit or plant.

URBAN AND COMMUNITY FORESTRY

Noni is an attractive shrub which is generally well suited for homegardens and landscapes, but only where the odoriferous, fallen fruits do not create a nuisance. The tree produces fresh fruits year-round, so fruits are always available. It thrives in waste areas and is a very hardy roadside plant throughout the Pacific. The plant is easy to care for, responds well to severe pruning, and does not require much fertilizer or water.

Size in an urban environment

The size of a noni tree in an urban environment depends upon soil qualities and spacing. Plants growing in full sun and without competition can reach a height of about 6 m (20 ft) or more with a canopy spread of 2.4–3.6 m (8–12 ft) diameter. Crowded or shaded noni plants tend be less vigorous and become stunted.

Rate of growth in a landscape

Young noni plants grow relatively slowly in a landscape, about 30–60 cm (1–2 ft) per year in height, depending on environment. Upon reaching maturity, noni plants grow much more slowly in height, becoming mostly more dense within the canopy. Plants derived from cuttings tend to become established more rapidly than plants derived from seeds, but also tend to remain more prostrate and do not grow as tall as seedlings.

Root system

Noni has a deep taproot and an extensive surface-feeding root system. The tree may not compete well in a landscape with plants that have aggressive, surface-feeding roots, such as grasses. Noni is not considered to have an invasive root system, although once a noni plant is established in a landscape it is very difficult to kill. Volunteer plants growing in cracks in cement or asphalt or other undesirable locations should be uprooted as early as possible.

Products commonly used in a Pacific island household

Noni leaves and fruits are commonly used for medicine in Pacific island households. One or two mature trees can easily supply the needs of a family.

Light requirements

Noni is commonly found growing in full sun along sunny roadsides, at the edges of clearings, or in open fields such as the 'a'ā and pāhoehoe lava fields of the island of Hawai'i. However, the plant grows very well in full sun to about 80% shade.

Water/soil requirements

Noni has no special or unusual water or soil requirements. It tolerates a wide range of soil conditions including acidic to alkaline, saturated to dry, and well drained to compacted soils.

Life span

A noni plant, without significant pest or disease attack or other stresses, may be expected to live for at least 40–50 years in a landscape, probably longer.

Varieties favored for use in homegardens or public areas

The variegated noni, *M. citrifolia* cultivar 'Potteri', is a popular landscaping type of noni due to its beautiful leaves. Variegated noni is also used medicinally, although fruit yields tend to be lower and fruits are smaller than regular Hawaiian noni. Otherwise, seedlings grown from seed collected from trees with desirable qualities (e.g., large fruit) can be planted.

Seasonality of leaf flush, flowering, fruiting

Noni fruit production varies somewhat with the seasons in the Pacific, with more fruit being produced in summer than in winter. However, noni produces new leaves and fruits all year long wherever it is grown.

Exceptional ornamental values

The variegated noni has exceptional ornamental value due to its unusual leaf coloring and relative rarity in the landscape. Noni plants have exceptional value for being salt-tolerant and able to grow in rocky areas or on old lava flows.

Use as living fence, hedge or visual/noise barrier

Noni plants can have a very dense canopy and be very useful as hedge plants or living fences. The plants can thrive where other plants have difficulty growing. Noni can withstand heavy pruning although more frequent, light pruning can be used to ensure adequate foliage always remains to serve hedge functions.

Birds/wildlife

Noni flowers attract honeybees. Fallen noni fruits may attract rats and pigs.

Maintenance requirements

Noni is a low-maintenance landscape plant. It responds well to mulching as long as the mulch is kept away from direct contact with stem. Noni can be pruned or thinned to virtually any extent without damaging the plant. "Stumped" plants may grow back even bushier than before. Plants require very little fertilizer, but do respond well to periodic applications of organic or inorganic, balanced fertilizers. Extra phosphorous may be applied to simulate flowering and fruit production. Typical balanced fertilizers used include 13-13-13 and 16-16-16. To stimulate flowering and fruit production use 10-20-10 if a soil test indicates that phosphorous levels are low. If noni leaves are turning yellow, they could be fertilized with about 225–450 g (0.5–1 lb) of fertilizer per plant, depending on age. The plants also respond very well to foliar fertilizers. Because noni plants are salt-tolerant, it is very unusual for their root systems to be burned by excess fertilizer.

Special considerations regarding leaf, branch, and fruit drop

Fruit drop occurs year round. Dropping fruits are not considered to be a hazard to humans or animals during normal conditions or during storms. People could slip on ripe fruits along footpaths and sidewalks. Noni trees do not topple easily during foul weather, although branches can break, especially when heavy with fruit. Climbing noni trees should only be done with caution, as branches can suddenly crack off.

Nuisance issues

The fruits have a strong, unpleasant aroma which is considered by some to be a nuisance. The foul odor of noni fruits is considered by many to be a significant detriment to using noni in a landscape.

Hazards

Noni plants are not toxic to humans or animals, nor are there any spines, thorns, etc., on the plant.

Common pest problems

Insect pest and plant disease problems of noni are usually less common and severe in mixed plantings in urban environments. The types of problems encountered depend on the environment in which noni is grown. In wetter locations, for example, fungal leaf spots and blights might occur. In drier locations, insect infestations may become established. The most common pest problem for noni in the urban landscape is perhaps root-knot nematodes, the small plant-parasitic roundworms that cause conspicuous galls and swellings on roots that severely weaken the plant. Root-knot nematodes are best controlled by avoiding them, i.e., by starting with nematode-free seedlings and by planting the seedlings in a nematode-free location. If nematodes are present, their effects can be minimized by adding compost around plants or other forms of organic mater to the soil and by the use of foliar fertilizers. Noni plants in the urban landscape may also become infested with ants and sap-feeding insects such as scales, aphids, whiteflies, and mealybugs. These sap-feeding insects may be controlled with regular sprays of soapy water or a mixture of soap, water, and vegetable oil.

COMMERCIAL PRODUCTS

The primary commercial products from noni include beverages (fruit juice, juice drinks), fruit powders (for manufacture of reconstituted juice or juice drink products made from dried ripe or unripe fruits), toiletries (lotions, soaps, etc.), oil (from seeds), and leaf powders (for encapsulation or pills).

Site selection

Although choice of soil type is not a critical consideration, areas that do not support natural populations of noni should be avoided for commercial plantations.

Spacing

Spacing of 4–5 m (13–16 ft) within and between rows is common.

Management objectives

Year 1: Land clearing and preparation; weed control; plant establishment.

Year 2: Promote vegetative growth of seedlings.

Year 3 and thereafter: Promote flowering and fruiting.

Yields

Annual fruit yield varies among noni varieties or genotypes and depends upon the environment (soil, water) and cultivation system and/or ecosystem. Yearly yield may be only a few pounds per year for tall, spindly plants growing under heavy forest shade. Annual yields of up to approximately 80,000 kg/ha (71,000 lb/ac) or more may be realized with large-fruited genotypes grown in monoculture (about 716 plants/ha [290 plants/ac]) in full sun with heavy fertilization. Yields depend upon many factors, including soil fertility, environment, genotype, and planting density.

Newly planted commercial field. PHOTO: S. C. NELSON

Processing required

Fermented fruit juice

Ripe fruits are washed and sometimes pulped before they are placed into large fermentation containers, sometimes with added water. With time, the juice separates naturally from the fruit pulp, and ferments naturally via a bacterial (acidification) process. The preferred minimum processing (fermentation) time for fermented juice products is 60 days; thereafter the juice is drained from the fermentation vessel and bottled. Fermented juice (when uncontaminated and with low pH, e.g., approximately 3.5–4.0) will store well at room temperature without pasteurization. The juice is bottled in glass or plastic containers.

Fresh-squeezed fruit juice

The juice is pressed directly from ripe fruits using a mechanical device and bottled directly into glass or plastic containers and not allowed to ferment. These products are either pasteurized or refrigerated to preserve their integrity.

Re-constituted fruit juice and fruit juice drinks

These products are made from dehydrated fruits (green or ripe).

Ripe fruit ready for processing (left) and noni juice product (right). PHOTOS: S. C. NELSON

Fruit juice drinks

Raw juice is mixed in various proportions with other compatible liquids (e.g., other fruit juices, coconut milk, etc.).

Fruit juice concentrates

Fermented juice is subjected to flash evaporation or other evaporation technology to produce concentrated juice (a percentage of water is removed). The concentrate may be used to produce a range of juice products or cosmetics.

Fruit powders

Fruits (whole or seedless, green or ripe) are dried and crushed into powders and sold wholesale to drink or tablet/capsule manufacturers.

Fruit leather

Another product is noni fruit leather, which is a thin sheet of dehydrated fruit pulp.

Oil

Oil is derived from pressed seeds.

Leaf powders

Dried leaves are crushed into powders and used to produce a range of products for internal consumption or cosmetic use.

Markets

The market for products is worldwide, with the largest markets in North America, Mexico, Asia, and Australia. The worldwide market for noni products was an estimated US$400 million in 2002.

INTERPLANTING/FARM APPLICATIONS

The benefits of interplanting may include fewer disease and pest problems. However, negative plant pest and disease interactions are also possible with some interplanting systems.

Some interplanting systems include

- traditional subsistence farming intercropping with breadfruit, kava, papaya, mango, coconut, cordage plants, banana, timber species, coastal shrubs, and grasses
- modern commercial intercropping with papaya and coconut.

Noni can also thrive in forest understory settings and can benefit from the composting organic matter and mulch provided by associated plant species (benefits include nutrition, weed suppression, soil structure, and soil moisture retention).

Example system 1

Location

Federated States of Micronesia (e.g., Pohnpei).

Description

Traditional, low-yield, sustainable system.

Other crops/yields/services

Other crops in the system include banana, coconut, papaya, breadfruit, betel nut, citrus, kava, yam, taro, sweetpotato, and cassava.

Spacing

Random/natural.

Example system 2

Location

Northern Marianas

Description

Traditional, low-yield/sustainable system.

Other crops/yields/services

Coconut, banana, pasture.

Spacing

Random/natural.

Example system 3

Location

Hawai'i.

Description

Newly developed, moderate-high yields (experimental).

Other crops/yields/services

Interplanted with papaya.

Spacing

The spacing is 4–5 m (13–16 ft) between plants within rows.

PUBLIC ASSISTANCE AND AGROFORESTRY EXTENSION

The Cooperative Extension Service (CES) of the University of Hawai'i can assist landowners with questions relating to noni.

University of Hawai'i at Mānoa
College of Tropical Agriculture and Human Resources
Cooperative Extension Service
Komohana Agricultural Complex
875 Komohana St., Hilo, HI 96720
Tel: 808-959-9155; Fax: 808-959-3101
Web: <http://www.ctahr.hawaii.edu>

Extension offices for agroforestry and forestry in the Pacific: <http://www.traditionaltree.org/extension.html>.

INTERNET

"The Noni Website" (University of Hawai'i at Mānoa) by the author is full of practical information about noni: <http://www.ctahr.hawaii.edu/noni/>.

"Sorting *Morinda* names" maintained by the University of Melbourne presents a wide range of noni names and references: <http://gmr.landfood.unimelb.edu.au/Plantnames/Sorting/Morinda.html>.

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Species Profiles for Pacific Island Agroforestry (www.traditionaltree.org)

Morinda citrifolia (noni)

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Acknowledgments: The author and publisher thank Robin DeMeo, Dale Evans, Eileen Herring, Kent Lighter, Michael Robotham, Art Whistler, and Kim Wilkinson for their input. The author acknowledges the generous support from academic colleagues and farmers in Hawai'i and throughout the Pacific.

Recommended citation: Nelson, S.C. 2006. *Morinda citrifolia* (noni), ver. 4. In: Elevitch, C.R. (ed.). Species Profiles for Pacific Island Agroforestry. Permanent Agriculture Resources (PAR), Hōlualoa, Hawai'i. <http://www.traditionaltree.org>.

Sponsors: Publication was made possible by generous support of the United States Department of Agriculture Western Region Sustainable Agriculture Research and Education (USDA-WSARE) Program; SPC/GTZ Pacific-German Regional Forestry Project; USDA Natural Resources Conservation Service (USDA NRCS); Kaulunani, an Urban Forestry Program of the DLNR Division of Forestry and Wildlife and the USDA Forest Service; State of Hawai'i Department of Land & Natural Resources Division of Forestry & Wildlife; USDA Forest Service Forest Lands Enhancement Program; and Muriel and Kent Lighter. This material is based upon work supported by the Cooperative State Research, Education, and Extension Service, U.S. Department of Agriculture, and Agricultural Experiment Station, Utah State University, under Cooperative Agreement 2002-47001-01327.

Series editor: Craig R. Elevitch

Publisher: Permanent Agriculture Resources (PAR), PO Box 428, Hōlualoa, Hawai'i 96725, USA; Tel: 808-324-4427; Fax: 808-324-4129; E-mail: par@agroforestry.net; <http://www.agroforestry.net>. This institution is an equal opportunity provider.

Musa species (banana and plantain)

Musaceae (banana family)

aga‘ **(ripe banana) (Chamorro), banana, dessert banana, plantain, cooking banana (English);** ***chotda*** **(Chamorro, Guam, Northern Marianas);** ***fa‘i*** **(Samoa);** ***hopa*** **(Tonga);** ***leka, jaina*** **(Fiji);** ***mai‘a*** **(Hawai‘i);** ***maika, panama*** **(New Zealand: Maori);** ***meika, mei‘a*** **(French Polynesia);** ***siaine*** **(introduced cultivars),** ***hopa*** **(native) (Tonga);** ***sou*** **(Solomon Islands);** ***te banana*** **(Kiribati);** ***uchu*** **(Chuuk);** ***uht*** **(Pohnpei);** ***usr*** **(Kosrae)**

Scot C. Nelson, Randy C. Ploetz, and Angela Kay Kepler

IN BRIEF

Distribution Native to the Indo-Malesian, Asian, and Australian tropics, banana and plantain are now found throughout the tropics and subtropics.

Size 2–9 m (6.6–30 ft) tall at maturity.

Habitat Widely adapted, growing at elevations of 0–920 m (0–3000 ft) or more, depending on latitude; mean annual temperatures of 26–30°C (79–86°F); annual rainfall of 2000 mm (80 in) or higher for commercial production.

Vegetation Associated with a wide range of tropical lowland forest plants, as well as numerous cultivated tropical plants.

Soils Grows in a wide range of soils, preferably well drained.

Growth rate Each stalk grows rapidly until flowering.

Main agroforestry uses Crop shade, mulch, living fence.

Main products Staple food, fodder, fiber.

Yields Up to 40,000 kg of fruit per hectare (35,000 lb/ac) annually in commercial orchards.

Intercropping Traditionally grown in mixed cropping systems throughout the Pacific.

Invasive potential Banana and plantain are not considered to be invasive.

PHOTO: C. ELEVITCH

Banana and plantain are traditionally found in Pacific island gardens such as here in Apia, Samoa, although serious pests and diseases have reduced their productivity in many areas.

INTRODUCTION

Musa, a plant genus of extraordinary significance to human societies, produces the fourth most important food in the world today (after rice, wheat, and maize), bananas and plantains. *Musa* species grow in a wide range of environments and have varied human uses, ranging from the edible bananas and plantains of the tropics to cold-hardy fiber and ornamental plants. They have been a staple of the human diet since the dawn of recorded history. These large, perennial herbs, 2–9 m (6.6–30 ft) in height, evolved in Southeast Asia, New Guinea, and the Indian subcontinent, developing in modern times secondary loci of genetic diversity in Africa, Latin America, and the Pacific. *Musa* species attained a position of central importance within Pacific societies: the plant is a source of food, beverages, fermentable sugars, medicines, flavorings, cooked foods, silage, fragrance, rope, cordage, garlands, shelter, clothing, smoking material, and numerous ceremonial and religious uses. With the exception of atoll islands, banana and plantain are ideally suited for traditional Pacific island agroforestry, for interplanting in diversified systems, and for plantation-style cultivation in full sun. Although mostly consumed locally in the Pacific region, the fruit enjoys a significant worldwide export market.

Not considered invasive, *Musa* nonetheless is a persistent plant that competes relatively well with other species within managed agroforestry settings. Many cultivars are particularly susceptible to certain pests and diseases, making monocrops or even backyard banana plantings relatively challenging and requiring high labor inputs to maintain them in healthy, productive condition.

Local or indigenous selections are generally more useful and tolerant of local conditions, and have lower input requirements (compost, fertilizer, water) to obtain satisfactory yields. However, the Pacific's indigenous banana and plantain cultivars as a whole are highly sensitive to nematode, insect, and viral infestations. Some disease-resistant hybrids have been developed in recent years.

BOTANICAL DESCRIPTION

Preferred scientific name

Musa species

There are five taxonomic sections in the genus *Musa*, two of which contain edible bananas.

Family

Musaceae (banana family)

Common names

banana, dessert banana, plantain, cooking banana (English)

Pacific islands

aga' (ripe banana) (Chamorro)
chotda (Chamorro, Guam, Northern Marianas)
fa'i (Samoa)
leka, *jaina* (Indian derivation) (Fiji)
mai'a (Hawai'i)
maika, panama (New Zealand: Maori)
meika (Cook Islands)
meika, *mei'a* (French Polynesia)
siaine (introduced cultivars), *hopa* (native) (Tonga)
sou (Solomon Islands)
te banana (Kiribati)
uchu (Chuuk)
uht (Pohnpei)
usr (Kosrae)

Fe'i banana cultivars have a host of common names in different islands.

Other regions

Banane, bananier (France)
Banane, Bananen, Bananenpisang, Bananenstaude (German)
banano (plant), *plátano, platanero* (plantain), guineo (dessert banana) (Spain, Latin America)
chotda banana (plant), *banana no tsubomi* (flower) (Japan)
djantoong (plant), *jantung pisang* (flower) (Indonesia, Malaysia)
pisang, getang (Indonesia)
saging (Philippines)
barbaro, zapolete (Mexico)

Size

Banana is a large, perennial, monocotyledonous herb 2–9 m (6.6–30 ft) in height that arises from large, subterranean rhizomes (usually called "corms").

Flowers

Upon flowering, the true stem or growing point emerges from the center of the tightly rolled bunch of leaves. This odd-looking "flower cluster" is actually an elongated, plump, purple to green "bud" (sometimes called the "bell" or "heart"), which at first displays large female flowers (whose ovaries ripen into fruit). As the "bud" elongates, it exposes semicircular layers of female flowers, then neutral flowers, and finally small, generally non-functional (with no viable pollen) male flowers. Each group of flowers is arranged radially on the stem in nodal clusters. Each flower cluster is borne on a prominence on the stem bearing the fruit (peduncle) and covered by a bract. About 12–20 flowers are produced per cluster. Collectively, the flowering parts and fruit are referred to as the bunch. Individual clusters of fruits are known as hands, and individual fruits are known as fingers.

Leaves

The entire above-ground portion of the plant is not a true woody trunk, as in other trees, but a "false trunk" or "false stem" that consists of leaves and their fused petiole bases, referred to as a pseudostem. The pseudostem supports a canopy consisting of 6–20 (or more) leaves.

Fruit

Musa fruits are variable in size, shape, and color. They are generally elongate-cylindrical, straight to strongly curved, 3–40 cm (1.2–16 in) long, and 2–8 cm (0.8–3 in) in diameter. The fruit apex is important in variety identification; it may be tapered, rounded, or blunt. The skin is thin and tender to thick and leathery, and silver, yellow, green, or red in color. Inside the ripe fruit, the flesh ranges from starchy to sweet, and in color from white, cream, yellow, or yellow-orange to orange. Bananas also vary in peel thickness. Some varieties have a thin peel and are more susceptible to damage in transport, whereas others have a comparably thicker peel (the Fe'i variety 'Karat' and others, for example).

Seeds

Cultivated varieties are typically seedless. When seeds are present, they vary among species in shape and morphology. Seeds of *Musa balbisiana*, parent of many commercial edible banana varieties, are dark brown, ovoid, about 4 mm (0.2 in) long, with a conspicuous white, powdery endosperm.

Rooting habit

Plants have numerous (200–500) fibrous roots. In well drained, deep, and fertile soils, roots may extend 1.5 m (5 ft) deep and 4.9 m (16 ft) laterally. In dry, shallow, or rocky soils, roots of *Musa* may not compete well; otherwise, *Musa* is an average to good competitor.

Emerging banana bunch of 'Pisang Awak', Nu'u Research Station, Upolu, Samoa. PHOTO: A. K. KEPLER

Differences in flesh color. The banana on the left is a seedless hybrid dessert banana 'Silk' (AAB group); the yellow-fleshed banana on the right is a Fe'i banana 'Karat'. PHOTO: L. ENGLBERGER

GENETICS

Musa species are grouped according to "ploidy," the number of chromosome sets they contain, and the relative proportion of *Musa acuminata* (A) and *Musa balbisiana* (B) in their genome. Most familiar, seedless, cultivated varieties (cultivars) of banana are triploid hybrids (AAA, AAB, ABB). Diploids (AA, AB, BB) and tetraploids (AAAA, AAAB, AABB, ABBB) are much rarer; the latter essentially being experimental hybrids.

Fruits of cultivated *Musa* species are typically sterile or have extremely low fertility. They produce fruit pulp without pollination and fruits lacking seed (i.e., they are parthenocarpic). Although sterility and parthenocarpy are important factors that contribute to the desirability of banana fruits, sterility has impeded progress in breeding programs. Through natural somatic (vegetative) mutation, hybridization, and selection over many thousands of years, considerable genetic variability has arisen within the cultivated bananas, giving rise to more than 1000 varieties worldwide. There is a great diversity of banana varieties in the Pacific, particularly in Papua New Guinea and the Solomon Islands. There is much global concern that some varieties are becoming increasingly rare and that the important diversity of banana is being eroded.

Due to problems with male and female fertility among many of the desirable parents (e.g., the Cavendish subgroup is virtually sterile), breeding programs have only recently developed useful cultivars. Also, many natural and artificially bred hybrids are susceptible to important diseases and pests.

The edible bananas of the world belong to the Eumusa section of the genus *Musa*, except for the Fe'i group, which belong to the Australimusa section. The Fe'i bananas are characterized by erect bunches, pink-red to purple sap and deep yellow or orange colored fruit pulp.

HAWAIIAN SAYINGS (PUKUI 1983)

'A'ohe hua o ka mai'a i ka lā ho'okāhi.

"Bananas do not fruit in a single day."

(A retort to an impatient person.)

He mai'a ke kanaka a ka lā e hua ai.

"A man is like a banana on the day it bears fruit."

(One can tell what kind of man he is by his deeds. In olden days banana stalks were often likened to men. When a man's body was removed from a grave, a banana stalk was laid in to take its place.)

He mai'a ua pa'a i ke ko'o.

"A banana well supported by props."

(A man well supported by his followers.)

DISTRIBUTION

Native range

Musa species are native to the Indo-Malesian, Asian, and Australian tropics.

Current distribution

The distribution of *Musa* species is pantropical. They may be grown in temperate, relatively frost-free climates such as California, but generally fail to fruit due to the limitations of cool temperatures.

ASSOCIATED PLANT SPECIES

Bananas are associated with tropical lowland forest inhabitants of all types; many varieties grow wild on slopes above streams. As an aboriginal introduction to Pacific islands, the banana is still associated with many traditional cultivated plants including breadfruit (*Artocarpus altilis*), seeded breadfruit (*Artocarpus mariannensis*), taros (*Colocasia esculenta, Cyrtosperma chamissonis, Alocasia* spp., and *Xanthosoma* spp.), ti (*Cordyline fruticosa*), kukui (*Aleurites moluccana*, candlenut), pandanus (*Pandanus* spp.), noni (*Morinda citrifolia*, Indian mulberry), coffee, avocado, papaya, yam (*Dioscorea* spp.), coconut, *Piper* spp. including kava (*Piper methysticum*), sweetpotato, sugarcane (*Saccharum officinarum*), Polynesian arrowroot (*Tacca leontopetaloides*), mango (*Mangifera indica*), betel nut (*Areca catechu*), edible hibiscus (*Abelmoschus manihot*), etc., all of which are important throughout Oceania. In homegardens, bananas and plantains are grown together with all types of homegarden fruits, vegetables, and ornamentals.

ENVIRONMENTAL PREFERENCES AND TOLERANCES

Climate

Elevation range

Acceptable elevations are generally 0–920 m (0–3000 ft) or more, depending on latitude. There are reports of banana fruiting at up to 2000 m (6600 ft) in Papua New Guinea. In Kula, Maui, certain cultivars such as 'Cuban', 'Santa Catarina', 'Dwarf Chinese', and others are productive up to 1000 m (3300 ft). 'Dwarf Chinese' can produce at even higher elevations, and Hawai'i's 'Maoli ka'ualau' does well up to 1220 m (4000 ft).

Mean annual rainfall

The minimum rainfall requirements for *Musa* depend on soil type, planting location, sun exposure, and variety or species. For production of commercial cultivars (e.g., 'Giant Cavendish'), a minimum of 500 mm (20 in) per year will sustain the plants if the rainfall is evenly distributed throughout the year and the soil is fertile. However, approximately 2000 mm (80 in) per year, more or less evenly distributed, is considered to be a minimum requirement for a successful commercial banana plantation. There is no upper rainfall limit, given well drained soil.

Rainfall pattern

Seasonal rainy periods and/or drought periods are fairly normal for most banana-growing areas. Bimodal or seasonal rainfall patterns are tolerated well by edible banana growing in forested situations and/or in fertile, deep soils. Uniform rainfall distribution throughout the year is best for commercial production of edible banana; 375,000 l/ha/week (40,000 gallons/ac/week) are required for irrigation of banana plantations in dry areas. Some dwarf *Musa* species used in ornamental landscapes are relatively drought-tolerant and can tolerate a wider range of rainfall and distribution patterns.

Dry season duration (consecutive months with <40 mm [1.6 in] rainfall)

The ability of *Musa* spp. to survive for a given length of time in the absence of rainfall is dependent on the following factors:

- soil type, structure, and drainage
- shade level; transpiration requirements
- mono-cropping vs. a diversified/ agroforestry system
- pest and disease pressure
- plant nutrition and soil fertility.

Because the plants can store a significant amount of water within their pseudostems and rhizomes, they can survive extended periods of drought, although their growth will slow down or cease under such conditions. In Hawai'i's rocky volcanic soils, banana suffers significant drought stress and yield reductions after only a few weeks without rain.

Since *Musa balbisiana* is considerably more drought hardy than *M. acuminata*, increasing proportions of B in a cultivar's genome are correlated with increased drought tolerance. In other words, cooking varieties such as 'Saba' (ABB) and 'Bluggoe' ('Largo' in Hawai'i, ABB), can be grown more successfully in dry, windy areas than many other varieties. 'Sucrier' (AA), with much A in its genome, is notably difficult to grow and rarely survives with low moisture or humidity.

Typical mixed forest planting of banana, breadfruit, taro, and many other useful species. PHOTO: S. NELSON

Mean annual temperature

26–28°C (79–82°F) is optimum for shooting (vegetative growth of banana). 29–30°C (84–86°F) is optimum for fruiting.

Mean maximum temperature of hottest month

35–37°C (95–99°F)

Mean minimum temperature of coldest month

–2–30°C (28–86°F)

Minimum temperature tolerated

The minimum temperature tolerated depends upon the species. At 16°C (60°F) banana plant growth slows; at 10°C (50°F), growth stops. Chilling damage and tissue necrosis occurs at or below 13°C (55°F). Temperatures below –2°C (28°F) may kill plants to the ground, but they can often recover through new growth from subterranean parts. Damaging low temperatures generally do not occur in the lowland tropics of the Pacific but are more likely to occur in upland areas, such as on the slopes of Hawai'i's volcanoes. For example, in Kula, Maui, at about 975 m (3200 ft), winter temperatures often fall below 10°C (50°F), causing the banana plants to virtually hibernate, without producing any more leaves until warmer conditions return. This does not harm the plant, although high elevation plants will bear up to a year later than lowland plants. In Hawai'i, the best bananas for growing at higher elevations are: 'Chinese Dwarf', 'Dwarf Cuban Red', 'Grande Naine' (a Cavendish type), and some of the native Maoli varieties.

Soils

Soil texture and drainage

Banana tolerates a wide range of soils, but well drained loams are optimal. Heavy, clayey soils are suboptimal, especially if they are low in organic matter and aeration.

Soil pH

Banana tolerates a wide range of soil acidity; pH 5.5–7.5 is optimal.

Special soil tolerances

Banana tolerates, but will not thrive in, shallow soils.

Tolerances

Drought

Musa spp. vary in drought tolerance but grow and produce best where rainfall is evenly distributed throughout the year. Because of their water-filled energy reserves, they can "tough out" long dry periods but will subsequently produce only small bunches.

Full sun

Musa spp. thrive in full sun, especially if winds are not high.

Shade

Banana and plantain can even grow well in higher shade levels, up to 80%. Fruit production will be delayed by several months if plants are excessively shaded. For commercial production of banana, full sun is usually best, and a maximum of 50% shade is recommended. Although *Musa* in general grows best in full sun, the Fe'i varieties thrive best in shady conditions during establishment. Mature plants do quite well in full sun when provided with sufficient water.

Fire

Banana plants will generally recover from fire by regrowing from corms.

Frost

Although significant plant damage can occur due to frost, banana plants generally recover from subterranean parts when warm weather returns, especially if provided winter protection in the form of mulch or complete covering.

Waterlogging

Disease-free banana plants can withstand waterlogged soil but will produce poorly. Excessive irrigation or poorly drained sites may cause banana mats to "float" upon loosely rooted corms.

Salt spray

Musa spp. are tolerant of salt spray and may even produce small bunches of fruit if grown in tidal mud flats.

Wind

Winds 40–72 km/hr (25–45 mph) can topple plants when they bear fruit. Height has a dramatic affect on wind tolerance. Tall cultivars are not recommended in areas with a high probability of hurricanes, although strong enough winds will topple any banana variety. Steady winds cause significant leaf shredding, leaf drying, distortion of the crown, or (in extreme winds), complete or partial toppling of the entire plant. Winds cause more damage if the underground corm is weakened by insect pests (banana weevil) or disease (nematodes, fungal pathogens). In windy areas, dwarf varieties are best: 'Dwarf Chinese' (AAA, 'Cavendish', etc.), 'Dwarf Cuban Red', and 'Dwarf Brazilian' ("apple," AAB, Pome) varieties such as 'Santa Catarina', 'Rio Nain', or dwarf native varieties, e.g., 'Iholena Ha'aha'a' (Hawai'i). Short cultivars such as 'Dwarf Pisang Awak' are characterized by thick, short pseudostems, compact structure, and short, broad leaves; they are excellent choices for homegardeners throughout the Pacific and elsewhere. They also have the dual advantage of being easier to harvest, with less green waste for disposal. In Kīpahulu, Maui, a popular new short-trunked variety, with an extremely heavy, solid base, is dubbed 'Hurricane'.

During or before hurricanes, some industrious Pacific islanders may choose to slash off banana pseudostems to about half their height to prevent entire plants from being blown over. In this way, the basal suckers have more of a

Strong winds can shred leaves and thereby reduce productivity. Tall cultivars are not recommended for windy areas, as their trunks tend to fold over in the middle. PHOTO: C. ELEVITCH

chance to survive after the winds have passed, and the parent may even produce a small bunch of fruit also.

Abilities

Regenerate rapidly

Banana plants are known for their ability to regenerate rapidly from corms. They quickly recover after fields are damaged by strong winds or hurricanes and will produce again in 6-9 months.

GROWTH AND DEVELOPMENT

Growth rate

Growth rate is rapid until flowering; after the flower bud shoots, vertical growth of the pseudostem ceases and no additional leaves are added.

Flowering and fruiting

Flowering and fruiting occur year-round but often fluctuates seasonally, with maximum production during summer and fall.

Potential for invasiveness

Most *Musa* species are not considered to be invasive. However, due to birds feeding on them, seeded varieties have the potential to spread and become pests.

PROPAGATION

Banana and plantain are propagated principally by vegetative division and far more rarely by seeds (usually only for banana breeding, ornamental types, and wild species). In addition, tissue culture has become standard for commercial plantations in recent years, primarily because of the advantage of starting with disease-free planting material. Edible bananas are almost always seedless (however, some, such as 'Pisang Awak', produce many seeds when growing near a fertile pollen source).

Propagation by division

Propagule collection

Division by rhizomes in banana is referred to as sucker production and collection. This is the most common method used to obtain banana planting material. Sword suckers are preferred to water suckers for planting new fields because of their superior vigor and eventual yield. Sword suckers have narrow, sword-shaped initial leaves and are attached to a healthy, fruiting mother plant. Water suckers are those young plants that no longer have a physical connection with a living mother plant. Water suckers do not have the sword-shaped initial leaves. The sword suckers (with narrow leaves) can be obtained from healthy mother plants that are devoted (either in full or in part) to the production of sword suckers. These sword suckers are not removed during the normal process of thinning out banana clumps, but are reserved for collection and subsequent planting. Suckers to be used for planting can be given extra light (by trimming overhanging leaves) and fertilizer before removing them from the mother plant to enhance their viability. Suckers are ready for removal from the mother plant when they reach a minimum of 15 cm (6 in) diameter and 50 cm (20 in) height above the soil (Stover and Simmonds 1987). The sucker is removed (cut away and out) from the mother plant using a sharp tool such as a narrow-bladed, straight-sided shovel, making sure to obtain an appreciable amount of corm with the sucker. It is not advisable to use "peepers" (suckers less than 30 cm [12 in] tall) for propagation ma-

Left: A banana "sword sucker" at the stage of development suitable for propagation (right). The sword sucker is carefully separated from the mother plant where it is attached to the underground rhizome, and usually planted directly in the field. Right: Field recently planted with banana suckers as an example of monocropping. PHOTOS: S. NELSON

terial because they are extremely slow-growing, may not survive, and if they do survive will produce small bunches the first year.

Banana suckers intended for agroforestry should be allowed to develop longer on the mother plant, reaching 2–2.5 m (6.6–8 ft) in height with 6–7 leaves, and given extra nitrogen fertilizer in the weeks before their collection and use as planting material. These plants are better able to compete in a shaded agroforestry setting.

Propagule processing

Detached suckers are inspected for disease and pest damage. If rhizomes are infested with weevils or nematodes, the affected tissue should be removed before washing and immersing the rhizomes in hot water (54°C [129°F] for 20 minutes) and/or 10% bleach solution. Roots may be entirely trimmed from rhizomes without significant detriment to the plant. Trimmed suckers sprout new roots readily if irrigation or rainfall follows planting. Suckers may be planted almost immediately or allowed to sit for a few days without loss of viability. To reduce problems with *Erwinia* soft rots (bacterial diseases), it is usually a good idea to let the cut surfaces heal over (suberize) for 2 days. Suckers may have disease or pests. Care should be taken not to transfer infested suckers that contain nematodes or other banana pathogens to a new field.

Propagule storage

Suckers remain viable for several days after collection and trimming. The sooner they are planted after collection, the better is the recovery and growth after planting.

Growing area

Suckers are planted directly into planting holes in the field for plantation or agroforestry production. For suckers intended for nurseries, a light, well drained, pathogen-free growth medium will suffice. If suckers are irrigated after planting, they can begin to form new roots within days of planting, and leaf emergence can begin within 7–10 days after planting. Expected survival, if sufficiently irrigated and with proper nutrition and absence of disease, is 90–100%.

Propagation by seeds

The inedible, ornamental *Musa* species such as 'Fuzzy Pink' or 'Pink Velvet' banana (*M. velutina*), or fiber species such as the abaca 'Manila Hemp' (*M. textilis*), are two examples of *Musa* species that are commonly grown from seed.

Ease of germination depends on species, variety, and environment. Some germinate quite readily; others are more challenging. Store seeds in a cool, dry place. Seeds do not require scarification, although soaking them in water for 24–48 hours before planting is recommended. Sow seeds in a light, well drained medium, place in full sun, and keep moist. Seeds may take several weeks to germinate.

PESTS AND DISEASES

Susceptibility to pests and diseases in the Pacific

Banana and plantain are susceptible to a wide range of pests and diseases. Some pests and diseases are highly aggressive or very contagious and easily spread, and once established they are persistent and practically impossible to eradicate.

In general, the severity and occurrence of pest outbreaks and plant damage depend upon several mitigating factors:

- environmental conditions
- specific banana variety
- specific disease or pest.

Environment

Wet, rainy environments favor fungal and bacterial diseases. Relatively dry weather or climate favors many types of insect outbreaks (e.g., mites) and banana virus diseases; however, some pests, such as scab moths, cause damage during normal weather patterns in the Pacific. Disease and pest outbreaks are more common where banana plants are grown together in large numbers (monocultures), rather than where planted in small numbers and spatially separated, as in agroforestry settings. Despite the planting method, the highly contagious nature of some diseases means that many or most plants in a region may become infected by a given pathogen. The severity of the reaction depends upon the environment.

Banana variety

Although most banana varieties are susceptible to certain severe diseases, some varieties are far more sensitive than others. For example, *Fusarium* wilt was responsible for destroying many commercial plantations of the once-popular and widely grown variety 'Gros Michel', also known as 'Bluefields'. With regard to banana bunchy top virus—which has now spread throughout SE Asia and much of the Pacific—the most susceptible varieties are in the Cavendish subgroup ('Chinese', 'Williams', 'Grand Naine', 'Valery'). Members of the Pome subgroup are more tolerant of bunchy top, i.e., 'Brazilian' types (Hawaiian "Apple"), French Polynesian 'Rio' or 'Pime', and 'Australian Improved Lady Finger'. Some varieties or types of bananas are well suited for local conditions and are tolerant of existing pest and disease populations. These are primarily the "new varieties" such as FHIA-01, FHIA-02, FHIA-03, 'Giant Kalapua', which are not quite as well received as the older types but are relatively disease resistant. Researchers worldwide are continually working to develop disease-resistant varieties.

Host to crop pests/pathogens

Several significant pests and pathogens of general agricultural concern are parasites of *Musa* spp. (e.g., sap-feeding insects and root-knot nematodes). These pests have wide host ranges and may initiate or cause significant damage to some crops (e.g., vegetables). Because *Musa* spp. attract ants, some sap-feeding insects (e.g., aphids) may be a concern for certain vegetable intercropping designs with *Musa* spp.

Insect pests of banana in the Pacific

Insect pests of banana can cause significant damage to fruits (e.g., thrips, moths/caterpillars, scales), leaves (e.g., mites, moths/caterpillars), corms, and pseudostems (e.g., weevils), and can transmit important plant pathogens (e.g., aphids transmit banana bunchy top virus). Damage due to insects can greatly reduce the marketability of banana fruits. Listed and described below are some of the most common and important insect pests of bananas in the Pacific region.

APHIDS

***Aphis gossypii* (melon aphid)**
***Pentalonia nigronervosa* (banana aphid)**

These are found wherever bananas are grown. The banana aphid is a significant pest of banana due to its ability to transmit banana bunchy top virus (BBTV). Aphid excretion of "honeydew" provides a nutritional and physical substrate for sooty mold fungi, which may diminish fruit quality and physically block photosynthesis. Banana aphid populations are often tended by ant species.

BEETLES

***Adoretus sinicus* (Chinese rose beetle)**

The Chinese rose beetle, *Adoretus sinicus*, and other rose beetles are common pests on all major banana-producing islands in Hawai'i and the Pacific. The larvae primarily dwell in the soil and leaf litter surrounding the plant crop, and the adults do the damage to banana. The adult beetle is nocturnal and feeds primarily on leaf and interveinal tissue. Chinese rose beetle damage is most easily detected on younger plants.

***Cosmopolites sordidus* (banana weevil)**

The banana root borer can be very damaging to commercial and home growers. The larvae bore into corms, suckers, and roots; extensive root destruction is possible; diminished plant growth and yield results; premature toppling of plants and plant death (of young plants) can occur. A night-feeder, the borer can be trapped by baiting the field with slices of banana pseudostem. **Management**: Peel the rhizomes free of lesions and immerse in hot water at 54°C (129°F) for 10 minutes; minimize plant debris around mats; remove infested stumps after harvest; apply insecticides. Also, a 10% household bleach solution treatment also is useful for disinfesting corms. Pruning the corm and lower trunk first until no "tunnels" are evident and treating with household bleach is the best for the home grower. It is very important that growers of bananas everywhere are aware of this weevil and its damage, because it is spread by people unknowingly (or carelessly) giving away suckers to home gardeners with "clean" gardens. Symptoms: banana plants fall over, even in light winds. Dirt-filled tunnels creating a labyrinth of weakened tissue in the corm and lower trunk up to about 30 cm (12 in) high.

***Trigonops* sp. (weevil)**
***Polytus mellerborgi* (banana corm weevil)**
***Odioporus longicollis* (banana pseudostem borer)**

Weevils are a major pest in SE Asia. Entire banana fields were destroyed by weevils in Okinawa in 1997 (S. Nelson, pers. comm.). **Management:** If suckers are infested with weevils, all infested material should first be trimmed with a machete. This includes trimming all roots, small suckers, and all necrotic tissues until only white, clean tissues remain. Then soak the trimmed suckers in 10% household bleach solution, let them air-dry for a few days, and plant in a new spot. Let the original field remain fallow for 1–2 years. Weevils may be trapped overnight by placing freshly cut pseudostem on the ground, with the cut surface in contact with the soil.

CATERPILLARS

***Chrysodeixis eriosoma* (green garden looper)**

The larval (caterpillar) stage feeds on banana leaves.

***Erionota thrax* (banana leafroller)**

The caterpillar stage feeds on banana leaves. **Management:** The leafroller can be controlled effectively in some locations with naturally occurring biological control insect species (e.g., parasitic wasps).

Damage from weevils in Okinawa, probably *Odioporus longicollis*. PHOTO: S. NELSON

Banana corm weevil (borer), Waipi'o Bay, Maui. PHOTO: F. G. RUST

***Spodoptera litura* (rice cutworm)**
***Eudocima* (*Othreis*) *fullonia* (Pacific fruit-piercing moth)**

The fruit-piercing moth is an important pest in localized areas. The adult moth punctures and feeds on ripening fruit, which may result in premature ripening/fruit drop. **Management:** Natural enemies of this pest may reduce pest populations over time.

***Decadarchis flavistriata* (sugarcane bud moth)**

This is a localized insect pest (caterpillar); the caterpillar stage feeds on decaying flowers and causes fruit scarring. **Management:** De-flowering prior to bagging; use of sprays of *Bacillus thuringiensis* ("BT") products.

***Erionota thrax* (banana skipper)**

The banana skipper, *Erionata thrax,* rolls up banana leaves starting from the leaf midrib. Due to the effective biological control of the banana skipper in some locations (Hawai'i), chemical treatments are uncommon. **Management:** The banana skipper can be controlled effectively in some locations with naturally occurring biological control insect species (e.g, parasitic wasps). The best way for the homegardener to control these caterpillars, which eat extensive areas of leaves, is to recognize the damage (easy) and kill them by hand.

***Opogona sacchari* (banana moth)**

The banana moth lays eggs on senescing flowers and on decaying leaves, pseudostems or fruit. The larvae feed on detritus and decaying plant material. They are often found feeding on healthy tissue at the interface with decaying plant parts. Moth larvae can destroy several palm species in tropical areas (e.g., *Chamaedorea*, areca palms, etc.). **Management:** the removal of flowers and application of insecticidal bunch treatments prior to bagging appears to greatly reduce damage larval damage.

***Nacoleia octasema* (scab moth)**

The scab moth is a very significant pest of banana fruits in Samoa and many places in the southwest Pacific. The pest also attacks *Heliconia* in some locations, as well as *Pandanus*. Banana scab moth females lay eggs on banana flower bracts or leaves as the inflorescence emerges. Larvae hatch, enter the flower, and feed on the developing fruits within. The feeding results in rough and irregular scars (brownish-black) on fruit skin. Large infestations can scar the entire fruit and cause deformed fingers. **Management:** the best control is achieved by injecting an insecticide (as recommended by local agriculture authorities) into the flower after it emerges and before it starts bending downward. A single injection, applied about one-third of the way down from the flower tip, is sufficient to provide control. Some varieties appear to be less susceptible to scab moth damage.

Banana scab moth damage, Western Upolu, Samoa. PHOTO: A. K. KEPLER

FRUIT FLIES

***Bactrocera dorsalis* (Oriental fruit fly)**
***Ceratitis capitata* (Mediterranean fruit fly)**

Fruit flies are significant quarantine pests for some destinations. They attack ripe banana fruits.

LEAFHOPPERS

***Sophonia rufofascia* (two-spotted leafhopper)**

MEALYBUGS

***Planococcus citri* (citrus mealybug)**
***Pseudococcus jackbeardsleyi* (banana mealybug)**
***Dysmicoccus brevipes* (pineapple mealybug)**
***Dysmicoccus neobrevipes* (gray pineapple mealybug)**
***Ferrisia virgata* (striped mealybug)**
***Pseudococcus orchidicola* (orchid mealybug)**

Mealybugs feed on banana leaves and fruits, but they are not a significant economic pest of *Musa* in most locations. Some mealybugs transmit banana streak virus (BSN).

MITES

***Phytonemus pallidus* (cyclamen mite)**

Mites can build large colonies during dry weather, primarily on the undersides of *Musa* leaves. Their feeding damage can cause large, dry, brown patches of necrosis on banana leaves. Generally, they are not economic pests and transmit no other diseases.

SCALES

Scales are sap-feeding insects that attack banana leaves and fruits.

Abgrallaspis cyanophylli **(armored scale)**
Aonidiella aurantii **(California red scale)**
Aonidiella inornata **(inornate scale)**
Aspidiotus destructor **(coconut scale)**
Chrysomphalus dictyospermi **(dictyospermum scale)**
Coccus hesperidum **(brown soft scale)**
Coccus viridis **(green scale)**
Diaspis boisduvalii **(boisduval scale)**
Eucalymnatus tessellates **(tessellated scale)**
Hemiberlesia lataniae **(latania scale)**
Icerya aegyptiaca **(Egyptian fluted scale)**
Ischnaspis longirostris **(black thread scale)**
Pinnaspis buxi **(ti scale)**
Saissetia coffeae **(hemispherical scale)**
Steatococcus samaraius **(steatococcus scale)**

The coconut scale (*Aspidiotus destructor*) causes a localized discoloration and yellowing of plant tissue. It is classified as an armored scale; feeds on underside of banana leaves, in circular colonies; can attach to petioles, peduncles, and fruits; and is a significant quarantine pest for banana fruits shipped from the Pacific (Hawai'i) to the U.S. mainland. **Management:** Scales are controlled with sprays of insecticidal oils in Hawai'i; scale populations decline if ants can be controlled, as ants tend these insects and feed on the honeydew produced by them.

THRIPS

Thrips can scar, stain, or deform banana fruits by feeding on the fruit skin. Thrips are small, winged insects that feed on banana flowers and/or the tender green skin of developing fruits. The two factors of feeding site and species determine the type and extent of fruit damage. Thrips outbreaks can occur during periods of dry weather. The following thrips species are important pests of *Musa* in the Pacific region.

Chaetanaphothrips signipennis **(banana rust thrips)**

Feeding by rust thrips creates areas of reddish-brown "rust" that develop on the banana fruit, especially where two adjacent fingers touch; skin cracking can occur, leading to severe damage. The damage is caused by populations of the banana rust thrips feeding on young, developing green banana fruits. **Management:** monitor rust thrips activity; apply approved insecticides to soil, plant, and fruit; use thrips-free planting material; destroy neglected or abandoned plants or banana plantations; cover the developing bunches with perforated polyethylene sleeves.

Coconut scale colony on banana leaf. PHOTO: S. NELSON

Elixothrips brevisetis **banana (rind thrips)**
Hercinothrips femoralis **(banded greenhouse thrips)**
Thrips hawaiiensis **(Hawaiian flower thrips)**

Feeding by the Hawaiian flower thrips causes "corky scab," a superficial, corky scarring of the banana fruit skin; the scab is patchy, discolored, and raised. Corky scab is caused by populations of the flower thrips (*Thrips hawaiiensis*) feeding on young, developing, green banana fruits. **Management:** Monitor the crop for flower thrips populations; spray registered insecticides; keep plants moist with overhead irrigation during dry periods.

WHITEFLIES

Whiteflies are *Musa* leaf parasites and generally do not damage banana fruits directly. They feed on the leaf undersides; they are sap-feeding insects that deposit honeydew on the surface of the banana fruits and leaves in the canopy below them. This sugary deposit on leaves and fruits can lead to the growth of sooty mold fungi, which use the honeydew as a food source. Sooty mold can lessen fruit quality and reduce overall leaf photosynthesis. Whiteflies may be tended by ant species that feed on the honeydew and protect the insects. Whiteflies may be controlled effectively in some locations with naturally occurring biological control insect species.

Aleurodicus dispersus **(spiraling whitefly)**

The spiraling whitefly is a sap-sucking insect causing tissue damage and discoloration; it excretes honeydew, which is a substrate for the growth of sooty mold on the surface of plant organs. **Management:** Natural enemies of the spiraling whitefly may keep this pest in check locally; foliar sprays of insecticidal oils can reduce whitefly populations.

GRASSHOPPERS

Valanga excavate **(large short-horn grasshopper)**
Valanga nigricornis **(Javanese grasshopper)**

OTHERS

Leptoglossus australis **(leaf-footed plant bug)**
Proutista moesta **(erect-winged blue plant hopper)**
Lamenia caliginea **(derbid planthopper)**
Lamenia caliginea **(a fulgorid planthopper)**
Siphanta acuta **(torpedo bug)**

DISEASES IN THE PACIFIC

Diseases are major production constraints wherever bananas are grown. The most significant disease of bananas in the Pacific is black leaf streak, caused by the fungus *Mycosphaerella fijiensis*. Bunchy top, a viral disease caused by the banana bunchy top virus (BBTV), has also emerged as a major problem for banana plantations in Hawai'i and the Pacific. Here we briefly identify and summarize current information on the most common and important biotic (infectious) and abiotic (noninfectious) diseases of banana in the Pacific. More in-depth coverage of these diseases is found in Ploetz (2003) and Jones (2000).

BIOTIC DISEASES

Biotic diseases are infectious and caused by plant pathogens.

DISEASES CAUSED BY FUNGI

Fungi are the most important and prevalent pathogens of banana. All banana plant organs are attacked by fungi. Fungal diseases cause the greatest pre- and postharvest production losses and account for a large share of plantation management expenses.

Leaf diseases

Phyllacora musicola **(black cross)**

Black-cross is a distinctive but relatively minor leaf disease of banana. The disease is found in Australia, Indonesia, the Philippines, and the southwestern Pacific. Symptoms are most evident on the undersides of older leaves, scattered about the leaf or occurring in large groups. The lesions are black and star-shaped, with four cardinal points and elongated along the leaf vein axes. **Management:** Specific control measures for this black cross are usually not warranted; 'Cavendish' varieties are resistant.

Pseudocercospora fijiensis **(**syn. *Mycosphaerella fijiensis*)
black sigatoka, black leaf streak

A debilitating and contagious leaf disease caused by the fungus, *Mycosphaerella fijiensis*. It is globally distributed and epidemic in many locations and is the most important disease of *Musa* worldwide. Symptoms develop as follows: reddish-brown streaks (1–5 mm [0.04–0.2 in] long and 0.25 mm [0.1 in] wide) appear initially on the undersides of the third or fourth youngest leaf; streaks develop into elongated spots with gray or tan centers and dark brown to black margins; lesions may be surrounded by yellow halos; lesions may coalesce to form large, blighted areas of leaves in parallel with leaf veins, or bands of dark streaks, causing leaves to turn brown and wither. Significant defoliation may occur; a banana plant may have only a few or no green (disease-free) leaves upon flowering. The cost of disease management is high. Bunch yield loss can be significant. **Management:** A combination of cultural and chemical practices is recommended: field sanitation, host nutrition and sound cultural practices; fungicides; de-trashing (deleafing); pruning; ensuring good drainage and canopy aeration; plant nutrition; resistant cultivars. The indigenous Fe'i banana of Pohnpei, 'Karat', shows good resistance to black leaf streak in that region. The best way for the home-gardener to control the disease is to destroy the severely diseased leaves or remove them and place them topside-down on the ground to reduce the chance of spore dispersal into the banana canopy.

Pseudocercospora musaea **(syn. *Mycosphaerella musicola*)**
sigatoka, yellow sigatoka

Yellow sigatoka was formerly of greater importance in the Pacific than the similar black sigatoka. Symptoms are yellowish streaks on leaves, enlarging into narrowly elliptical gray spots with dark brown borders, up to 15 mm (0.6 in) long and 5 mm (0.2 in) wide. Leaves may turn gray or brown and hang from the plant, defoliating it. Bunches are small due to the presence of relatively few, healthy leaves at flowering. **Management:** see black sigatoka.

***Cladosporium musae* (cladosporium speckle)**

Cladosporium speckle is a leaf spot disease of minor importance to most banana varieties and locations. Symptoms are variable among regions, affecting older leaves. Control is usually not warranted. Other fungi may also cause leaf speckle, such as *Acrodontium simplex*.

***Drechslera gigantean* (eye spot)**

Leafspots

***Cordana musae* (cordana leafspot)**
***Curvularia* sp.**
***Phyllosticta* spp.**
Hendersonia toruloides
***Helminthosporium* sp.**

Cordana leaf spot is a common but minor leaf spot disease on most banana varieties but can be severe on plantain varieties. Symptoms are pale brown, oval patches on leaves, surrounded by bright yellow halos. The disease may be controlled with the same fungicides used to control the sigatoka diseases.

***Fusarium oxysporum* f. sp. *cubense* (Panama disease, fusarium wilt)**

A lethal disease caused by races of a soil-borne fungus, *Fusarium oxysporum*. It is a devastating disease of banana worldwide. Infection occurs through roots and progresses to the pseudostem. Symptoms are internal stem necrosis (reddish or reddish-brown xylem), root and rhizome rot, yellow leaves, plant wilting, and plant death. Plants may die during flowering or during periods of moisture stress. The fungus may survive decades in soils. **Management:** Largely preventive, by planting resistant varieties or pathogen-free materials (preferably tissue-cultured plants) in non-infested soil.

Pythium root rots

Pythium arrhenomanes
Pythium aphanidermatum
***Pythium* sp.**

***Marasmiellus inoderma* (stem rot)**

A sometimes-severe pseudostem disease occurring in marginal soils (soils with poor nutrition or physical structure, low in organic matter, high in clay) or poorly drained or wet areas where *M. inoderma* occurs. The causal fungus is able to penetrate leaves, pseudostems, or roots to cause the following symptoms: decay and withering of outer leaf sheaths/blades; leaf stunting; cracked pseudostems; slow plant growth; plant stunting and death; and narrow pseudostems. White mushrooms often appear along the cracks in the affected pseudostems. Alternative hosts of *M. inoderma* include coconut, rice, taro, and maize. **Management:** Selection and use of disease-free planting material; moderate irrigation; fertilizers; soil improvement (compost, mulch); removal and destruction of diseased plants; promote conditions for vigorous plant growth.

Fruit diseases

***Colletotrichum musae* (anthracnose)**

A spot, rot, or blemish of ripening banana fingers. Initial lesions are roughly lens-shaped to circular and sunken and brown. The spots turn black, enlarge, and merge eventually; the spots become deep depressions covered in pink fungal spore masses. The splash-borne fungus, *Colletotrichum musae*, the spores of which infect the green banana fruits well before ripening, causes anthracnose. **Manage-**

Left: Black sigatoka symptoms. Right: Cordana leaf spot. PHOTOS: S. NELSON

 

Left: Banana fruits affected by anthracnose. PHOTO: WAYNE NISHIJIMA **Right: Crown rot.** PHOTO: R. PLOETZ

ment: Regular cutting and removal of overly necrotic banana leaves (>50% necrotic) near bunches and throughout the field; careful fruit handling to minimize abrasions and wounds; keep fruit as cool as possible to slow down the disease; prompt ripening; on-time harvest; good packing house hygiene (e.g., clean water and equipment); prompt cooling of fruits to appropriate storage temperature after processing.

***Colletotrichum musae*, *Nigrospora sphaerica*, or *Fusarium* spp. (black end)**

Black decay of the finger stalk and the adjacent part of the finger; usually confined to the banana peel. **Management:** Good plantation and packinghouse hygiene and ventilation; mulch dead leaves in field; keep packing house free of plant debris, rejected fruit, and other trash; de-hand bunches in clean water; use sharp de-handing knife for good, clean cut surfaces; keep fruit as cool as possible after harvest (both before and after ripening).

***Ceratocystis paradoxa* (syn. *Chalara paradoxa*) (ceratocystis fruit rot)**

A crown rot, stem end rot, and tip rot of green or ripe fruit. Crowns are soft, black, and water-soaked; dark fungal growth may develop in a mass; stem ends and skin may turn black. Fungal growth may cover the fruit skin with a white to greenish-black color; the pulp may rot and fingers may drop or ripen. **Management:** Good packing house hygiene (clean and disinfest the packing house regularly; do not allow rotting fruit to accumulate). See also management for black end.

***Verticillium theobromae* and *Trachysphaera fructigena* (cigar end rot)**

A finger tip rot, dark brown to black; the fruit pulp is characteristically dry and fibrous or stringy; spore masses occur on the lesions, gray and powdery. **Management:** Frequent removal of dead flowers from banana fingers, followed by bagging of bunches with perforated polyethylene sleeves; removal of bracts and dead flower parts that may accumulate in the sleeves after bagging; field sanitation; field cultural practices (de-leafing, pruning) to modify the environment (promote canopy aeration and exposure to light);

packinghouse sanitation; culling of infected fruits before placing them in a wash tank; fungicide sprays.

***Fusarium* spp., *Verticillium* spp., *Colletotrichum musae*, and *Acremonium* sp. (crown rot)**

A blackening and rotting of the cut ends of banana fruit hands. As the fruit ripens, the rot advances down into the fruit stalks, contributing to fruit rot and premature ripening. A whitish-gray fungal growth may be present on the surface of affected crowns. Numerous fungi are associated with this disease. **Management:** Good packing house hygiene (e.g., clean water in the wash tank); approved fungicides; rapid cooling of fruit after de-handing; refrigeration of fruit at not less than 13°C (55°F) during storage and sale.

***Phyllosticta musarum* syn. *Guignardia musae* (freckle)**

A relatively minor fruit disease in the Pacific. However, the pathogen also infects *Musa* leaves, which can serve as a source of disease for fruits. The symptoms are raised black pinpoint spots, occurring in groups, on leaf or fruit surfaces. The disease may render fruit unmarketable. **Management:** Choice of banana variety ('Cavendish' is resistant); periodic and regular de-trashing (removal of diseased leaves, especially near developing or unprotected bunches); bagging of bunches; fungicides.

Sooty mold

A patchy, black, sooty surface mold on green or mature banana fruits. Sooty mold is the surface growth and spores of fungi, which use as their food source the sugary excretions of sap-feeding insects such as aphids, mealybugs, scales, and whiteflies. **Management:** Bagging of the developing bunches to block access of insects to fruit and to block fruits from deposition of sooty mold from insect-infested leaves surrounding the bunch; bunch sprays of copper fungicides; insect control methods; soak bananas in 1% bleach solution for a few minutes in a postharvest wash tank.

***Deightoniella torulosa* (swamp spot, speckle, black tip)**

A widely distributed disease but rarely a severe problem in maintained orchards; symptoms are reddish brown to black speckles on fruit skin or black fruit tips; overall, considered to be a common but minor disease that is dependent on poor air circulation within *Musa* plantations or habitats.

NEMATODE DISEASES OF BANANA

Banana nematodes are microscopic roundworms that live as soil-borne parasites of roots. The root-knot nematodes (*Meloidogyne* spp.) and the burrowing nematode (*Radopholus similis*) can significantly weaken root systems, reduce yields, topple plants before harvest, make plants more prone to wind knockdowns, reduce fertilizer uptake and utility, and reduce the banana-growing lifespan of a given piece of land. Nematodes are managed with avoidance, clean (nematode-free) planting material, heat treatment of planting material, pre-plant soil fumigation, crop rotation, mulching and composting, fallow, chemical nematicides, plant propping, fertilizer use, and varietal resistance.

Toppling caused by burrowing nematode damage. PHOTO: R. PLOETZ

Following are the principal plant-parasitic nematodes associated with banana, in order of their relative threat to *Musa* production and/or as plant quarantine pests:

***Radopholus similis* (burrowing nematode)**

This is a major banana root pathogen, causing lesions to roots and rhizomes, banana decline, yield losses, and toppling; the nematode has relatively wide non-*Musa* host range. **Management:** Nematode-free rhizomes are required to prevent large losses and dissemination of the nematode; nematicides; in severe infestations, bunch-bearing plants must be supported to prevent toppling before harvest; composting and mulching; soil treatment before planting; crop rotation; fallow.

***Meloidogyne* sp.*, Meloidogyne incognita* (root-knot nematodes)**

Infection leads to swelling and galling of banana roots. Galled roots may crack and rot. Plants rise from the soil ("float") and can topple during bunch development coupled with wet weather or water draining through the field. Root-knot nematodes can make a field unusable for commercial banana production after 5 years. **Management:** Avoidance; nematicides; cultural practices; nematode-free planting material; composting and mulching; soil treatment before planting; crop rotation; fallow.

Other nematodes

***Helicotylenchus* spp. (spiral nematode)**
***Rotylenchulus reniformis*, *Rotylenchulus* sp. (reniform nematode)**
***Pratylenchus coffeae* (lesion nematode)**
***Tylenchorhynchus* sp. (stunt nematode)**
***Criconemoides sphaerocephalum* (ring nematode)**
Criconemella sphaerocephala
***Hoplolaimus* sp.**

VIRUS DISEASES OF BANANA IN THE PACIFIC

Banana bunchy top virus (BBTV) (bunchy top)

Banana bunchy top is a very severe disease of banana. Initial symptoms are dark green dots and streaks ("Morse code" streaking, up to 25 mm (1 in) in length) on the veins of banana leaves. As the disease progresses, leaves become progressively smaller, erect, and brittle, with pale, ragged, necrotic margins. The most conspicuous symptom is the "stacking up" or bunching up/rosetting of leaves; the disease name derives from this reduced internode distance between leaves of affected plants. Symptoms can appear on plants of all ages, although young plants, when infected, may not bear fruit. Banana varieties vary somewhat in their reaction to the disease. Disease is spread by planting infected material or by insect transmission of the virus between plants. The banana aphid, *Pentalonia nigronervosa*, is

Left: Symptoms of bunchy top disease. PHOTO: S. NELSON **Right: Symptoms of bunchy top in suckers.** PHOTO: HAWAI‘I DEPARTMENT OF AGRICULTURE

Green dots and streaking, a subtle symptom of banana bunchy top disease. PHOTO: S. NELSON

Banana field destroyed due to banana bunchy top infestation. PHOTO: W. NISHIJIMA

the sole insect vector of BBTV and can transmit the virus by feeding on banana leaves, petioles, or pseudostems. *P. nigronervosa* is specific to *Musa* spp. **Management:** Aphid scouting and management or spot-treatment (kerosene, mineral oil, soapy water, or conventional insecticides); field surveys for symptomatic plants; complete eradication of diseased plants and mats; use of virus-free planting material; tissue culture; and effective regional and international plant quarantine are important to control bunchy top. Once a region has been contaminated with BBTV, eradication is very difficult. Prevention of the disease is a key component to its management. There are no known resistant commercial banana cultivars, and there appears to be more than one strain of the virus. However, in Hawai'i the 'Dwarf Brazilian' cultivar is more tolerant of bunchy top than Cavendish cultivars.

Banana streak virus (BSV) (banana streak)

The symptoms consist of a combination of chlorotic streaks (broken or continuous) and narrow lesions on leaves. As the leaves age, the yellow streaks may turn brown and necrotic, resulting in a pattern of fine black streaks running parallel to leaf veins. Diseased plants may be stunted and have smaller bunches. Banana streak is transmitted by mealybugs. **Management:** Control the disease through the use of virus-free planting material and eradication of diseased plants. Banana plants infected with BSV may periodically show no symptoms and therefore should be kept in quarantine for a period of 9 months or more.

Cucumber mosaic virus (CMV) (banana mosaic)

Banana mosaic is a disease of relatively minor importance to banana. Symptoms included yellow streaks or flecks on leaves in a mosaic pattern, leaf yellowing, and leaf mosaic. CMV is distributed worldwide and has perhaps the widest host range of any plant pathogenic virus. **Management:** Use of pathogen-free planting material and control of alternate hosts (weeds, legumes, cucurbits, members of the Solanaceae, such as tomato).

BACTERIAL DISEASES IN THE PACIFIC

Ralstonia solanacearum race 2 (biovar 1) (moko disease)

Moko disease is a wilt of banana and plantain and cooking banana (especially Bluggoe [ABB Group]) common in Central and South America (moved there in seed pieces). There is no known resistance to *Ralstonia solanacearum* among edible bananas ('Pelipita' ABB and FHIA-03 have some resistance where the insect-transmitted form exists; the absence of a male bud and/or "dirty stem" below the bunch provides useful control). Insect transmission of the bacterium enables the disease to spread rapidly in some locations. **Management:** Control of the disease is difficult and expensive. Methods include quarantine; routine plant inspection and destruction of diseased plants; variety selection; tool disinfestations; destruction of neighboring plants (adjacent to diseased areas); prompt removal of the male flower bud after the last female hand has emerged.

***Erwinia* spp. (rhizome rot)**

This disease is caused by a bacterial genus known for its ability to cause soft rots on a wide range of host plants and tissues. These bacteria infect banana plants through leaves and pseudostems, causing the following symptoms: wilting or death of leaves before fruit has ripened, vascular discoloration, and internal rot of the pseudostem (usually accompanied by a characteristically foul odor). **Management:** Cultural control tactics such as planting of disease-free material, and prompt identification and eradication of diseased plants (preferably by burning).

ABIOTIC DISEASES OF BANANA IN THE PACIFIC

Abiotic diseases are noninfectious and include nutrient deficiencies and environmental disorders.

Common nutrient deficiencies and abiotic conditions of Musa in the Pacific

Nutrient deficiency symptoms are common for banana grown in Pacific island soils. In some cases, deficiency symptoms may appear as a group because several elements may be lacking (e.g., N, K, Ca, and B). The symptoms are usually both preventable and correctable with choice of location, improved soil characteristics and fertility, and the use of amendments and fertilizers.

Boron (B)

Chlorotic streaking of leaves, oriented perpendicular to and crossing the primary veins; leaf malformation; interveinal chlorosis. Foliar malformation may result. This deficiency can develop slowly over time.

Calcium (Ca)

General dwarfing; reduced leaf length; reduced rate of leaf emission; leaves are undulated; tissue near midrib thickens, may turn reddish-brown. Fields should be limed periodically; correctable with calcium nitrate.

Iron (Fe)

General chlorosis of the entire lamina of young leaves; retarded plant growth; small bunches. Apply iron compounds to soil; foliar sprays of Fe using naturally occurring or manufactured iron-containing compounds.

Magnesium (Mg)

Marginal chlorosis of older leaves; violet-colored marbling of petioles; fruit may have defective flavor and not ship well; symptoms are reduced by use of magnesium sulfate.

Nitrogen (N)

A generalized yellowing of leaves; rose-colored tints on petioles and leaf sheaths; stunting; rosetting; slender pseudostem; small petioles and leaves; reduced life span of leaves; notable reduction in yield. Banana is more sensitive to a lack of nitrogen than any other element; problem is compounded by dense stands of weeds or grass.

Potassium (K)

Rapid yellowing of oldest leaves, which then turn orange and dry up; leaves may become tattered and fold downward; leaves are crumpled in appearance; bunches are poorly filled; correctable with potassium fertilizers such as potash.

Sulphur (S)

Leaves are chlorotic and reduced in size, with a thickening of secondary veins; undulating leaf edges; necrosis along edge of lower leaves. Correctable with sulfate fertilizers

Calcium and boron deficiencies are a big problem throughout the Pacific. PHOTO: S. NELSON such as ammonium sulfate, potassium sulfate, and magnesium sulfate.

Zinc (Zn)

Rosetting and stunting; chlorotic, strap-shaped leaves; leaf chlorosis in stripes or patches; abnormal bunch and hand characteristics; symptoms may be more severe in sandy soils.

Abiotic fruit disorders

Abiotic fruit disorders reduce fruit quality and may reduce fruit grade or render fruit unmarketable.

Chilling injury

A necrotic flecking just below the surface of the green skin and pulp of the banana fruit, caused by exposure of banana fruits to temperatures below 13°C (55°F). **Management:** Avoid refrigeration at below 13°C (55°F).

Fused fingers

The fusion of banana fingers is the result of a genetic mutation or defect, seen particularly in Cavendish varieties. Hands with fused fingers may not be marketable but are completely safe to eat. **Management:** Destroy the affected plant and its suckers if found on a commercial farm; use the fused hands as animal food.

Maturity bronzing

A reddish-brown to brown discoloration of mature green bananas; fruit skin may develop cracks and scabs. The cause of this problem is unclear; however, it appears to be a physiological disorder resulting from periodic water stress. Calcium deficiency may also be implicated. **Management:** Irrigate to avoid moisture stress when bunches are young. Do not allow bunches to "over-fill" before harvest.

Precocious ripening or mixed ripe

Individual fingers ripen prematurely, which could be caused by harvesting over-mature bananas; excessive postharvest storage or transit temperatures; anthracnose wound infections on fruit skin. **Management:** Harvest fruit that is at a proper stage of maturity; adequate temperature control after harvest; fungicide dips of fruit; well ventilated fruit storage. This problem may occur as a result of severe leaf disease, such as black leaf streak (black sigatoka).

Sap damage

Stains on banana fruit skin, caused by contact of the sensitive green fruit surface with its own banana sap during de-handing and packing activities. **Management:** Avoid sloppy de-handing work; soak banana hands in clean water in a washing/de-sapping tank for enough time to allow the fresh wounds (from the cutting and de-handing process) to stop emitting the staining sap. The water in the tank dilutes the flowing sap so that it cannot damage the green banana tissue.

Herbicide (paraquat) injury to banana leaves. PHOTO: S. NELSON

Rat feeding injury to banana fruits. As shown here, their feeding is not restricted to ripe fruits. PHOTO: S. NELSON

Senescent spots

Senescent spots, a natural part of the ripening process for Cavendish bananas, are numerous, superficial brown flecks on peels. Spots are shallow (less than 1 mm [0.04 in] deep) and do not enlarge or change color. The brown spots are caused by the death of small groups of cells in the outer peel, usually after treatment in a ripening room. The condition is associated with the forced ripening of overly mature banana fruits. **Management:** Avoid the harvest and ripening of overly mature fruit.

Splitting of fingers

Longitudinal splits in fingers; ripe fingers separate from the hand. The splitting can be caused either by high relative humidity (>95%) during final fruit ripening or harvest and ripening of over-mature fruit or over-caliper fruit (bunches left on plant too long, leading to overly swollen fingers). **Management:** Lower the relative humidity to 70–75% during fourth and fifth day of ripening; ensure good aeration in ripening room; restack cartons so that ventilation slots are aligned with each other; harvest fruits on time according to caliper grade. Avoid harvesting and ripening bunches with swollen fingers due to late or missed harvest.

Compost piles made primarily of banana leaves and stalks. PHOTO: C. ELEVITCH

Other pests

Wild birds, bats, and rodents not only feed on banana fruits but often construct nests within the bunch, poised to feed their young when the bananas ripen. Rats can be a serious problem for islanders dependent on bananas; therefore bananas should be harvested just before or at the first sign of rat damage, then hung upside-down in a rat-free environment until ripe.

AGROFORESTRY/ENVIRONMENTAL PRACTICES

Mulch/organic matter

Musa species produce profuse amounts of vegetative mass that, upon composting, produces a significant amount of natural mulch and organic matter. The cut leaves and stems are also laid down on the ground around the plants to suppress weed growth. However, it is important to remember that cut-up trunks used as mulch will stifle the growth of suckers if placed too close to the mother plant (this is a common error, even among backyard gardeners who are anxious to expand their banana mat). Also, if banana corm weevils are present, avoid using cut-up banana pseudostems as mulch, as these will serve as a breeding ground for the weevils.

Left: Pineapple cultivated under banana, American Samoa. Right: Kava grown in the shade of banana, Kona, Hawai'i. PHOTOS: C. ELEVITCH

Soil stabilization

Musa species grow very well on steep, soil-covered banks of stream gulches, provided there is vegetative cover. If the soil is bare and rainfall high, banana plants tend to topple.

Crop shade/overstory

Banana is a source of shade when grown in and around gardens, and in multi-cropping systems. A vigorous monocrop of banana can suppress many weeds with a combination of natural mulch and shade.

Alley cropping

Banana is suitable for alley cropping with a wide range of plants.

Homegardens

Banana is ideally suited for homegardens, growing readily and fruiting reliably and profusely. Dwarf varieties are easy to harvest. Also, dwarf varieties are relatively wind-tolerant and tend to be more disease resistant.

Living fences

Musa coccinea, a brightly colored, crimson-flowered ornamental, has been recommended as a component in a living fence. *Musa balbisiana,* one of the parents of edible hybrid bananas, was introduced into Hawai'i for this purpose (as a windbreak). However, because it is seeded and fruit-eating birds eat the seeds, it has come to be regarded by some as a pest in some areas of Maui. In windy and dry areas, a living fence of banana tends to look ragged and unkempt.

Animal fodder

Banana fruits, stems, and cut-up pseudostems (trunks), are suitable for animal fodder for horses, cattle, and pigs (provided the material is not contaminated by pesticides already recommended in the text)

Wildlife habitat

Birds feed on banana fruits and on the insects that are attracted to the plant. Flying foxes (bats) are banana eaters in the Western Pacific, where they are indigenous.

Ornamentals

Musa species and banana varieties are used ornamentally in many locations and under a wide range of landscapes, from backyards to coastal resorts. Some examples of ornamental *Musa* species include self-peeling 'Hot Pink' or 'Fuzzy pink' (*M. velutina*); 'Ornata' (several varieties of *M. ornata*); 'Blood/Rojo/Zebrina' or 'Variegated Red' (*M. acuminate* subsp. *zebrina*); and 'Okinawa torch' (*M. coccinea*).

USES AND PRODUCTS

Staple food

Bananas, consumed cooked or raw, either as the green, half-ripe, or ripe fruit, are one of the most significant sources of calories for the human diet worldwide. Bananas are a particularly good source of potassium. The yellow and orange-fleshed bananas are also rich in provitamin A and other carotenoids. Provitamin A carotenoids (including beta-carotene, the most important one) are important for protecting against vitamin A deficiency and anemia (as vitamin A is involved in iron metabolism). Carotenoid-rich foods may also protect against diabetes, heart disease, and certain cancers, which are serious emerging problems of epidemic proportion in the Pacific. Recently, attention has been focused on the carotenoid-rich bananas in Pohnpei, in particular the 'Karat', a Fe'i banana with an erect bunch. It has been shown that levels of beta-carotene may reach as high as 8508 µg/100 g edible portion in some Fe'i bananas. Other bananas in Pohnpei were also found to be carotenoid-rich, including 'Kudud' (internationally known as 'Sucrier'), which contained 315 µg beta-carotene/100 g. This is over 10 times higher than the beta-carotene content in the common Cavendish banana (21 µg/100 g).

Famine food

All banana plants have starchy corms and pseudostem bases that were and still are used in times of famine on Pacific islands (mostly SW islands and New Guinea). This was evidently the original use of banana for human food (de Langhe 1995).

Beverages

Alcohol, beer, vinegar, and wine can be produced from fruit. More of this was done in the past, but even in modern French Polynesia, vinegar is produced in small quantities by small-holding farmers (in this case, using 'Yangambi km5' (AAA, Ibota subgroup) bananas, introduced initially for livestock but found to be perfectly edible and excellent for fermenting into vinegar.

Flowers

The small male flowers (inside the "bud") of certain varieties, notably 'Saba' and 'Dippig', are cooked and eaten in the Philippines and within the Filipino community of Hawai'i. The entire bud can also be cooked as a vegetable; however, it is necessary to use the correct variety and boil it in several changes of water, otherwise it will be very bitter. Thick nectar from the male flowers of the Iholena, Maoli, and Pōpō'ulu subgroups was traditionally fed to babies in precontact Hawai'i. In contrast to the flowers, this semi-jelled

Left: Bananas are a staple of the Pacific islands: here plantains accompany sweetpotato, yam, and breadfruit in Tongatapu Market, Tonga. PHOTO: C. ELEVITCH **Right: Home-made banana dryer, heated by an open fire, in remote Hanahi Valley, Hiva 'Oa, using 'Giant Cavendish' bananas (called "Hamoa" here). O'Connor farm, MQ, French Polynesia.** PHOTO: A. K. KEPLER

"honey" is a delightful gift of the banana plant to those with a sweet tooth.

Leaf vegetable

Leaf buds can be eaten as vegetable. Evidently, leaves of the beautiful, red-variegated ornamental *M. acuminata* subsp. *zebrina* are particularly tasty.

Medicinal

Flowers, fruits, and roots are still used medicinally in some Pacific cultures, but most of these practices have died out. Stalks were mashed and used as poultice for sprains or broken bones (Hawai'i). Root sap from certain varieties was used as a medicine for thrush, a child's mouth irritation (Hawai'i), and to treat skin warts (French Polynesia). Pounded banana peels—used in many Pacific cultures as a wound "bandage"—have been found recently to contain antibiotic properties.

Flavoring

Ashes produced from burning banana leaves and pseudostems are used in curries and as a salt substitute (India).

Cut flowers

Some *Musa* species and hybrids with colorful floral bracts and flowers are utilized in ornamental landscapes and tropical flower arrangements.

Fuel wood/cooking

Throughout the Pacific, banana trunks are still used to line underground ovens (to provide steam), together with banana leaves placed over the food to keep it dirt-free.

Fodder and silage

Fruits and stems are made into silage and used as cattle feed. Underground parts are also used for pig and cattle feed (e.g., Marquesas).

Banana grows together with many other useful plants, as here on Tongatapu Island, Tonga (left), and 'Upolu Island, Samoa (right). PHOTOS: C. ELEVITCH

Canoe/boat/raft making

Stalks were used as canoe rollers in ancient times in Hawai'i, and still today in some of the remote Micronesian and Polynesian communities (e.g., Yap and Tuvalu).

Fiber/weaving/clothing

Leaf and plant fibers are used to make thread and cloth. The shiny black outer trunk sheath surface of *M. fehi* and "black" traditional Polynesian-introduced varieties (e.g., 'Maoli 'Ele'ele' in Hawai'i, 'Mā'ohi 'Ere'ere' in Tahiti) was formerly used in weaving pandanus mats and other crafts to achieve dramatic patterns. This was practiced throughout Oceania, including New Guinea. *Musa basjoo* (the Japanese fiber banana) and *M. textilis* are still used to make high-quality clothing and fabrics. Thin parings carefully cut from the outer pseudostem of these fiber bananas are shiny, strong strips of natural fiber suitable for hand or machine weaving. In old Hawai'i, early Polynesian settlers braided their clothing (especially skirts) from dried banana sheaths and also plaited banana leaves for inner house linings.

Rope/cordage/string

Leaf fibers are used to make string, thread, cordage, and rope, e.g., *Musa textilis* for "Manila hemp" and "Taiwan hemp."

Wrapping/parcelization

Leaves are used as packing material and as parcels to hold things, leis and garlands for example. Banana leaves are also used to separate layers of paper mulberry bark at a soft, partly fermented stage of making tapa (Hawai'i and elsewhere in Polynesia). In Micronesia, banana leaves are used as liners in the traditional method of preserving breadfruit via pit preservation, as is now an historical traditional art in the Marquesas Islands. Banana leaves are also used for wrapping foods such as pulasami and valuvalu.

Thatch/roofing/mats

Leaves are used for house roofs and wall linings. Leaf sheath fibers are used in thatching.

Resin/gum/glue/latex

Banana sap has been used in many cultures as dye. Any banana sap will stain clothes indelibly black. The bright magenta sap of Fe'i bananas still finds uses in SW Pacific cultures.

Body ornamentation/garlands

Leaf sheath fibers are used to string leis and garlands and for tying and plaiting clothing. Some lei makers in Hawai'i still prefer to use twisted strips of banana trunk (about 2.5 cm [1 in] wide) on which to thread their leis, particularly haku-style leis. One of Hawai'i's ancient varieties, 'Maoli Manai-'ula', was named for its tough outer leaf sheaths, which were used—along with a needle fabricated from a coconut leaflet midrib—for stringing leis.

In many remote Pacific islands, especially in the southwest close to New Guinea, islanders still use banana fibers for tying together food packets or as string. However, beach hibiscus (*Hibiscus tiliaceus*) bark fiber is preferred if available, because it is stronger and more durable.

Fishing

Fruits of certain varieties were used to feed sharks and ensure good fishing (Hawai'i).

Tannin/dye

The sap is used as dye and ashes used for dye, tanning (India), and, on some Pacific islands, for tattooing.

Eating utensils

Leaves are used as plates and tablecloths (e.g., Polynesia and India).

Agricultural

Leaves are used to wrap root balls of seedlings or plants before transplanting.

Protection

Leaves are used as umbrellas and temporary raincoats.

Smoking

Leaves are used as tobacco paper, especially in the southwest Pacific and Micronesia.

Ceremonial/religious importance

- Fruit was used as offerings throughout the Pacific, including Hawai'i. In the latter case, tradition tells us that all mai'a ("native" bananas) were planted by the gods Kane and Kanaloa, so fruit was routinely offered to them as "gifts of the land" at heiau (places of worship) and other sacred places.
- Consumption of the fruit of some varieties (Maoli Group, except 'Maoli Ka'ualau') was taboo for females or was considered as food for male ali'i (royalty) and priests (Hawai'i). Varieties that have red (and later gold) pseudostems, petioles, or fruit at some stage of their development were considered royal or sacred.
- Leaves were used to cover altars in Hawai'i and throughout Oceania.
- Stalks were used to symbolize a man and under certain circumstances, Maoli bananas were utilized in ceremonies where banana offerings were substituted for human sacrifices (Hawai'i).
- Bananas were regarded as the embodiment of Kanaloa/Tangaroa/Ta'aroa, one of the four primary Pacific deities (Hawai'i, Society Islands, Samoa, and possibly Fiji).
- Wild bananas were regarded as primordial sustenance for the gods (Polynesia).
- Fruit was used in the ceremonial feeding of ancestral spirits (Hawai'i). The variety particularly planted around heiau for this purpose was 'Iholena Lele', a delicious cooking banana with salmon-fleshed fruit.
- The fruit was used as "love magic" (Hawai'i). Throughout the Pacific, Maoli bananas in particular are closely linked with sexuality. This is very evident even today in the Society and Marquesas Islands, where most of the

Typical home and garden, Nuku Hiva, with 'Rio' ('Pome'), a native Maoli banana ('Maoli Maoli'), 'Hamoa' ('Giant Cavendish'), and 'Kina' ('Dwarf Chinese'). Upland of Taiohae, Nuku Hiva, MQ, French Polynesia. PHOTO: A. K. KEPLER common Maoli and Pōpō‘ulu-type bananas are graced with old (and new) "specially appropriate" names. This was likely one of the reasons that Maoli bananas were forbidden for women to touch or eat in old Hawai‘i.

- Banana plants were used in rituals associated with the birth of children, especially royal children (e.g., Marquesas Islands and Tahiti).

URBAN AND COMMUNITY FORESTRY

Bananas and plantains are ideally suited for homegardens. They are probably grown and cultivated in more gardens throughout the Pacific than any other single plant species. The nutritious and tasty fruits are eaten by people of all ages and health conditions. The plants are easy to grow, regenerate themselves without re-planting, and produce good yields. Bananas in highly maintained landscapes require regular fertilizing, irrigation, pruning, and debris removal. In natural landscapes, some of these intensive inputs may not be necessary. Bananas also provide high starch yields relative to most root crops.

Size in an urban environment

The height and canopy spread of the plants in urban environments depends on a number of factors including the variety, impact of pests and diseases, plant nutrition, soil moisture, amount of sunlight, soil conditions, and other environmental factors. Under optimum conditions, most banana varieties grow to about 5 m (16 ft) tall and produce bunches which are higher than the average person can reach. Some varieties can be even taller, growing to about 6 m (20 ft) or more in height. The dwarf Cavendish type (the so-called 'Chinese' variety in Hawai‘i) grows to a height of 3 m (10 ft) or less and is preferred by people who are not prepared to harvest bunches from tall plants. Canopy spread for mature plants is 3–4 m (10–13 ft) for most varieties. Plants grown in shade may become taller than the same plants grown in full sun.

Rate of growth in a landscape

With minimal disease and weed competition and fertile and consistently moist soil, most bananas in the Pacific reach maturity (bunch production) in about 12–18 months. A plant that reaches 4 m (13 ft) in height at flowering grows at a rate of about 30–50 cm/month (12–20 in/month), on average. Each mother plant can produce several suckers during its lifetime. Plants in locations that are close to the equator may grow and develop more quickly than plants at other latitudes.

Root system

Banana root systems are not considered invasive; plants coexist very well with a wide range of landscape plants, including grasses and other aggressive plants.

Products commonly used in a Pacific island household

Musa species are most widely used in Pacific island households for fresh fruit and for cooking. Traditionally, the fruit is cooked in underground ovens and the foliage (leaves and pseudostems) is used to separate food from coals or hot rocks. Leaves have a wide variety of useful everyday applications, including as disposable umbrellas, food wrappers, and plates. Banana peels make a very nutritious food for pigs.

Light requirements

Musa species can grow well in the shade as a forest understory plant or in full sun. However, larger bunches and plants growing in full sun produce more vigorous growth.

Water/soil requirements

Bananas grow best where rainfall is distributed evenly throughout the year. The plants are susceptible to stunting and damage due to prolonged drought.

Life span

The life span of individual plants is about 1–1.5 years. Where plants receive care, the life span of a banana mat is virtually unlimited because it continually regenerates new plants.

Varieties favored for use in homegardens or public areas

Both dessert and cooking types are commonly grown in homegardens. Older people or those who want an easy harvest prefer dwarf varieties. Locally popular varieties vary throughout the Pacific; some are apparently well suited for certain geographic areas and preferred by certain populations.

Seasonality of leaf flush, flowering, fruiting

Plants produce leaves, flowers, and foliage throughout the year. Individual plants only flower and fruit once.

Exceptional ornamental values

A few species have exceptional ornamental value. There are varieties with green-and-white variegated foliage and fruit and some with unusual or beautiful inflorescences, such as the ornamental *Musa velutina* that produces inedible fruit.

Use as living fence, hedge or visual/ noise barrier

Musa species may be used as a living fence. The plants absorb noise well, grow quickly, and can block the view.

Maintenance requirements

Musa species are beautiful landscape plants and add to the tropical feel of a garden. Bananas do require management because the mats tend to expand radially and use up more and more space over time. New suckers along the perimeter of the mat should be cut off to prevent encroachment upon the landscape or nearby buildings.

Musa species are heavy feeders and, in the presence of other landscape plants with equally demanding nutritional requirements such as grasses, may develop nutritional deficiencies rather quickly. However, where esthetically acceptable, banana mats provide a very good place to compost yard waste and mulch; this feeds the plants and helps retain soil moisture during dry periods.

Although beautiful ornamental plants, they are not as well suited for high-maintenance, high visibility landscapes and parks because they tend to create a lot of unsightly leaf and stem debris. For this reason, it is usually better to plant bananas at the edges of landscaped areas, out of full view. In low-maintenance or more natural landscapes, banana debris is not a problem.

Top: A dense commercial planting of bananas, taro, and breadfruit in American Samoa. Bottom: Bananas are widely spaced in this taro field along with coconut and sago palm, Tutuila, American Samoa. PHOTOS: C. ELEVITCH

Special considerations regarding leaf, branch, and fruit drop

Bananas may topple during average storms, especially if they are bearing bunches or are undermined by the erosive effects of running water. Toppled plants may sometimes be saved by propping them back up. Bananas usually topple during hurricanes but can re-grow readily from underground parts.

Nuisance issues

Banana sap can be a great nuisance; it can permanently stain clothing and is very sticky to the touch. Banana plants can attract undesirable wildlife such as rodents, pigs, chickens, and other nuisance birds. Because banana debris can hold small puddles of rainwater, banana serves as good habitat for mosquitoes. Banana produces a considerable amount of plant debris that must be dealt with in some landscapes and gardens.

Hazards

If ladders are required for harvesting fruit, there is a potential for falling.

Common pest problems

Some banana pest and disease problems are locally severe. The most important and damaging disease is probably banana bunchy top virus. It is critical to plant only virus-free plants and to consult with the local extension agent or agricultural office as soon as symptoms of the disease appear. If the disease is not controlled, it may make growing bananas impossible in some locations. The most common, widespread problems in gardens and landscapes in the Pacific are probably fungal leaf diseases (i.e., black leaf streak), nutritional deficiencies, moths, weevils, and insect attacks, nematodes, banana bunchy top virus, and soil-borne root-infecting fungi such as *Fusarium* and *Marasmiellus*. Please refer to the "Pest and disease" section above for more information. Plants should be kept well irrigated and fertilized to help them withstand the effects of pest and disease attacks.

Other comments about this species in urban environments

Bananas are probably best suited for natural landscapes, due to the debris they create. Although they regenerate themselves and may grow to maturity without many inputs, the size of the harvest depends greatly upon the plant care provided. So if bunches are not important, they can be grown without much input or attention at all.

COMMERCIAL PRODUCTS

Primary commercial products

Spacing

Homegardens

Bananas should be planted at least 2–3 m (6.6–9 ft) from the side of a building.

Plantations

Two-line system with access roads: 1.8 m (6 ft) within rows (Cavendish subgroup); 2.1 m (7 ft) within rows ('Dwarf Brazilian'); roads are 3–3.7 m (10–12 ft) wide on 6 m (20 ft) centers. Two adjacent plant lines (1.8–2.1 m [6–7 ft] apart with plants on 1.8–2.1 m [6–7 ft] centers) separate each road. This gives a planting density of about 1850 plants/ha (750 plants/ac).

Agroforestry

Bananas are planted at random spacing, usually a minimum 2 m (6.6 ft) from nearest banana plant.

Along roadsides

To make use of marginal lands along roadsides, bananas are planted a minimum of 2 m (6.6 ft) apart.

Design considerations

- Avoid flood-prone areas or areas where surface water runs off or drains through. Running water undermines the root systems of banana plants, making them prone to topple when bearing a heavy fruit load or during windy weather.
- Avoid windy areas or areas prone to very high winds. Dwarf banana varieties (less than 4.6 m [15 ft] tall) withstand winds better than tall varieties (up to 9 m [30 ft] tall).
- Avoid areas where the topsoil has been scraped off, leaving only a hardpan or soil with very high clay content and poor aeration. Although banana requires large amounts of water, they also need drainage. If banana must be planted in heavy soils, allow side channels or French drains (channels with gravel and/or wire netting) to siphon off excess water. Planting on a gentle slope (not too steep) is recommended to facilitate drainage, with the plants in bowl-shaped terraces, so that water has a change to infiltrate rather than immediately running off downslope.
- Choose southern or western exposures (northern exposure in Southern Hemisphere) for a new plantation, and orient the rows according to wind and/or sun considerations. Planting bananas in alignment with the east-west movement of the sun encourages banana mats to "walk" in a straight line over the life of the farm, preserving row spacing and road width.
- Consider single-row planting or intercropping for high-rainfall areas with black sigatoka. Single rows allow good aeration of the banana canopy, allowing wet leaves to dry more rapidly, reducing fungal disease severity.

Yields

Yields depend largely upon the cultivation system, species or variety.

Commercial plantations

- For the Cavendish subgroup, e.g., 'Grande Naine', given a planting density of approximately 1750 bearing plants/ha (700 plants/ac), yields can be as high as 40,000 kg/ha/yr (35,000 lb/ac). Higher yields are possible in productive commercial ratoon crops.
- For the Pome subgroup, e.g., 'Brazilian' (often also called by some people "Apple" in Hawai'i), 'Improved Australian Lady Finger' (Central and West Pacific), 'Rio' or 'Pime' (French Polynesia), yields of 22,800 kg/ha (20,300 lb/ac) are expected.

Subsistence or wild cultivation systems

The bunch weight can be 1–18 kg (2–40 lb) or more, depending on variety, conditions, soil richness, amount of care, and fertilization application (bananas need large amounts

Intercropping of banana with cassava (left), taro (center), and sweetpotato (right) in Pohnpei. PHOTO: S. NELSON

of potash, as well as nitrogen and phosphorus), whether dead leaves are pruned or not, and the degree of disease infestation. Subsistence-style or low-input banana farming typically yields bunches in the 9–13.5 kg (20–30 lb) range.

Processing required

Commercial farming

Activities include harvesting, transport to packing shed, hanging, de-handing, cutting, sorting, labeling, washing, drying, packing, handling, boxing, stacking, storing, refrigeration, ripening, shipping, and marketing. Other types of commercial processing are employed for *Musa* fruit, such as drying, juicing, baking, chip making, fiber extraction, etc. The "native" Samoan variety, 'Fa'i Pau Manifi' (a Maoli type), is now exported to New Zealand for use as ice cream and drink flavoring.

Subsistence agriculture (food)

Cutting and hanging of bunches is the primary processing carried out.

Markets

In the Pacific, the primary markets are urban and metropolitan centers, farmer's markets, and roadside stands.

INTERPLANTING/FARM APPLICATIONS

Although *Musa* species require space and light, they co-exist well with a wide range of plants and trees in the Pacific, with the exception of allelopathic plants.

Some benefits of interplanting include

- disease and pest control
- complete diets for subsistence agriculture
- maintenance of soil fertility
- wind protection
- soil stabilization.

Some potential drawbacks of interplanting are

- Disease transmission from alternative hosts can be a problem.
- Root competition is a very important consideration, especially in areas where exceptionally invasive species not only shade but drastically drain the banana plants of water and nutrients. Be aware of this intense root competition with trees such as Java plum (*Syzygium cumini*), ironwood (*Casuarina equisetifolia*), eucalyptus trees (*Eucalyptus* spp.), and Christmas berry/Brazilian pepper (*Schinus terebinthifolius*).
- Most banana plants will not yield well if planted under more than 50% shade. The more sun, the better the yields and smaller the likelihood of fungal diseases. A few ornamentals, e.g., 'Blood' banana (*Musa acuminata* subsp. *zebrina*) flourish in, and actually prefer, 60–80% shade.

EXAMPLE INTERPLANTING SYSTEMS

Example system 1

Location

Micronesia (Pohnpei).

Description

These are traditional, subsistence cultivation methods where banana is intercropped with a range of other naturally occurring and cultivated plants such as papaya (*Carica papaya*), coconut (*Cocos nucifera*), kava (*Piper methysticum*), breadfruit, yam, sweetpotato, cassava, palms, ornamentals, etc. This system is low maintenance and usually easy to plant and harvest.

Yields

Approximately 11–13.5 kg (25–30 lb) per bunch.

Spacing

The spacing is more or less random.

Example system 2

Location

Micronesia (Pohnpei).

Description

This method is to plant bananas along roadsides. This system is more recently developed as a part of governmental assistance to address losses due to banana pests and diseases, which may be so serious that people must leave their land fallow for 1–2 years before replanting. The only other available soil is along common roadsides.

Yields

Approximately 11–13.5 kg (25–30 lb) per bunch.

Spacing

Spacing is systematic in relatively close and dense patches along roadsides.

PUBLIC ASSISTANCE AND AGROFORESTRY EXTENSION

Extension offices for agroforestry and forestry in the Pacific: http://www.traditionaltree.org/extension.html

INTERNET

California Rare Fruit Growers: <http://www.crfg.org/pubs/ff/banana.html>.

"Canoe Plants" of Ancient Hawai'i: <http://hawaii-nation.org/nation/canoe/canoe.html>.

Crop Knowledge Master, University of Hawai'i at Mānoa, College of Tropical Agriculture and Human Resources: <http://www.extento.hawaii.edu/kbase/crop/crops/banana.htm>.

Julia Morton's chapter on banana: <http://www.hort.purdue.edu/newcrop/morton/banana.html>.

Promusa—Bananas in the World: <http://www.inibap.fr/promusa/bitw.html>.

Promusa's home page for more information and banana links: <http://www.inibap.fr/promusa/>.

Tico Ethnobotanical Dictionary: <http://www.ars-grin.gov/duke/dictionary/tico/m.html>.

USDA's "The Ethnobotany Database:" <http://probe.nal.usda.gov:8300/cgi-bin/browse/ethnobotdb>.

International Network for the Improvement of Banana and Plantain (INIBAP): <http://www.inibap.org/>.

Insect pests of Micronesia: <http://www.crees.org/plantprotection/AubWeb/bugweb/bugroot.htm>.

Science and Technology Reference Department, Pacific Botany Internet Resources: <http://www.hawaii.edu/sciref/pacbotany.html>.

Advancing Banana (INIBAP): <http://www.inibap.org/publications/proceedings/advancingbanana.pdf>.

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Musa species (bananas and plantains)

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Acknowledgments: The authors and publisher thank Jeff Daniells, Robin DeMeo, Lois Englberger, Diane Ragone, and Fred Stone for their input. Photo contributions from Lois Englberger, Frank Rust, Wayne Nishijima, and the Hawai'i Department of Agriculture are gratefully acknowledged. The authors are deeply thankful for the generous support they have received from academic colleagues and farmers throughout the Pacific.

Recommended citation: Nelson, S.C., R.C. Ploetz, and A.K. Kepler. 2006. *Musa* species (bananas and plantains), ver. 2.2. In: Elevitch, C.R. (ed.). Species Profiles for Pacific Island Agroforestry. Permanent Agriculture Resources (PAR), Hōlualoa, Hawai'i. <http://www.traditionaltree.org>.

Sponsors: Publication was made possible by generous support of the United States Department of Agriculture Western Region Sustainable Agriculture Research and Education (USDA-WSARE) Program; SPC/GTZ Pacific-German Regional Forestry Project; USDA Natural Resources Conservation Service (USDA NRCS); Kaulunani, an Urban Forestry Program of the DLNR Division of Forestry and Wildlife and the USDA Forest Service; State of Hawai'i Department of Land & Natural Resources Division of Forestry & Wildlife; USDA Forest Service Forest Lands Enhancement Program; and Muriel and Kent Lighter. This material is based upon work supported by the Cooperative State Research, Education, and Extension Service, U.S. Department of Agriculture, and Agricultural Experiment Station, Utah State University, under Cooperative Agreement 2002-47001-01327.

Series editor: Craig R. Elevitch

Publisher: Permanent Agriculture Resources (PAR), PO Box 428, Hōlualoa, Hawai'i 96725, USA; Tel: 808-324-4427; Fax: 808-324-4129; E-mail: par@agroforestry.net; Web: <http://www.agroforestry.net>. This institution is an equal opportunity provider.

April 2006
ver. 1.1

Pandanus tectorius (pandanus)

Pandanaceae (screwpine family)

***ajbwirōk*, *anewetāk* (Pingelap Atoll, Pohnpei), *binu* (Kapingamarangi Atoll, Pohnpei); *bōb* (Marshall Islands); *choy*, *fach*, *far* (Yap); *deipw*, *fach*, *far* (Chuuk); *deipw*, *kipar* (Pohnpei); *épo* (Nauru); *fa*, *fafa*, *laufala*, *falahola*, *kuku-valu*, *lou'akau* (Tonga); *fala*, *lau fala* (Samoa, Tuvalu); *hala* (Nukuoro Atoll, Pohnpei); *hala*, *pū hala* (Hawai'i); *kafu* (Guam); *mweng* (Kosrae); *ongor* (Palau); *pandanas* (Vanuatu: Bislama); *pandanus*, *vacouet* (French); pandanus, screw pine (English); *te kaina* (Kiribati); *vadra*, *voivoi* (Fiji)**

Lex A.J. Thomson, Lois Englberger, Luigi Guarino, R.R. Thaman, and Craig R. Elevitch

PHOTO: C. ELEVITCH

Pandanus growing along the southern coast of 'Upolu, Samoa.

IN BRIEF

Distribution Native throughout the Pacific islands and parts of Southeast Asia and northern Australia.

Size Reaches 4–14 m (13–46 ft) in height, with about the same canopy diameter.

Habitat Usually elevations of sea level to 20 m (66 ft), but can grow at elevations of 600 m (1970 ft) or higher.

Vegetation Associated with species of coastal forests.

Soils Adapted to a very wide range of light to heavy soil types.

Growth rate Stem growth is slow to moderate, 2–80 cm [0.8–31 in] per year.

Main agroforestry uses Coastal protection, windbreak, homegardens.

Main uses Food, weaving, thatch.

Yields 10–300 leaves per tree per year or 8–12 fruits.

Intercropping Often planted in and around mixed agro-forests in the Pacific.

Invasive potential Naturally spreads into coastal plant communities. Since it is native to Pacific islands, the tree is not considered to be invasive.

INTRODUCTION

Pandanus (*P. tectorius*) is a large shrub or small tree of immense cultural, health, and economic importance in the Pacific, second only to coconut on atolls. A highly variable species complex, it grows wild mainly in semi-natural vegetation in littoral habitats throughout the tropical and subtropical Pacific, where it can withstand drought, strong winds, and salt spray. It propagates readily from seed, but it is also widely propagated from branch cuttings by local people for farms and homegardens. It grows fairly quickly, and all parts are used, from the nutritious fruits of edible varieties, to the poles and branches in construction, to the leaves for weaving and garlands. The plant is prominent in Pacific culture and tradition, including local medicine. Hundreds of cultivated varieties, collectively recognized in the Pacific but specific to numerous independent cultural traditions, are known by their local names and characteristics of fruits, branches, and leaves. At present, there is evidence that this diversity is declining, with certain varieties becoming difficult to find. The reasons include less replanting, deforestation, fire, flagging interest by the new generation, and rapid population growth leading to urbanization. Planting pandanus should be promoted in both rural and urban areas. For example, small shrubby varieties could be planted along boundaries or borders. Plantings should be encouraged in protected areas and in well maintained public areas. For example, in Hawai'i plantings of pandanus on hotel grounds were utilized and greatly appreciated by local weavers, due to good access and ease of harvesting. Special attempts should be made to collect and replant endangered varieties that are valued for their edible fruits and other uses.

DISTRIBUTION

Native range

Pandanus tectorius naturally occurs in strandline and near-coastal forests in Southeast Asia, including the Philippines and Indonesia, extending eastward through Papua New Guinea and northern Australia, and throughout the Pacific islands, including Melanesia (Solomon Islands, Vanuatu, New Caledonia, and Fiji), Micronesia (Palau, Northern Marianas, Guam, Federated States of Micronesia, Marshall Islands, Kiribati, Tuvalu, and Nauru), and Polynesia (Wallis and Futuna, Tokelau, Samoa, American Samoa, Tonga, Niue, Cook Islands, French Polynesia, and Hawai'i).

Current distribution

Many traditionally recognized and named varieties have originated through selection and vegetative propagation of wild plants in Melanesia, Micronesia, and Polynesia. These have sometimes been widely planted as aboriginal introductions to many islands. Additionally, new variants may be selected from seedling progeny or mutations in cultivated varieties.

BOTANICAL DESCRIPTION

Preferred scientific name

Pandanus tectorius Parkinson

Family

Pandanaceae (screwpine family)

Non-preferred scientific names

In this treatment, *P. tectorius* is recognized as a highly variable species complex that is widespread on strandline and coastal forest communities throughout the tropical and subtropical Pacific Ocean. Numerous, often minor, morphological variants of pandanus have been recognized and formally described as species, mainly by St. John. Some of the more widely used and important synonyms encompassing entities within the *P. tectorius* complex include *P. pedunculatus* R. Br., *P. pyriformis* (Martelli) St. John, and *P. spurius* Miquel. The concept of variety is useful to designate socio-economically important, and/or striking and unusual forms.

Common names

ajbwirōk, *anewetāk* (Pingelap Atoll, Pohnpei)
binu (Kapingamarangi Atoll, Pohnpei)
bōb (Marshall Islands)
choy, fach, far (Yap)
deipw, fach, far (Chuuk)
deipw, kipar (Pohnpei)
épo (Nauru)
fa, *fafa*, *laufala*, *falahola*, *kukuvalu*, *lou'akau* (Tonga)
fala, *lau fala* (Samoa, Tuvalu)
hala (Nukuoro Atoll, Pohnpei)
hala, *pū hala* (Hawai'i)
kafu (Guam)
mweng (Kosrae)
ongor (Palau)
pandanas (Vanuatu: Bislama)
pandanus, *vacouet* (French)
pandanus, screw pine (English)
te kaina (Kiribati)
vadra, *voivoi* (Fiji)

In the atoll island countries of the central and northern

Pacific, several hundred traditional varieties (many used by people for food) are recognized and given individual names in the local languages and maintained largely through vegetative propagation.

Size and form

Pandanus tectorius is a stout, branching, often multi-stemmed, large shrub or small tree (2–) 4–14 (–18) m ([6.6–]13–46[–59] ft) in height, with about the same canopy spread. Plants of most varieties have numerous aerial and prop roots and thick, forking, often spiny trunks. Wild seedling-derived plants often have a single bole or trunk for 4–8 m (13–26 ft) before forking. Maximum stem diameter is 12–25 cm (4.7–10 in).

Flowers

The species is dioecious—there are separate male and female plants. Flowers are borne in heads at the shoot apex. Male flowers are fragrant, tiny, white, pendant, arranged in racemes or branched in clusters, with large white showy bracts. Male flowers only last for about a day, with the inflorescence decaying within 3–4 days (Brink and Jansen 2003). Female flowers are pineapple-like.

Leaves

There is considerable variation in leaf shape and size, both on and among trees. Leaves are spirally-arranged in three rows and clustered at branch apices, dark green, 1–3 m (3.3–10 ft) long by 11–16 cm (4.3–6.3 in) wide, V- to Y-shaped in section, with spiny/prickly margins and midribs. Marginal prickles are usually 0.8–2.5 mm (0.03–0.1 in) long. A few traditionally recognized and named varieties have leaves with smooth margins, e.g., 'Tutu'ila' in Tonga, 'Nei Naobua' in Kiribati, 'Lau fala' in Samoa, and at least one variegated form in Fiji.

In fully expanded leaves, the midrib is bent, and the up-

Top left: Male inflorescence. PHOTO: C. ELEVITCH **Top right: Female inflorescence.** PHOTO: C. ELEVITCH **Bottom: Fruit heads comprise an aggregate of many tightly bunched wedge-shaped phalanges or drupes; these are also called "keys," as removing one will allow the rest to come apart easily.** PHOTOS: L. THOMSON per third (or so) of the leaf hangs down, giving pandanus plants their characteristic drooping appearance.

Fruit

The multiple fruit head displays considerable plant-to-plant variation in morphology, size, and color, and many of the traditionally named varieties (females) are recognized by their particular combination of fruit head characteristics (Hiyane 1971).

The shape of the fruit head may be ovoid, ellipsoid, subglobose or globose, with overall dimensions of 8–30 cm (3–12 in) long by 4–20 cm (1.6–8 in) diameter. Fruit heads are made up many (38–200) tightly bunched, wedge-shaped fleshy phalanges or drupes (also referred to as keys).

Individual phalanges are narrowly oblong to ovoid and 2.5–11 cm (1–4.3 in) long by 1.5–6.7 cm (0.6–2.6 in) wide (at widest point). The endocarp (internal tissue surrounding the seeds) is dark reddish-brown, hard/bony, and 15–35 mm (0.6–1.4 in) long. The mesocarp comprises apical and basal sections. The apical mesocarp formed in the apex of each carpel comprises an elongated cavern with aerenchyma of a few longitudinal fibers and white membranes. The basal

Phalange split lengthwise to reveal a seed (cut in half). PHOTO: L. THOMSON

mesocarp is fibrous and fleshy, about 10–30 mm (0.4–1.2 in) long. This is the portion of the fruit that is chewed and eaten in edible varieties. At maturity the color of the basal section of the phalanges varies from pale yellow to dark yellow, orange, and orange/red. For intact fruiting heads the visible apical portion of the phalange is typically green with brown markings at maturity, turning yellow with age, after falling. In some varieties the apical portion may be colored dark orange at maturity, e.g., 'Fala'hola' in Tonga.

The apical profile of individual phalanges ranges from truncate and sub-truncate to convex. There are 1–15 carpels per phalange, and these are arranged either radially or in parallel rows. The central apical sinuses range from 1–28 mm (0.04–1.1 in) deep.

Seeds

The seeds are obovoid, ellipsoid, or oblong; 6–20 mm (0.25–0.8 in) long; red-brown and whitish/gelatinous inside. The small (10 mm [0.4 in] long) white seeds of pandanus found in some varieties have a coconut-like taste.

Phalanges are widely dispersed by ocean currents and can float for many months, during which time the seeds maintain viability.

Bark

The bark is grayish- or reddish-brown, smooth/flaky, with characteristic undulating leaf scars and rows of prickles.

Rooting habit

The root system of pandanus plants is dominated by thick, slightly spreading prop roots originating from the lower part (1–1.5 m [3.3–5 ft]) of the trunk. The prop roots penetrate and are mainly concentrated in the surface soil layers. In some plants, there may be a few aerial roots hanging vertically from branches.

Similar or look-a-like species

***Pandanus odoratissimus* L.f.** is another highly variable *Pandanus* species that is taxonomically very close to *P. tectorius*. It is widely distributed along Indo-Malayan coasts from India and Sri Lanka throughout Southeast Asia to Taiwan, the Ryukyu Islands, and western parts of Micronesia. The main morphological difference is considered to be the larger white or very pale leaf spines in *P. odoratissimus*, compared with smaller greenish spines in *P. tectorius*. The two species are thought to hybridize readily where they co-occur and are possibly better treated as subspecies of *P. tectorius*.

The following *Pandanus* species occur naturally and/or are

Left: Characteristic ring pattern on bark left after older leaves fall off. PHOTO: L. THOMSON **Right: Prop roots descending into a thin substrate over lava rock, 'Upolu, Samoa.** PHOTO: C. ELEVITCH

cultivated in near-coastal locations in the Pacific islands and are sometimes confused with the *P. tectorius* complex.

Pandanus dubius **Sprengler** grows in coastal forests, including beaches and rocky shores in Southeast Asia and the Western Pacific region, including Palau, Northern Marianas, Guam (local name pahong), Kiribati (local name tekaureiko), Federated States of Micronesia (local names mweng kaki, kipar-n-ai), Papua New Guinea, Solomon Islands, Vanuatu, and Rotuma. It is occasionally cultivated for its edible seeds and thick leaves for basket making and floor mats. It is distinguished from *P. tectorius* by its long penducles, 60–80 cm (24–32 in) in length, and large, white, edible, and tasty rounded seeds (1–1.5 cm [0.4–0.6 in] in diameter) situated at the base of the phalange. Its trunk is covered with sharp prickles (lenticels), and the roots are covered in vertical rows of lenticels.

Pandanus whitmeeanus **Martelli** is a female clone that probably originated in Vanuatu. It is now widely cultivated near sea level in swampy, grassy areas in Fiji, Wallis and Futuna, Samoa, Tonga, and the Cook Islands for its leaves, which are used to make fine mats and handicrafts. It is distinguished from *P. tectorius* by the position of its stigma, which is oblique to vertical on the distal, outer face of the phalange apex, compared with apical on carpel summit in *P. tectorius*. The multiple fruit heads are subglobose to ellipsoid, up to 25 cm long by 22 cm diameter (10 x 9 in), and the basal section of the phalange is bright red when mature.

GENETICS

Variability of species

Pandanus tectorius is a geographically widespread and an exceptionally morphologically variable species or species complex. Female plants within a geographically localized population, such as on the same stretch of beach, may exhibit distinctively different fruit characteristics (fruit shape and size, number of phalanges per fruit, phalange shape, color, size, texture, nutrient content, carpel number, shape and appearance, edibility, taste, seed shape, etc.). Such variants have sometimes been described as different species, but in a biological sense they are part of the same interbreeding population and, furthermore, it is not possible to designate male plants to such "species." Morphological variation is also evident in plant form, trunk, and branch thickness, presence and number of prop and aerial roots, leaf characteristics and spiral arrangement, and extent of spines on different plant parts. Varieties may represent geographic races or provenances, morphologically distinctive individuals, vegetatively propagated clones, polyploids, and interspecific hybrids. Variation within populations is generated through recombination during sexual reproduction and long-distance dispersal by ocean currents of buoyant phalanges. The mating system is expected to be highly outcrossing (due to separate male and female plants) or facultative apomictic (in the absence of male plants) (Brink and Jansen 2003). Variation in economically important characters is also maintained through people vegetatively propagating individual plants with preferred traits. For weaving, plants with strong, flexible, non-spiny leaves are preferred, while for human consumption, female plants with sweet, soft-textured fruits, low in oxalates, and with small keys that fit better in the mouth for chewing are favored.

Known varieties

Hundreds of traditional varieties of *Pandanus tectorius* have been recognized, named, and propagated by local people in different parts of the Pacific islands. An individual plant may have originally been identified as having value for a particular use, such as fruits for human consumption or leaves for weaving fine mats, and then vegetatively propagated and widely planted. An important botanical variety for weaving is *P. tectorius* var. *laevis* (synonyms include *P. spurious* Miquel, *P. laevis* Kunth, and *P. inermis* Reinw.). This variety has spineless (or near spineless), fragile leaves and is known as 'Kie' in Tonga, 'Lau Fala' in Samoa, and 'Lau Hala Kilipaki' in Hawai'i. Useful varieties or clones may be propagated vegetatively and cultivated on many islands in different countries, either under the same or similar name, or a completely different name. For example, on Kiribati the traditionally recognized variety 'Antinakarewe' or 'Teantinakarewe' is prized for its flavorsome, edible fruits and is cultivated under the same name on many islands, including Abiang, Butaritari, and Tarawa, but has a different name elsewhere in Kiribati. Within this variety, there may be two types distinguished on the basis of key/phalange size and bunch size; the form with big keys is very similar or the same as the variety 'Ļōjokdād' in the Marshall Islands (Englberger 2004). More frequently, traditionally named varieties have limited distributions, for example, on one or just a few neighboring islands. In Kiribati, there may be up to 200 different traditionally recognized, named and cultivated varieties of pandanus, many of which may be exclusive to a village or family, although only 16 names are apparently widely recognized on Tarawa. Some botanists have named morphologically distinctive varieties (or morphotypes) of *P. tectorius* as separate species, but these may be extremes of a continuum or else only identifiable as female plants and thus do not fit into the accepted biological definition of species.

Culturally important related species in the genus

Some entities within the *P. tectorius* complex may prove to be taxonomically and biologically valid species, and culturally important in the areas in which they occur. An example might be *P. odoratissimus* L.f., which naturally intergrades with *P. tectorius* in Southeast Asia/western Pacific rim, presumably through interspecific hybridization.

ASSOCIATED PLANT SPECIES

Pandanus is common in littoral habitats throughout the Pacific (Melanesia, Micronesia, and Polynesia), including on atolls. In all parts of its natural range, pandanus is a frequent component of strandline and coastal vegetation, including grassy or swampy woodlands, secondary forests, and scrub thickets developed on makatea (raised fossilized coralline limestone terraces). It commonly occurs on the margins of mangroves and swamps. Pandanus also occurs as an understory tree in plantations and forests on atolls and larger islands (either planted or naturalized).

Associated species of native habitats

In strandline communities, associated species include creepers such as *Ipomoea pes-caprae*, *Canavalia sericea*, and *Vigna marina*. Other coastal thickets and forest associates include *Acacia simplex*, *Amaroria soulameoides*, *Tournefortia argentea*, *Barringtonia asiatica*, *Bruguiera gymnorrhiza*, *Calophyllum inophyllum*, *Casuarina equisetifolia*, *Cerbera manghas*, *Chrysobalanus icaco*, *Cocos nucifera*, *Cordia subcordata*, *Excoecaria agallocha*, *Guettarda speciosa*, *Hernandia nymphaeifolia*, *Hibiscus tiliaceus*, *Intsia bijuga*, *Morinda citrifolia*, *Podocarpus neriifolius*, *Santalum insulare*, *Scaevola taccada*, *Schleinitzia insularum*, *Terminalia catappa*, *T. littoralis*, *Thespesia populnea*, and *Vitex trifoliata*. Peat swamp associates include *Sphagnum cuspidatum* and various sedges.

Species commonly associated as aboriginal introductions in Pacific islands

Pandanus is frequently planted or protected in garden areas and homegardens, sometimes in monocultural patches or as border plantings. Associated species include *Artocarpus altilis*, *Colocasia*, *Citrus* spp., *Polyscias* spp., and a host of other food crops, fruit trees, and ornamentals.

Species commonly associated in modern times

It is planted in homegardens with many different recent introductions, including ornamentals, fruit and nut trees, and timber trees (e.g., *Swietenia macrophylla* and *Agathis robusta* in Tonga).

ENVIRONMENTAL PREFERENCES AND TOLERANCES

Climate

Pandanus grows in maritime (usually less than 20 m [66 ft] above sea level), tropical, humid and subhumid climates. The species is very well adapted to exposure to strong, often salt-laden winds, including buffeting from moderate to severe tropical cyclones, over a large part of its range.

Rainfall varies considerably across its range, both in amount and seasonal distribution. Rainfall may be distributed more or less uniformly throughout the year, bimodally, or with a peak over 4–6 months at any time of the year, usually during the hottest period. Pandanus mainly occurs in localities with 1500–4000 mm (60–160 in) annual rainfall, and with no or a short dry season (i.e., no or a few months receiving <40 mm [1.6 in] on average). In near-equatorial Pacific regions there is considerable year-to-year variation in annual rainfall, such that plants may have to tolerate extended dry periods of up to 6 months.

In its native habitats, temperatures are warm to hot throughout the year and show little variation, both seasonally and diurnally.

Elevation range

0–20 m (0–66 ft). It may be cultivated at higher elevations, e.g., up to about 600 m (1970 ft) in Hawai'i (Little and Skolmen 1989).

Mean annual rainfall

1500–4000 mm (60–160 in)

Rainfall pattern

Pandanus is adapted to climates with summer, bimodal, and uniform rainfall patterns.

Dry season duration (consecutive months with <40 mm [1.6 in] rainfall)

Long-term average rainfall data suggest that across its range there is a short (less than 3 months) or no dry season. However, in some locations, especially in the central or equatorial Pacific, there may be a dry season of up to 6 months, or longer, in some years.

Mean annual temperature

24–28°C (75–82°F)

Mean maximum temperature of hottest month

28–36°C (82–97°F)

Mean minimum temperature of coldest month

17–25°C (63–77°F)

Minimum temperature tolerated

12°C (54°F) (absolute minimum temperature recorded in its native range)

Left: Typical littoral forest community including beach heliotrope (*Tournefortia argentea*) and beach she-oak (*Casuarina equisetifolia*), Houma, Tongatapu, Tonga. PHOTO: L. THOMSON **Right: Pandanus often grows on shorelines exposed to salt spray and wind, 'Upolu, Samoa.** PHOTO: C. ELEVITCH

Soils

Pandanus naturally occurs on various coastal soils, especially sandy and rocky beaches, including raised coralline terraces and recent basalt (lava flows). It is adapted to an extraordinarily wide range of light to heavy-textured soil types, including brackish/saline soils, light-colored, infertile coralline atoll sands, alkaline sands, thin soils over limestone, and peaty swamps.

Soil texture

The tree grows in light to heavy soils (sands, sandy loams, loams, sandy clay loams, clay loams, sandy clays, and clays).

Soil drainage

Pandanus grows in soils with free or impeded drainage, including seasonally waterlogged soils.

Soil acidity

It grows in acid to alkaline soils (pH 6–10).

Special soil tolerances

The tree grows in shallow, saline, sodic, and nutrient-poor soils, as well as peat swamps.

Tolerances

Drought

The species is tolerant of moderately long droughts, e.g., 3–6 months or more, which are experienced infrequently in the central Pacific (and which are masked by long-term climatic averages). It also frequently occurs on thin soils of low moisture-holding capacity, which also indicates good drought tolerance. During very dry periods it will usually continue to bear fruit, albeit smaller and fewer in number, and it is considered more drought tolerant than coconut in atoll environments (Stone et al. 2000).

Full sun

The species is very well adapted to growing in full sunlight, and it predominantly occurs in open, exposed sites.

Shade

Pandanus also grows well at intermediate levels of shade (e.g., 30–50% shade). The range of shade tolerated is 0–70%. At higher shade levels plants cease flowering and fruiting.

Fire

Pandanus naturally occurs in grasslands that are regularly burned. Older plants are tolerant of low- to medium-intensity fires but are killed by high-intensity fires. Moderately intense fires mainly kill juvenile plants less than 0.5 m (20 in) tall and 5 cm (2 in) stem diameter. Low- to moderate-intensity fires may be important for long-term maintenance of pandanus populations, as pandanus is more fire-tolerant than many of its larger, and competing, woody associates.

Frost

Its frost tolerance is unknown but likely to be limited, with plants expected to be damaged by low temperatures (e.g., <10°C [50°F]) and killed at temperatures approaching freezing.

Waterlogging

The species generally tolerates waterlogging well and is often found in swampy localities with impeded drainage. However, in Kiribati, it is recommended that planting in swampy areas be avoided in order for pandanus plants to be healthy and give high fruit yields. Pandanus is likely to tolerate waterlogging for at least 6 months and possibly indefinitely in suitable soil types, such as peat. It occurs on the margins of saltwater mangroves, and it evidently tolerates periodic saltwater inundation during unusually high tides and storm surges.

Salt spray

The species is exceptionally tolerant of salt winds, with plants often colonizing the most exposed seaside locations.

Wind

Pandanus is tolerant of strong, steady winds, such as southeast trade winds, and is capable of surviving gale force storm winds associated with category 1–2 tropical cyclones. Cyclone damage includes bent leaves, fruits broken off, broken branches, and broken stems. During the most severe cyclones (category 3–5), about 10% of larger individuals (>6 m [20 ft] tall) in more exposed sites may be broken and die. Stem breakage typically occurs just above the prop roots.

Abilities

Regenerate rapidly

Under suitable conditions, the plants will regenerate fairly rapidly from seed in fallen fruit segments.

Self-prune

Pandanus plants display a form of self-pruning. In older plants (>30 years of age), the rate of branching is equaled or exceeded by the rate of branch death, such that the total number of branches stays about the same or declines.

Left: Trees grow in very harsh, windy conditions such as here on east coast of ʻEua, Tonga. Right: Pandanus colonizing limestone pillar in Haʻapai, Tonga. PHOTOS: L. THOMSON

Coppice

The coppicing ability of pandanus has not been well investigated. However, plants in which the main stem is broken by cyclones fail to regrow. Accordingly, single-stemmed plants are likely to have limited or no coppicing ability. Multi-stemmed, shrubby individuals, propagated from cuttings, may have some limited coppice regrowth ability, especially if some live stems are retained.

Pollard

In general, pandanus plants do not respond well to pollarding, with limited regrowth occurring after branch cutting.

GROWTH AND DEVELOPMENT

Growth rate

Growth and development varies with sex of plant (male or female), variety, and types of planting stock (seedling or branch cutting).

For seedling plants, there is a 4–9 year semi-prostrate juvenile phase, followed by an erect trunk growth phase of 5–12 years, and then a sexual/flowering phase of 40 or more years. Male plants are usually more branched, up to about 30 branches (maximum 60), than females, up to about 15 branches (maximum 30). The rate of stem growth varies from very slow to moderate (2–80 cm [0.8–31 in] per year). Branch diameter is usually reduced by 10–30% at each branching, and branching ceases when branch diameter is less than about 3.5 cm (1.4 in) in males and 4.5 cm (1.8 in) in females. The life span of established pandanus plants is typically about 50–80 years (but longevity may be much greater, as long as 100–150 years in some environments). The productive fruiting life of vegetatively propagated plants may be only 20–25 years. Senescence is associated with a gradual decline in branch diameter, leaf size, and number of live branches. Branch death is due to the death of the apical meristem, mainly due to insect damage or breakage.

Plants developed from branch cuttings usually grow much faster in earlier years than seedling-derived plants, e.g., elongating about 50–80 cm (20–31 in) per year, and branch from a lower height.

Flowering and fruiting

First flowering in seedling-derived plants commences at about 15 years, while plants derived from branch cuttings typically flower in (2–) 3–4 (–6) years. Seasonality of flowering varies greatly among countries/localities, and among varieties. In Fiji, male plants usually flower once per year (March–May), although flowering plants may be found at any time of the year. Female plants flower heavily every second year; anthesis and fertilization typically occur in March–May, with fruits reaching maturity about a year later, during the following February–April period. In northern Australia, the main fruiting season is April–August. In Kiribati, Marshall Islands, and the Federated States of Micronesia, there are two main fruiting seasons, around December–March and later in July–September. Varieties vary in seasonality, some known to come early or late in the season. Plants may fruit occasionally during the off-seasons throughout the year. In female plants, the period from flower initiation to fruit maturation is about 2 years.

Reaction to competition

Pandanus plants react fairly well to root zone competition from grasses, sedges and woody plants, but growth is slowed and flowering ceases if plants are overtopped and become shaded.

PROPAGATION

The tree is mainly grown from branch cuttings, as plants derived from seeds do not usually reproduce the same qualities of the parental plant. Numerous cultivated traditional varieties (or clones) exist on atolls; most have been selected for their superior edible fruit qualities and are propagated from cuttings. The wild varieties reproduce from seed in their native habitats and are preferred for timber due to their longer, straighter boles.

Propagation by branch cuttings

Propagule collection

Branch cutting material is carefully selected; typically, shorter laterals including one or more aerial or prop roots are chosen. The length of cuttings is about 30–40 cm (12–16 in).

Where early fruiting is desired, the practice in Kiribati is to select branches already with fruits for cuttings. Prior to planting, the existing flowers/fruit are removed.

Propagule processing

The leaf area is reduced by about 70% by cutting and trimming the leaves.

Branch cuttings for propagation; note aerial roots are still attached and leaves are trimmed. PHOTO: L. THOMSON

Propagule storage

It is preferable to plant cuttings immediately or shortly after collection. If being transported to another locality, they may be kept in shaded, cool conditions in sealed, moistened plastic bags for several days.

Pre-planting treatments

None.

Growing area

During the wet season, cuttings may be planted out into their final position in the field, usually in full sun (or up to about 25–30% shade). In Kiribati, depending on type of cutting material and other factors, one or more of the following practices may be adopted to increase rooting and improve survival and growth:

- Planted cuttings in a swamp taro pit until roots develop.
- Plant cuttings late in the afternoon on rainy days (and during the new moon phase).
- Water cuttings daily during prolonged dry spells and during dry season.
- Include organic matter (especially coconut husks) and rusty cans in the planting hole.
- Mulch with dried leaves of pandanus, coconut, and breadfruit.

High survival and rooting of cuttings is likely to be achieved in shade houses with low to intermediate shade levels (up to 50%) and enhanced with misting and/or regular watering.

Media

A sand bed is recommended. On atolls, excavated taro pits are often used.

Time to outplanting

Cuttings rooted in the nursery or a taro pit are transplanted once they have developed several roots.

Approximate size

Rooted branch cuttings are usually about 40–60 cm (16–24 in) long at the time of field planting.

Guidelines for outplanting

The survival of branch cuttings may vary greatly depending on the material used, the variety, handling prior to planting and planting location. Cuttings with several pre-existing aerial roots will usually give high survival, and the presence of pre-existing aerial roots is essential when planting directly into more exposed, beach-side localities.

Propagation by seed

Seed collection

Collect intact phalanges (keys). Larger fruits may contain some seedless keys. The average number of seeds per phalange is about two (with a maximum number of eight).

Seed processing

To speed germination, keys may be soaked in cool tap water for 5 days, changing the water daily. Viable keys will float.

Seed storage

Seeds are probably recalcitrant, meaning that they lose viability if dried. However, because seeds are thought to remain viable after floating on ocean currents for some time, storage of clean keys for weeks or months may be possible.

Pre-planting propagule treatments

Phalanges may be mashed against screens to remove the

Left: Propagation of pandanus seedlings in Forestry Division Nursery, Vava'u, Tonga. Right: Volunteer seedling ready for transplanting. PHOTOS: L. THOMSON soft pulp and extract the seeds, although this is not necessary.

Growing area

Phalanges may be sown directly into their final location or propagated in full sun (or part shade) in a nursery. Direct sowing is a less expensive method and would generally be preferred, except where seed is in short supply or planting sites are weedy and/or subject to disturbance or burning.

Germination

One source recommends planting phalanges at a depth of two times their diameter (NTBG 1996), and another recommends removing the fleshy part of the key, laying it on the planting medium, and burying it half-way (Bornhorst 2005). Seedlings usually germinate within 4–10 weeks when intact phalanges are planted in moist soil/sand. Up to eight shoots (individual seedlings) may emerge from a single phalange, and many or all may survive, aided by the initially semi-prostrate growth habit, which reduces crowding.

Media/containers

A well drained, sandy, or coralline medium is recommended. Larger sized plastic bags, e.g., 15–20 cm (6–8 in) diameter, are preferable.

Time to outplanting

The nursery duration period is not especially critical for pandanus seedlings. It is recommended that plants be field planted when they are about 4–12 months old.

Approximate size at time of outplanting

The approximate height at outplanting is 30–40 cm (12–16 in).

Guidelines for outplanting

Seedling survival will normally be very high, except for mortality arising from extreme events such as erosion by tidal surge for beachside plantings, or wildfire.

In atoll environments the following factors are considered important for healthy growth and fruit yields of pandanus:

- Avoid planting in swampy areas.
- Provide windbreaks during establishment phase.
- Roots of other plants close to the base of the plant should be cut to increase yields.
- Apply ash from cooking fires (at rate of one coconut shell-full) around base of mature specimens.

Pandanus planted in understory of mixed garden, American Samoa. PHOTO: C. ELEVITCH

DISADVANTAGES

It may be hard to obtain planting stock of preferred varieties of pandanus in significant quantities. To obtain edible fruits, vegetative propagation is necessary. Also, cuttings are best taken only after the fruits of a tree have been harvested. There may be a lag of several to many years before planting stock can be bulked up for large-scale plantings. A further drawback is the difficulty of moving preferred varieties between islands and countries, due to the technical difficulties of either producing apomitic seed and/or the logistical and quarantine issues associated with moving planting stock in the form of large branch cuttings. Breeding for improved sex-specific traits, such as edible or perfumed fruits, is problematic in a dioecious species, with separate male and female plants.

Potential for invasiveness

This species naturally colonizes and spreads into beach and littoral plant communities throughout much of the Pacific islands (where it is highly valued for providing diverse products and services). It has a low potential for invasiveness beyond its natural habitats. Non-preferred genotypes, such as those resulting from volunteer seedlings, are sometimes considered weeds and cut down.

Diseases and pests

The most important pests in the central Pacific are sap sucking mealybugs that may weaken plants. Rats and hermit crabs may feed on green and ripe fruits. In general, pandanus appears to suffer only minor damage from pests and diseases. There is a serious scale affecting pandanus forests in Hana and the entire east Maui region in Hawai'i; this pest was first noticed in the early 1990s and is spread-

In many areas, pandanus forms dense stands, such as here in Kaneohe, Hawai'i. PHOTO: C. ELEVITCH

ing along the coast. Leaves are yellowing and trees are now in very poor health.

Recorded arthropod pests include *Aspidiotus destructor* (coconut scale), *Aspidiotus nerii* (oleander scale), *Graeffea crouanii* (coconut phasmid), *Oryctes rhinoceros* (coconut rhinoceros beetle), *Pinnaspis strachani* (hibiscus snow scale), *Pseudococcus giffardi*, and *Pseudococcus perforatus* (mealybugs).

In northern New South Wales (Australia) dieback of *Pandanus* species is caused by an infestation of the pandanus planthopper (*Jamella australiae*). The insects produce a sticky substance called honeydew, which encourages mold growth. This makes leaves drop and kills the tree's growing points, eventually causing death of the tree. In its native habitats in North Queensland, *Jamella* is controlled by natural predators, including wasps.

Recorded fungal species on pandanus include *Asteromella* sp., *Coniothyrium pandani*, *Dothidella pandani*, *Glomerella* sp., *Lembosia pandani*, *Macrophoma pandani*, *Melanconium pandani*, *Melanconium* sp., *Meliola juttingii*, *Microcyclus pandani*, *Oxydothis pandani*, *Phomatospora cylindrotheca*, *Phomatospora pandani*, and *Volutellaria fuliginea*. Recorded nematodes include *Helicotylenchus dihystera*. *Erwinia carotovora* subsp. *carotovora* has been recorded as a bacterial disease of *Pandanus*.

Host to crop pests/pathogens

Pandanus is a host for several insect pests of coconut (see above).

Other disadvantages or design considerations

Members of the *kochi* group of *Aedes* (*Finlaya*) mosquito species breed almost exclusively in leaf axils, such as those of aroid root crops, including taro, and Pandanaceae (Taylor 1998).

AGROFORESTRY/ENVIRONMENTAL PRACTICES

The plants provide a wide range of environmental services, including control of coastal erosion; windbreak, including protection of food crops from salt spray; improvement of soil fertility and organic matter levels; shade for humans; and shelter and nesting sites for birds.

Mulch/organic matter

On atoll islands of Micronesia all parts of pandanus may be used for production of compost, as well as in mulching and raising fertility and organic matter levels in sandy, coralline soils. In Kiribati pandanus leaves are used for mulching in giant swamp taro pits.

Soil stabilization

When grown on the seaward slopes and crests of frontal dunes, pandanus helps to bind the sand and prevent wind erosion.

Crop shade/overstory

Pandanus is rarely used as crop shade as the crown is low, interfering with tending of crops, and the asymmetrical branch habit results in variable, often heavy, shade levels.

Alley cropping

Due to its size and habit, the species has good potential for inclusion in alley cropping systems, especially in near-coastal sites where it can act as a low to mid-level windbreak.

Homegardens

Pandanus is commonly planted in homegardens in coastal areas, because of its ornamental appeal, hardiness, and ability to provide a wide range of products, including leaf material for weaving into everyday products, edible fruits, flowers for perfume, and traditional medicines.

Living fences

Pandanus is commonly planted along fence lines and as a boundary marker, especially in near-coastal sites with sandy soils.

Windbreaks

When established at close spacing on or near the crests of beach frontal dunes, pandanus plants function as a windbreak, protecting less tolerant dune plants from the dam-

Left: House thatched with pandanus in Butaritari, Kiribati. PHOTO: R. THAMAN **Right: A boundary hedge of pandanus together with sago palm (*Metroxylon warburgii*), 'Upolu, Samoa, which serves as a cultural resource for craft materials.** PHOTO: C. ELEVITCH

aging effects of salt-laden winds. Pandanus is often planted as a windbreak in atolls to protect crops from salt spray.

Silvopasture

Pandanus is recorded as providing fodder for animals such as pigs and horses.

Woodlot

The plant is sometimes grown in block configurations for production of leaves for weaving. When these plantations have matured and are no longer producing high yields of easily harvested leaves, they can be harvested for timber.

Native animal/bird food

The fruits are eaten and dispersed by crabs, birds, and fruit bats.

Wildlife habitat

Pandanus provides nest sites for birds, especially in atolls.

Bee Forage

Honeybees have been observed foraging on female flowers and fruits.

Fish/marine food chain

Pandanus undoubtedly provides benefits for marine ecosystems and food chains, through its role in beach protection and stabilization.

Coastal protection

The tree is tolerant of foliar salt spray, sand blasting, exposure to strong winds, and high levels of solar radiation. It is considered to be a secondary sand dune colonizing plant and is a useful species for planting on exposed frontal dunes that have already been partly stabilized against wind erosion.

Ornamental

Pandanus is widely planted as an ornamental in homegardens, especially as a boundary along front fences in Pacific islands. Both female and male plants have ornamental

STORIES AND LORE

Pandanus is one of the Pacific's must useful plants and is featured prominently in Micronesian and Polynesian creation mythology, cosmogony, proverbs, riddles, songs, chants, and sayings (e.g., Grimble 1933-34, Thaman and Whistler 1996, Meilleur et al. 1997, Natake and Kairo 2002, Kayser 2002). For example, one legend in Kiribati tells of a man from Makin Atoll who awoke from death and asked that the 'Tearabukitaba' variety of pandanus be planted (Englberger 2004). A legend from the Marshall Islands describes how two people from Bikini Atoll stole the fruit of the variety 'Robijen', and how they went to Kwajalein Atoll and stole pandanus fruit of the 'Anberia' variety (Downing et al. 1992). Another legend tells of a traditional leader's young infant, who was washed away to another island by a big wave; parts of the legend mention pandanus, including a game using pandanus sticks and the woven mat used for burial woven from pandanus leaves. These stories emphasize the cultural importance of pandanus and illustrate the specific use of variety names.

potential. Variegated cultivars are being increasingly planted in Fiji and elsewhere.

USES AND PRODUCTS

Different parts of the pandanus plant are used to provide a myriad of end products throughout the Pacific islands, especially on atolls. The trunk and large branches are commonly used for building materials in house construction, and for ladders. They are also used to make headrests/hard pillows, vases, and fish traps, as sources of glue or caulking for canoes, to extract cream from grated coconuts, and as an aid in making string. Trunks and branches may be burnt for fuelwood or used to make compost. Prop or aerial roots are used in fabrication of house walls, and as supports, basket handles, paintbrushes, and skipping ropes. They are also used to produce dyes and in production of traditional medicines.

The leaves of selected varieties are treated by soaking in the sea and/or boiling or heating and dying and are then used to make mats, baskets (including for ladies and to keep valuables), hats, fans, pillows, canoe sails (formerly), toys, and other plaited wares. The leaves are also used for thatching (both walls and roofs), and for making compost, including special composting baskets woven around the base of giant swamp taro, cigarette wrappers, balls for children's games, and ornaments. They are used for traditional medicines and as a cooking aid in some recipes. The young leaves are used in traditional medicine and for lancing boils, making fans, decoration, and pig feed.

Throughout the atoll island countries of the central/northern Pacific, the fleshy keys of the fruits of many traditionally selected, named, and cultivated varieties are consumed fresh or made into various preserved foods. The fruits are also consumed in Solomon Islands and Papua New Guinea. In Polynesia the fragrant, ornamental fruits of different varieties are strung into leis or garlands and used to make perfume. The fibrous, dried, mature drupes are used as paint brushes for painting tapa, for fuel, compost, and as fishing line floats. In Kiribati the fruit may also be used as bait for catching lobster. The fragrant male flowers are used to scent coconut oil, perfume tapa cloth, and make garlands.

Left: A village leader in Mand Village, Pohnpei, displays an open bunch of the cultivar 'Aspwihrek', prized among Pingelapese for its edible fruit. PHOTO: A. LEVENDUSKY. **Right: A key of the edible cultivar 'Enewedak' is happily held by a boy in the Pingelapese village of Mand, Pohnpei.** PHOTO: L. ENGLBERGER

Staple food

Keys of the edible cultivar 'Enewedak'. PHOTO: L. ENGLBERGER

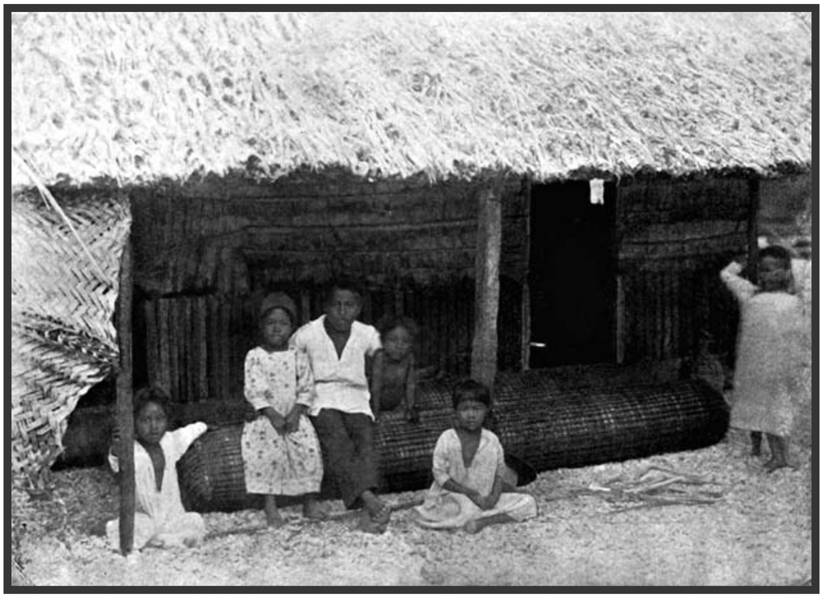
Pandanus fruits are a staple food in parts of Micronesia including the Marshall Islands, Federated States of Micronesia, and Kiribati providing up to 50% of energy intake (Miller et al. 1956, Englberger et al. 2003). They are also widely consumed on Tokelau and Tuvalu (Englberger 2003). In some places the consumption of pandanus has decreased in recent decades due to the availability of imported foods; e.g., pandanus was formerly a major staple food in Nauru (Kayser 2002). In Micronesia adults may commonly consume 20 fresh keys or about 1 kg (2.2 lb) of fruit per day. The fruit pulp is preserved in several different ways. A paste, which is compared to dates in taste, texture, and appearance, is made by boiling and baking the keys, followed by extracting, processing, and drying the pulp. Cultivars with large amounts of pulp are preferred, and the taste differs among cultivars. On average, 100 g pandanus paste provides 321 kilocalories, 2.2 g protein, 134 mg calcium, 108 mg phosphorus, 5.7 mg iron, 0.04 mg thiamin, 2 mg vitamin C (Murai et al. 1958, Miller et al. 1956, Dignan et al. 1994) and from 390 to 724 μg/100 g beta-carotene (a carotenoid that is a precursor to vitamin A), depending on variety and coloration (Englberger et al. 2006a and 2006b). Fresh pandanus is an important source of vitamin C. Preserved pandanus pulp mixed with coconut cream makes a tasty, sweet food item. Pandanus can also be made into flour that is consumed in different ways, usually prepared as a drink.

Fruit

The keys of selected edible cultivated varieties, those with low amounts of calcium oxalate crystals, are consumed raw or cooked. Juice and jam may also be prepared from the fruit. In parts of Micronesia, chewing pandanus keys is usually done outside of meal times and is a pleasurable, highly social activity. Adults may typically consume 20–50 keys daily during the main fruiting seasons (Englberger et al. 2003).

A 100 g portion of edible pericarp is mainly comprised of water (80 g) and carbohydrates (17 g). There are also significant levels of beta-carotene (19 to 19,000 μg) and vitamin C (5 mg), and small amounts of protein (1.3 mg), fat (0.7 mg), and fiber (3.5 g) (Dignan et al. 2004, Englberger et al. 2003, Englberger et al. 2006a and 2006b). The edible flesh of deeper yellow- and orange-colored varieties

Left: Drying pandanus fruit paste in the sun, Kiribati. PHOTO: L. THOMSON **Right: Roll of preserved fruit paste , as traditionally packaged in pandanus leaves, Marshall Islands.** PHOTO: L. ENGLBERGER



This photograph, taken around 1897, shows the huge size of preserved pandanus rolls as presented to the chiefs in the Marshall Islands. SOURCE: KRAEMER 1906

contain higher provitamin A carotenoid levels. The fruit of these varieties has considerable potential for alleviating vitamin A deficiency in Micronesia (Englberger et al. 2003). As carotenoid-rich food may protect against diabetes, heart disease, and cancer, the consumption of pandanus may also alleviate these serious emerging problems of the Pacific. Pandanus fruit is also a useful source of vitamin C (ascorbic acid), thiamine, riboflavin, and niacin (vitamin B-3) (Murai et al. 1958, Miller et al. 1956).

The fruit of wild forms of pandanus contains oxalate crystals that irritate the mouth unless broken down by cooking. The ripe fruit of wild forms may be consumed following cooking and straining the pericarp, but they are not especially palatable or sweet.

Nut/seed

The small seeds of a few varieties of *P. tectorius* are eaten. A similar species, *P. dubius*, has larger seeds that are eaten.

Beverage/drink/tea

Juice pressed from the fruits is sweet and slightly acid with a pungent flavor (Miller et al. 1956). It is being produced commercially in the Marshall Islands.

Medicinal

Pandanus is a very important medicinal plant, with certain varieties sometimes preferred for particular treatments. Leaves, especially the basal white section of young leaves, and roots are used. In Kiribati, pandanus leaves are used in treatments for cold/flu, hepatitis, dysuria, asthma, boils, and cancer, while the roots are used in a decoction to treat hemorrhoids. In Hawai‘i the main parts used in making traditional medicines are the fruits, male flowers, and aerial roots (Meilleur et al. 1997). These are used individually or in combination with other ingredients to treat a wide range of illnesses, including digestive and respiratory disorders. The root is used in Palau to make a drink that alleviates stomach cramps, and the leaves are used to alleviate vomiting (Del Rosario and Esguerra 2003). The root is also known for its use in traditional medicine in Pohnpei (Adam et al. 2003).

Animal fodder

Leaves, particularly young leaves, are recorded as providing fodder for domestic animals such as pigs and horses.

Masticant/stimulant

Male pandanus flowers have been credited with aphrodisiac properties in Marshall Islands.

Beautiful/fragrant flowers

The highly fragrant male flowers are widely used for decoration.

Timber

The stems are used in house construction and also for making ladders, especially on atoll islands. Male trees have hard, solid trunks with a yellow interior containing dark brown fiber bundles. The male wood is very strong, but brittle, meaning that it can suddenly break under a heavy load. It is also a difficult wood to split. Trunks of female trees are hard on the outside, but soft, pithy, or juicy in the interior (Little and Skolmen 1989). Slats made from the clean, dried aerial/prop roots are used for walls of houses and food cupboards.

Fuelwood

In the northern Pacific, the discarded, dried keys are highly prized as fuelwood for cooking because they are slow burning and therefore preferred for barbecues. The trunk and branches are occasionally used as fuelwood where other fuelwood is scarce, such as on atolls.

Craft wood/tools

The wood has many craft uses, such as headrests/pillows, vases, and as an aid for string making and extracting coconut cream. It was formerly used to make weapons (lances and batons). When the flesh is removed from the inner end of a dried key, fibrous bristles are exposed. The bristle

Harvesting of leaves for thatch on building structures. Misi-misi variety, Wainidoi, Fiji. PHOTO: L. THOMSON

end can be used as a brush for decorating tapa, with the hard, woody outer end acting as a handle. Fish traps are made out of the aerial roots in Kiribati.

Canoe/boat/raft making

The trunk of one variety in the Marshall Islands is used to make the masts of traditional canoes. In Hawai'i pandanus leaves were the traditionally main material for making canoe sails (Meilleur et al. 1997).

Fiber/weaving/clothing

In many Pacific countries pandanus leaves are used to weave traditional items of attire, including mats for wearing around the waist in Tonga, as well as hats and various types of baskets.

Rope/cordage/string

The roots are made into skipping ropes and basket handles. String or cordage is made from the cleaned and dried prop roots.

Wrapping/parcelization

The leaves are used to wrap tobacco/cigarettes in Micronesia.

Thatch/roofing/mats

Pandanus leaves are used to weave traditional floor mats in many Pacific countries, as well as in the construction of traditional houses (thatch for walls and roofing). A roof made from pandanus leaves is said to last about 15 years, while one of coconut leaves may last only 3 years (Little and Skolmen 1989).

Resin/gum/glue/latex

The trunk is a source of glue or caulking for canoes.

Body ornamentation/garlands

Leaves, often neatly cut, fragrant fruits, and flowers are used in making garlands or leis.

Tannin/dye

A black dye used in weaving is prepared from the roots in Kiribati. Charcoal from pandanus was used in various mixtures to dye and waterproof canoes; the beaten aerial root tips were used to apply the mixtures.

Top: Thatch wall. Bottom: House side panel made of pandanus slats. PHOTOS: L. THOMSON

Left: Colorful phalanges are often used in personal adornment, such as here in Cook Islands. PHOTO: L. THOMSON **Top right: A local expert teaches pandanus leaf weaving, Kealakekua, Hawai'i.** PHOTO: C. ELEVITCH **Bottom right: Children in the Pingelapese village of Mand in Pohnpei enjoy the shade of a pandanus tree bearing edible fruit.** PHOTO: L. ENGLBERGER

Cosmetic/soap/perfume

Male flowers picked from uncultivated pandanus are used alone or in combination with other flowers to perfume coconut oil in Polynesia. An exquisite, uniquely Pacific perfume is made from the aromatic fruits of selected traditional cultivated varieties in the Cook Islands. In South and Southeast Asia, the male flowers and preparations derived from them are used to scent clothes and incorporated into cosmetics, soaps, hair oils, and incense sticks. In Hawai'i, the male flowers were used to scent tapa.

Ceremonial/religious importance

Pandanus is sometimes considered to have supernatural and magical properties in parts of Micronesia and Hawai'i. In Kiribati it may be used as a ceremonial food, while in Indonesia the male flowers are used in ceremonies.

Other

In Kiribati and the Marshall Islands the leaves are formed into a ball for use in a kicking game. The trunks of female trees are hard on the outside but soft or juicy in the interior. The female trunks have been used as water pipes after removing the soft interior (Little and Skolmen 1989).

URBAN AND COMMUNITY FORESTRY

Pandanus has a striking appearance and is very suitable for planting in urban areas. As an ornamental, pandanus is as characteristic of the lowland tropics as coconut but does not have coconut's dangerous large falling fruits and fronds. The tree is salt, wind, and drought tolerant, and requires little care.

Size in an urban environment

Pandanus typically reaches 6–9 m (20–30 ft) in height with a similar canopy spread in urban areas. The rigid prop roots may extend out 1 m (3.3 ft) or more from the main trunk, and aerial roots off branches often dangle from further out.

Rate of growth in a landscape

The growth of seedlings is slow to moderate, 2–80 cm/yr (1–32 in/yr) in height. Trees grown from branch cuttings grow faster, about 50–80 cm/yr (20–32 in/yr).

Root system

The subterranean root system is concentrated in the surface soil layers. Apart from the aerial and prop roots, the tree's root system is unlikely to interfere with maintenance or recreational activities, lawns, or structures such as sidewalks or foundations.

Products commonly used in a Pacific island household

The pliable, strong, durable leaves are used throughout the Pacific for plaited mats, baskets, and other domestic wares. The ripe and fragrant fruit segments are used for personal adornment (e.g., in leis) and are consumed as a staple food in certain areas. Plant parts were used medicinally for thrush and other childhood diseases, chest pain, and difficult childbirth (Krauss 2001) (see "Medicinal" above).

Light requirements

Plants grow well in full sun and also will thrive in 30–50% shade.

Water/soil requirements

It grows best in well drained soils; however, it can tolerate a wide variety of substrates, including coral sand, young lava flows, and peaty swamps. Pandanus can grow in areas with up to 6 months of drought, although it typically grows in

Left: Variegated plant, Hoʻomaluhia Botanical Garden, Kaneohe, Hawaiʻi. Right: Growing in mixed garden together with citrus and breadfruit (*Artocarpus altilis*) at 460 m (1500 ft) elevation, Kona, Hawaiʻi. PHOTOS: C. ELEVITCH areas with less than 3 months of dry weather. It thrives in areas where groundwater is near to the surface.

Life span

The tree typically lives 20–80 years and can live over 100 years. Individual trees selected for desirable qualities can be vegetatively propagated to extend their lives indefinitely. In some atoll environments the productive fruiting life of cultivars may be only 20–25 years, and regular replanting is needed to maintain good yields of larger fruits.

Varieties favored for use in homegardens or public areas

Numerous local varieties are found throughout the Pacific, where they are propagated from stem cuttings in order to keep them true to type. A sought-after variety for weaving is *P. tectorius* var. *laevis*, which has leaves that are free of prickles along the edges and midrib. Possibly hundreds of locally named varieties have been selected for edible fruits. For ornamental use, striking variegated cultivated forms exist, such as 'Baptistii', which has 1–4 white or yellow stripes a long the middle of the leaves, and 'Veitchii', which has lengthwise stripes along the edges of the leaves.

Seasonality of leaf flush, flowering, fruiting

Vegetative growth occurs year-round. It is likely that male trees flower once a year, while female trees flower heavily every second year. However, both male and female plants may be flowering during the off-season any time of year. It takes fruits several months to ripen.

Exceptional ornamental values

Pandanus presents a bold image in the landscape with its spirally arranged leaves, prop roots, widely forking branches, and smooth trunk and branches. The bark is covered with leaf scars that give a ring-like pattern. The tree is often used singly or in small groups as an accent tree in lawns or mixed gardens. Both female and male flowers are visually striking, and the male flowers are very fragrant.

Use as living fence, hedge or visual/noise barrier

Grown close together, young plants form a barrier of intertwined, prickly leaves. As the trees grow older and trunks form, the usually prickly prop roots can take over as a form of physical barrier in a dense planting.

Birds/wildlife

Pandanus is used as a nesting tree for certain birds, including seabirds such as noddy terns.

Different fruit types. Top: 'Antinakarewe' (Kiribati). Middle: Unnamed variety (Kiribati). Bottom: 'Fala'hola' (Tonga). PHOTOS: L. THOMSON

Fruit color variations recognized by Hawaiian lei makers (adapted from MacDonald and Weissich 2003)

- hala—the common yellow to red fruit segments
- hala ʻikoi—lemon color at base, bright orange in outer half
- hala lihilihiʻula—bright yellow at base, changing to bright orange-red on the outer part of the fruit segment
- hala melemele—bright yellow fruit segments
- hala pia—small, canary-yellow fruit segments prized for leis and medicinal purposes
- hala ʻula—Entire fruit segments red-orange

Maintenance requirements

The tree requires little maintenance aside from removing the fallen leaves and fruits. Although the tree grows on nutrient-poor soils, moderate fertilizer or compost applications are beneficial. Surface mulching around the tree adds nutrients to the soil while helping to retain soil moisture and reducing erosion. Pandanus tends to regrow poorly or not regrow at all after heavy pruning. However, for larger trees with many branches, a small number of branches may be pruned off without undue harm to the tree.

Special considerations regarding leaf, branch, and fruit drop

Year-round drop of the long, prickly leaves can be a nuisance in public areas or gardens and will require regular clean-up in frequented locations. The large fruit segments fall from female trees and can be unsightly. If not removed, the scattered fruit segments will attract fruit flies and rats.

Nuisance issues

Dead leaves that accumulate in the branch crowns can be used by rats to build nests.

Hazards

The prickly leaves and aerial roots could be a hazard in public areas where people might rub against them.

Common pest problems

Mealybugs and scale insects are minor, occasional pests, both of which can be controlled with insecticidal soap or oil. Other pests include ants and whiteflies.

Other comments about this species in urban environments

Trees can be grown in containers in smaller garden areas or on terraces, although their usually spiny leaves make this problematic in small spaces.

COMMERCIAL PRODUCTS

The main commercial products from pandanus are woven products, often of high value; e.g., individual mats may be worth more than US$500 in Tonga, Fiji, and Hawaiʻi. In Tonga mats made from thin strips of leaves with intricate designs (fala) are important gifts and indicators of wealth. Simpler designs using wider strips (lotaha and papa) are used as everyday floor mats. Taʻovala mats are worn around the waist (Evans 2003). In the Haʻapai group, 80% of women are involved in handicraft production, mainly using pandanus and some paper mulberry (*Broussonetia papyrifera*). Most traditional handicrafts made from pandanus are produced for home use, as gifts, or are informally exchanged for other products, including other handicrafts. Because the commodities are locally produced, non-perishable, and can be processed a number of ways, there is a wide range of opportunities for producers and processors to enter into the handicraft marketing chain at any stage. Pandanus is an important income generating plant in Haʻapai (Thaman et al. 1997, Tupoulahi-Fusimalohi 1999), and the islands are well known as a producer of all types of mats known as fakahaʻapai and salusalu (Ika 1996). In Tonga, producers and sellers report that prices of pandanus products are relatively stable, indicating that supply is matching demand.

In the atoll islands of the central Pacific, the fruits are often sold fresh in local markets, and preserved food items are occasionally sold.

Spacing

In Tonga most farmers grow some pandanus (Evans 2003). Pandanus may be either grown in lines, especially borders, with 3–5 m (10–16 ft) between plants, or less commonly in block plantings at a spacing of about 5 x 5 m (16 x 16 ft). Plantations usually consist of a rather small number of plants, e.g., 20–100, as most of the leaves are used for weaving by family members and/or the limited land is needed for cultivating food crops.

Management objectives

Plantations need to be kept well weeded both for maintaining good growth and for access purposes when harvesting leaves or fruits.

PROCESSING LEAVES FOR WEAVING

Plant from which leaves have been harvested. Paongo variety (syn. *P. whitmeeanus*), Vava'u, Tonga. PHOTO: L. THOMSON

Drying leaves. Ha'apai, Tonga. PHOTO: L. THOMSON

Soaking leaves in sea water. Kie variety (syn. *P. spurious*), Ha'apai, Tonga. PHOTO: L. THOMSON

Weaving of mat, Butaritari, Kiribati. PHOTO: L. THOMSON

Advantages and disadvantages of growing in polycultures

Pandanus is well suited to growing in polycultures, because of its low stature and tolerance of variable light levels. It has excellent windbreak function in more exposed sites near the coast.

Yields

The main products from pandanus (depending on variety) are:

Leaves (for mats, handicrafts, traditional huts)

Harvesting of leaves usually begins at about 3 years of age. Leaves can be harvested every 3 months for a period of 5–10 years, but leaf size and accessibility for harvesting diminishes over time. Outside the Pacific islands, leaves have reportedly been harvested from much older specimens, e.g., 50–60-year-old trees. Published information on yields is limited. Mature, healthy plants in full production are likely to yield about 10–90 leaves per year on less fertile sites and 150–300 leaves per year on optimal sites.

Stems (for building/construction)

Larger stems for building poles and construction take about 15–20 years to develop.

Fruits (for human consumption and perfume)

Sexually mature plants produce about 8–12 fruits per plant every second year. The total weight of individual fruits for edible varieties varies from about 7 to 15 kg (15–33 lb). There are typically 35–80 phalanges per fruit in edible varieties, and the weight of the edible portion is from 30–75 (–100) g (1–2.7 [3.6] oz) per phalange.

Male flowers (for garlands)

Sexually mature plants typically produce 10–40 male flower spikes (about 1.5–5 kg [3.3–11 lb]) per plant each year. The potential yield of these products on a per-hectare basis depends on planting density. Density in native stands varies widely; typical planting density for final crop spacing is about 100–500 stems per ha (40–200 stems/ac).

On-farm processing

Pandanus leaves need to be dried and wrapped into bundles prior to sale in local markets. Certain varieties may need to be bleached in seawater, e.g., the kie variety (syn. *P. spurious*), for production of fine white mats in Tonga.

Markets

There is strong local and overseas demand (including by tourists) for woven pandanus handicraft products from the Pacific islands. These include beautifully crafted and expensive items such as fine white mats and hats from the Cook Islands and Tonga, respectively. Preserved pandanus paste (mokwan and te tuae) is marketed in the Marshall Islands and Kiribati, presented both in the traditional manner (wrapped in pandanus and tied tightly with coconut cord) and in plastic.

INTERPLANTING/FARM APPLICATIONS

Example system 1 (Thaman 1978)

Location

Tonga

Description

Pandanus trees, mainly the variety 'Paongo' for weaving, are planted along roadside borders of yam (*Dioscorea alata*) gardens. These are often cooperative or communal yam gardens, known as toutu'u ufi. These gardens are planted in yams, then interplanted with giant swamp taro (*Cyrtosperma chamissonis*), plantains (*Musa* spp., often including 'Maia Maoli/Popoulu', Pacific plantain), and sometimes taro (*Colocasia esculenta*). In the past, bunching onion, corn, and even cabbage were also planted among the yam mounds. Pandanus is grown along the fence line and serves not only as a boundary marker and living fence but also as an important cultural resource. After the yams are harvested, possible succeeding crops include cocoyam (*Xanthosoma* spp.), sweetpotato, and cassava. Sometimes paper mulberry is planted after the yam or succeeding crop.

Example system 2

Location

Kiribati

Description

In Kiribati edible pandanus is often seen planted around giant swamp taro pits. Other trees planted or protected nearby include coconut, breadfruit, and papaya. There are also trees that are important as sources of leaf mulch, such as beach heliotrope (*Tournefortia argentea*), *Guettarda speciosa*, and beach hibiscus (*Hibiscus tiliaceus*). In addition to being used as mulch, the leaves of pandanus are woven into baskets around the bases of the largest ceremonial giant swamp taro plants into which fertilizer is placed.

PUBLIC ASSISTANCE AND AGROFORESTRY EXTENSION

Extension offices for agroforestry and forestry in the Pacific: <http://www.traditionaltree.org/extension.html>.

GENETIC RESOURCES WHERE COLLECTIONS EXIST

In Kiribati, the Division of Agriculture (Ministry of Environment, Lands and Agricultural Development), with support from SPC/FAO/SPRIG/USP, has established a field gene bank of traditional *Pandanus tectorius* varieties. The gene bank is located in Bikenibeu South, South Tarawa, and included more than 60 varieties in 2003. It is strongly recommended that other Pacific island nations undertake similar programs to conserve pandanus diversity and the underlying cultural knowledge that has fostered and maintained this diversity. The National Tropical Botanical Garden maintains a modest collection of *Pandanus* species and cultivars at its Allerton and McBryde Gardens on Kaua'i, Hawai'i. A small genebank of nine varieties of pandanus from Pohnpei atolls have been planted at the Pilot Farm collection in Pohnpei, FSM. A list of morphological descriptors has been developed by the SPRIG project.

INTERNET

Access to selected papers and color photographs: <http://www.islandfood.org>.

Top: Boundary planting of pandanus around mixed agroforest, Tongatapu, Tonga. PHOTO: C. ELEVITCH **Bottom: Woven basket of pandanus leaves in which fertilizer and mulch is placed around the bases of the largest ceremonial giant swamp taro plants.** PHOTO: R. THAMAN

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Species Profiles for Pacific Island Agroforestry (www.traditionaltree.org)

Pandanus tectorius (pandanus)

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Acknowledgments: The authors and publisher thank Alfred Capelle, Dale Evans, Heidi Johansen, Kana'e Keawe, David Lorence, Brien Meilleur, Diane Ragone, and Nancy vander Velde for their input. A photo contribution from Amy Levendusky is greatly appreciated.

Recommended citation: Thomson, L.A.J., L. Englberger, L. Guarino, R.R. Thaman, and C. Elevitch. 2006. *Pandanus tectorius* (pandanus), ver. 1.1. In: C.R. Elevitch (ed.). Species Profiles for Pacific Island Agroforestry. Permanent Agriculture Resources (PAR), Hōlualoa, Hawai'i. <http://www.traditionaltree.org>.

Sponsors: Publication was made possible by generous support of the United States Department of Agriculture Western Region Sustainable Agriculture Research and Education (USDA-WSARE) Program; SPC/GTZ Pacific-German Regional Forestry Project; USDA Natural Resources Conservation Service (USDA NRCS); Kaulunani, an Urban Forestry Program of the DLNR Division of Forestry and Wildlife and the USDA Forest Service; State of Hawai'i Department of Land & Natural Resources Division of Forestry & Wildlife; USDA Forest Service Forest Lands Enhancement Program; and Muriel and Kent Lighter. This material is based upon work supported by the Cooperative State Research, Education, and Extension Service, U.S. Department of Agriculture, and Agricultural Experiment Station, Utah State University, under Cooperative Agreement 2002-47001-01327.

Series editor: Craig R. Elevitch

Publisher: Permanent Agriculture Resources (PAR), P.O. Box 428, Hōlualoa, Hawai'i 96725, USA; Tel: 808-324-4427; Fax: 808-324-4129; E-mail: par@agroforestry.net; Web: http://www.agroforestry.net. This institution is an equal opportunity provider.

April 2006
ver. 2.1

Pometia pinnata (tava)

Sapindaceae (soapberry family)

***dawa*, *tawa* (Fiji); *kava* (French Polynesia); *kava*, *tava* (Samoa); *igi, ako, dawa*, *tauna* (Solomon Islands); *nandao* (Vanuatu); *lychee sauvage*, *le pomet* (*pometier*), *bois de pieu* (French); oceanic lychee, island lychee (English); *taun* (PNG); *tava* (Cook Islands, Niue, Tonga, 'Uvea and Futuna)**

Lex A. J. Thomson and Randolph R. Thaman

IN BRIEF

Distribution Has a wide natural distribution in the Asia-Pacific region.

Size Varies greatly, from a small to very large tree, typically 12–20 m (39–66 ft) tall with a canopy diameter of about 10–20 m (33–66 ft).

Habitat Grows naturally in warm to hot, humid subtropical and tropical zones, elevation 0–500 (–1700) m (0–1640 [–5580] ft) with annual rainfall of 1500–5000 mm (60–200 in).

Vegetation Occurs mainly in evergreen or shortly deciduous, lowland, closed forest and secondary forest.

Soils Grows on a wide range of soils with best growth on slightly acidic to neutral (pH 5–8), well drained, fertile loams and clays.

Growth rate Grows rapidly, typically 1–2 m (3.3–6.6 ft) per year.

Main agroforestry uses Mulch, improved fallows, homegardens.

Main products Timber, fruit.

Yields Timber: 5–10 m^3/ha/yr (72–144 ft^3/ac/yr). Fruit: 2–8 mt/ha/yr (0.9–3.6 t/ac/yr).

Intercropping Mixed food gardens.

Invasive potential Considered to have a low invasive potential.

PHOTO: C. ELEVITCH

Tava growing in a Tongan village.

INTRODUCTION

Tava (*Pometia pinnata*) is a small to very large tree up to 50 m (164 ft) in height. It is found occurring naturally from Sri Lanka and the Andaman Islands through Southeast Asia, with extensions into southern China, Vietnam, Malesia, and the South Pacific as far east as Samoa, Tonga, and Niue. It is possibly an aboriginal introduction into some of the more eastern parts of its range in Polynesia, and probably a post-European-contact introduction into the Cook Islands and French Polynesia. It occurs in a wide variety of habitats and soils and vegetation associations. In Papua New Guinea (PNG) and some parts of the Pacific islands it may become a dominant vegetation component, being the most abundant tree and sometimes with a canopy emergent over other forest tree species. In Fiji and Tonga it is rarely found in undisturbed primary forest and is considered mainly a planted or cultivated species, i.e., where naturalized it is found only in secondary forests. However, in Samoa, where the fruits are not traditionally eaten by humans, it is common in late successional and closed rainforests and is unlikely to have been introduced.

In some lowland parts of PNG it is planted to supply leaves that are dried and used as a nutrient-rich mulch for yam cultivation. It is also planted around villages and planted or protected in garden areas in other parts of the South Pacific, mainly for the purpose of providing fruit, medicine, and firewood. Tava is considered one of the most promising trees for replanting in Samoa, both for commercial and ecological reasons. It is also recommended for protection and replanting in Melanesia (Fiji, Papua New Guinea, Solomon Islands, and Vanuatu) and Tonga because of its wide cultural utility and amenability to pruning and pollarding. Families living in many Pacific island environments would benefit from having at least one planted tree of a selected form of tava to provide fruit and other products.

Selection and breeding work may be needed to identify and propagate trees combining desirable timber characteristics (good bole form and timber properties) and fruit quality, in order to encourage development and enhance the economic viability of larger-scale commercial plantings.

DISTRIBUTION

Native range

Tava has a wide natural distribution in the Asia-Pacific region mainly in lowland subtropical and tropical areas from about 14°N to 20°S. The species is native to:

Borneo Sarawak, Sabah, Brunei, and Kalimantan) (forma *acuminata*, f. *glabra*, and f. *alnifolia*, plus two other paramorphs)

Eastern Indonesia Sumbawa, Timor, Wetar (forma *cuspidata*), and Tanimbar Islands (f. *cuspidata* and f. *pinnata*)

India Andaman Islands (probably f. *glabra* and f. *tomentosa*)

Laos

Papua New Guinea (f. *pinnata*, f. *glabra*, and f. *repanda*)

Peninsula Malaysia/Indonesia Simalur and Sumatra (f. *glabra*, f. *alnifolia*, f. *macrocarpa*); Indonesia, Java (f. *glabra* and f. *tomentosa*)

Philippines/Indonesia Sulawesi and Moluccas, Aru Islands, Irian Jaya

South China Yunnan Province (probably f. *tomentosa*)

South Pacific Solomon Islands, Vanuatu, Fiji, Tonga, Wallis and Futuna, Samoa, and Niue (f. *pinnata*)

Southern Thailand (rare, probably f. *glabra* and f. *alnifolia*)

Sri Lanka (f. *tomentosa*)

Taiwan

Vietnam (f. *tomentosa*)

Current distribution

In addition to its native habitats, tava is present as a modern introduction into New Caledonia, the North Pacific (including Yap, Federated States of Micronesia, and Hawai'i) and eastern Polynesia, including French Polynesia (Marquesas and Tuamotus) and the Cook Islands.

BOTANICAL DESCRIPTION

Preferred scientific name

Pometia pinnata J. R. Forst. & G. Forst

Family

Sapindaceae (soapberry family)

Subfamily

Nephelieae (tribe)

Non-preferred scientific names

Aporetica pinnata DC.
Dabanus acuminatus Kuntze
Dabanus pinnatus Kuntze
Eccremanthus eximius Thwaites
Euphoria pinnata Poir.
Irina alnifolia Blume
Irina diplocardia Blume
Irina glabra Blume
Irina tomentosa Blume

Nephelium acuminatum Hook. f.
Nephelium diplocardia F. v. M.
Nephelium eximium Thw.
Nephelium pinnatum Cambess.
Pometia acuminata Hook. f.
Pometia alnifolia Blume
Pometia annamica Gagn.
Pometia coriacea Radlk.
Pometia glabra Blume
Pometia glabra Tesman & Binn.
Pometia gracilis King
Pometia macrocarpa Kurz.
Pometia tomentosa Blume

Common names

Pan-Pacific

oceanic lychee, island lychee (English)
lychee sauvage, *le pomet* (*pometier*), *bois de pieu* (French)

Papua New Guinea (PNG)

taun (PNG Standard trade name, Pidgin), *ohabu* (Vailala), *koiawo* (Buna), *dame* (Evara), *okamu* (Motu), *bas* (Waria), *cuhinh* (Yabim), *Tze* (Yalu)

Irian Jaya

kalasina, *kablauw*, i*wa* (Sentani language)

Solomon Islands

tauna, *igi*, *ako*, *dawa* (Kwara'ae language), *nyia tava* (Ayiwo), *tava* (Vaiakau), *nodae* (Graciosa Bay), *gema* (Roviana), *mede* (Marovo), *piraka taba* (Varisi), *taoa* (Nginia), *tao* (Lengu), *awa* (Santa Ana)

Vanuatu

nandao (Bislama language), *netowe*, *tewen*, *tien*, *wuten* (Banks Group), *ndalawa*, *n'dalaoa* (Maewo), *jaria*, *jariea*, *ah*, *jarie*, *ha*, *kao*, *nsai*, *n'seire*, *jarie*, *ndao* (Santo), *vujarie*, *vujaria* (Malo), *rao* (Ambrym), *nendre*, *dra*, *nendo*, *nendro* (Malekula), *burklata* (Epi), *dau* (Erromango), *nandem* (Tanna), *tava* (Aniwa), *tava*, *dava*, *ndava*, *netva* (Aneityum), with many folk varieties also given local names on different islands

Fiji

dawa, *tawa* (with folk varieties including *dawa dawa*, *dawa moli*, *dawa sere*)

PolynesiaTonga

t*ava* (varieties include *tava kula*, *tava moli*, *tava toua*) (Tonga)
kava, *tava* (Samoa)
tava (Niue and Cook Islands)
kava (French Polynesia)

Size

Tava is a small to large tree, typically 12–20 m (39–66 ft) in height and 10–20 m (33–66 ft) in canopy diameter. The largest specimens reach 50 m (165 ft) in height and 1.4 m (4.5 ft) in diameter above buttresses.

Form

Variable, from stout trees with short twisted or fluted boles

Large tree with huge buttresses, 'Upolu, Samoa. PHOTO: C. ELEVITCH to slender, rather straight trees. Prominent buttresses are formed on older trees to about 1.5–3 (–5) m (5–10 [–16] ft).

Flowers

The floral inflorescences are highly variable. They include clusters of terminal, sub-terminal, or rarely axillary panicles, conspicuously projecting beyond the foliage, from stiff to hanging, 15–70 cm (6–28 in) long main branches, simple or with secondary branching. Panicle branches are sometimes subtended by auricle-like, densely to sparsely hairy or glabrescent leaflets. The species is monoecious, with unisexual male and female flowers on the same tree and within the same panicle. Female flowers may appear bisexual, but the anthers are reduced and sterile. Male flowers open first and greatly outnumber female flowers. The flowers are actinomorphic and 5-parted, calyx dish shaped to shallowly cup-shaped, 2–3 mm (ca. 0.1 in) in diameter with five short lobes and without any scent. Petals are small and regular, whitish to yellow-green, highly variable in shape, shorter or longer than calyx. Disk is annular, 1–1.5 mm (0.04–0.06 in) wide by 0.5 mm (0.02 in) high. Filaments are whitish, 3–6 mm (0.12–0.24 in), in the female flowers sometimes reduced to 0.5 mm (0.02 in), densely to sparsely hairy toward the base. Anthers are red or yellow, 0.7–1 mm (0.03–0.04 in) long, minutely hairy. Ovary in female flowers deeply 2-lobed (rudimentary in male flowers), densely brown-pubescent. Style is red, undivided, 1–2 mm (0.04–0.08 in) long, extending to 3–6 mm (0.12–0.24 in) after anthesis.

The age to first flowering and fruiting is not well documented and possibly varies among forms and genotypes. Fruits mature about 3–4 months after flowering.

The flowering times vary regionally and may occur more than once per year. In Fiji flowering occurs in December–March, while in Samoa flowering has been recorded in February–March, June–July, and October–November. In PNG flowering has been recorded throughout the year with peak flowering between January and April.

Leaves

The leaves are paripinnate, the rachis up to 1 m (3.3 ft) long, or rarely longer, with 4–8 (–13) subopposite pairs of sub-sessile leaflets. Leaflets are firmly herbaceous to coriaceous, asymmetrical to symmetrical, variably shaped (oblong/lanceolate/ovate), the first pair mostly suborbicular to elliptic, ≤ 3 cm (1.2 in) long, and often clasping the branch like stipules, leaflet tip subacuminate to acuminate with a tip up to 1.5 cm (0.6 in). The largest leaflets average 12–30 cm (5–12 in) long by 4–10 cm (1.6–4 in) wide. The midrib is flat above with a narrow keel that is triangular in section. Leaflet nervation is highly distinctive, comprising 11–25 pairs of parallel nerves at an angle of about 60° with the midrib, with every second nerve ending in a marginal tooth, and the in-between nerves bending upwards without reaching the margin. The leaflet margin is about 3 mm (0.12 in) deep, dentate or repand to subentire. Leaf surfaces are generally glabrous; however, juvenile leaves, including suckers, are densely covered in brownish hairs. The juvenile leaves are

Top: New leaf flush; Bottom: Fruits and leaves. PHOTOS: L. THOMSON large, thin, and initially brightly colored (pink to red).

Fruit

The fruits are highly variable, indehiscent (not splitting), round to elliptical, sometimes paired, and often with one or more vestigial ovary lobes at the base, 1.5–5 cm (0.6–2 in) long by 1–4.5 cm (0.4–1.8 in) diameter, the skin or pericarp smooth and variously colored (greenish-yellow, yellow, red, purple, blackish or brown) with a gelatinous, sweet, white to slightly pinkish, translucent pulp (mesocarp) partially encasing a single large seed. Age to first flowering and fruiting is not well documented and possibly varies considerably. In Lae, PNG a large-fruiting form bore fruit only 5 years after planting, but usually the first fruit crops on well managed trees appear at an age of about 8–10 years. In the South Pacific the fruiting season varies by locality and from year to year, e.g., the main season in the Santa Cruz Islands of SE Solomon Islands is November–January (main season), while the main season in Fiji and Tonga is February–March (but fruiting may occur from January to April in Fiji). In Samoa fruiting has been recorded in the months of March, August, and November.

Seeds

The seeds are large, to 2.5 cm long by 1.5 cm across (1 x 0.6 in), flattened and rounded on the ends, and brown. There are 300–500 seeds/kg (140–230 seeds/lb). Fruits are mainly dispersed by fruit bats (*Pteropinae*), birds, including pigeons in Samoa, and humans. Water dispersal is also likely in riverine populations.

Rooting habit

The species appears to have a strong lateral rooting system, with large lateral roots extending out from buttress flanges.

Similar species

The most detailed and recent taxonomic review of *Pometia* (Jacobs 1962) recognizes only two species, *P. pinnata* Forst. and *P. ridleyi* King emend. Radlk. *P. ridleyi* exists as a small homogenous population in Sumatra (Indonesia) and Malaysia, whereas *P. pinnata* is a highly variable entity with a wide natural range in the Asia-Pacific region.

GENETICS

Variability of species

There is considerable variation in all plant parts of tava, with the most taxonomically useful characters being the leaves and inflorescences. Floral parts may vary in shape, size, and proportions on otherwise identical plants. Tava fruits show considerable variation, but there are insufficient specimens with mature fruits to properly evaluate its taxonomic utility. Furthermore, tava fruits have been subject to varying levels of human selection that complicates their utility for taxonomic purposes.

Known varieties

There has been considerable confusion concerning the taxonomy of tava due to its complex and seemingly bewildering variation patterns that cannot be satisfactorily accounted for by conventional taxonomic categories (Whitmore 1976). The taxonomic approach adopted by Jacobs (1962) recognized eight distinct forms, plus a number of less distinct "paramorphs," leaving a residue of polymorphic, unclassified material. According to Jacobs, tava exists in at least three distinctive forms in New Guinea namely, f. *pinnata*, f. *glabra*, and f. *repanda* (possibly representing different taxa). The type form *pinnata* is the most important for timber production, although this form has often been referred to in PNG as *P. tomentosa*, an entity that does not occur east of Java, Indonesia (and east of Wallace's line). In this treatment the focus will be on forma *pinnata*, the only form present in the Pacific islands, and the one with most potential for production of both fruit and timber.

On the basis of inflorescence and leaf characters, the eight forms that have been recognized by Jacobs (1962) are:

forma. *acuminata* (Hook. f.) Jacobs
f. *alnifolia* (Blume) Jacobs
f. *cuspidata* (Blume) Jacobs
f. *glabra* (Blume) Jacobs
f. *macrocarpa* (Kurz) Jacobs
f. *pinnata*
f. *repanda* Jacobs
f. *tomentosa* (Blume) Jacobs

Numerous traditional varieties within f. *pinnata* are recognized locally in the South Pacific mainly on the basis of fruit characters, especially size, shape, skin color, and taste/sweetness of fruits.

ASSOCIATED PLANT SPECIES

The species occurs mainly in evergreen or occasionally deciduous lowland closed forest and secondary forest associations. In most of its range it occurs at relatively low frequency in mixed forests, but it may also occur as a principal forest component; e.g., in PNG and Samoa. In New Guinea, tava is among the most common and important hardwoods of lowland and lower montane evergreen rainforest, especially on ridges and spurs. In many parts of Melanesia tava's range and frequency has been increased by human influence both through planting around villages and protection of plants during garden development. In parts of Southeast Asia, including Malaysia and Java (Indonesia), its distribution is mainly associated with watercourses and swamp forest. In Fiji it is found almost exclusively in secondary forest, in shifting agricultural lands, and planted or protected around villages. Similarly in Tonga, where very little native forest remains, it is usually found planted or protected in semi-permanent shifting agricultural lands or planted in villages.

Associated species commonly found

Associated species in native habitats in the Asia-Pacific region include *Aglaia gigantea*, *Alstonia* spp., *Artocarpus altilis*, *Calophyllum* spp., *Celtis* spp., *Chisocheton lasiocarpus*, *Cinnamomum obtusifolium*, *Cryptocarya* spp., *Cynometra* spp., *Dillenia indica*, *Diospyros* spp., *Dracontomelon dao* and *D. vitiense*, *Duabanga sonneratioides*, *Elaeocarpus* spp., *Ficus* spp., *Homalium foetidum*, *Inocarpus fagifer*, *Intsia bijuga* and *I. palembanica*, *Ixora* spp., *Koordersiodendron*, *Mastixiodendron*, *Myristica subalata*, *Neonauclea* spp., *Octomeles sumatrana*, *Palaquium* spp., *Pimeleodendron* spp., *Planchonella* spp., *Podocarpus neriifolius*, *Pterocarpus indicus*, *Pterygota* spp., *Haplolobus* spp., *Radermachera* spp., *Saraca* spp., *Schoutenia* spp., *Terminalia* spp. including *T. richii* and *T. myriocarpa*, *Teysmanniodendron* spp., and *Tristania sumatrana.*

Species commonly associated as aboriginal introduction in Pacific islands

It is grown in gardens and associated with almost all aboriginal introductions in the South Pacific.

ENVIRONMENTAL PREFERENCES AND TOLERANCES

Climate

Tava grows naturally in the warm to hot, humid, subtropical and tropical zones.

Elevation range

0–500 (–1700) m (0–1640 [–5580] ft)

Mean annual rainfall

1500–5000 mm (60–200 in)

Rainfall pattern

Grows in climates with summer, bimodal, and uniform rainfall patterns.

Dry season duration (consecutive months with <40 mm [1.6 in] rainfall)

1–3 months

Mean annual temperature

22–28°C (72–82°F)

Mean maximum temperature of hottest month

25–32°C (77–90°F)

Mean minimum temperature of coldest month

18–24°C (64–75°F)

Minimum temperature tolerated

5–16°C (41–61°F)

Soils

Tava has a wide edaphic range but attains its best development on well drained, fertile loams and clays. In PNG the commercially important better timber tree forms of f. *pinnata* are found on better drained sites, whereas the poorer formed trees of f. *glabra* mainly occur on river flats and in low-lying areas.

Soil texture

It grows in medium and heavy texture soils (loams, sandy clay loams, clay loams, sandy clays, and clays).

Soil drainage

The tree grows in soils with both free and impeded drainage, as well as in seasonally waterlogged soils.

Soil acidity

Tava grows in acid to mildly alkaline soils (pH 4.0–8.0).

Tolerances

Drought

Examination of its natural distribution suggests that the tree is sensitive to an extended dry season, i.e., longer than 3–4 months.

Full sun

Mature trees grow best in full sunlight (or light shade up to about 25%), as do younger specimens (although specimens developing in open, sunny positions are likely to have short boles).

Shade

The tree tolerates 0–50% shade. Young seedlings and saplings are tolerant of high levels of shade. Planting under existing light to mid-density canopy (<50% shade) is a suitable technique for establishing plantings of tava.

Fire

The tree is susceptible to fire.

Frost

It is likely to have little or no tolerance of frost as the entire native range is frost-free.

Waterlogging

Certain populations occur in swampy/riverine habitats and appear to have a moderately high tolerance of waterlogging.

Salt spray

It has little tolerance of saltwater spray or temporary saltwater inundation due to storm surge or tsunamis.

Wind

The species is tolerant of strong, steady winds and will develop a more stout form under such conditions. It is moderately resistant to cyclonic winds, with about 10% mortality from cyclones in the Solomon Islands in natural forest conditions.

Abilities

Regenerate rapidly

In rather undisturbed, closed forests, seedlings establish and persist with slow growth. The species regenerates by discontinuous recruitment, favored by small-scale disturbance, but not large gaps. Vine cutting is effective in liberating advanced growth of vine-smothered saplings; this has resulted in rapid regrowth and development of tava-rich forests in trials in Samoa.

Self-prune

In forest situations the species has a moderately good self-pruning ability, as frequently exhibited by the long, clear bole in mature trees. In open situations young trees tend to develop a coarse, low branching habit and often have poor self-pruning.

Coppice

Younger specimens may coppice, but coppicing of mature trees is unknown.

Pollard

Trees have been observed to regrow well following pollarding (and cyclone breakage of larger limbs). Regular cutting back or light pruning during fruit collection appears to stimulate subsequent fruiting.

GROWTH AND DEVELOPMENT

Early height growth is fast, about 2 m (6.6 ft) per year on sites with good soil fertility and moisture levels and intermediate to high light levels. After the first few years, growth rates are typically 1–2 m (3.3–6.6 ft) in height per year. In field trials in the Solomon Islands the annual stem diameter increment was in the range of 1.6–2.5 cm (0.6–1 in), with growth declining with age. The fastest growing trees attained a diameter a breast height (dbh) of 30 cm (12 in) in 13–16 years but had poor form and short boles to only 4–8 m (13–26 ft).

Reaction to competition

The species copes well with competition from other trees and crops, but growth will slow in more heavily shaded conditions.

PROPAGATION

Stands may be established either by direct sowing, seedling planting stock, or assisted natural regeneration (by removal of smothering vines). Vegetative propagation by stem cuttings is possible, and this may be a useful technique for mass propagation of selected material.

Seedlings

Seed collection

Fruit collection time varies among locations, and in some areas there may be more than one fruiting season per year. In PNG and the Solomon Islands the main fruiting season is November–March. In Fiji and Tonga the main fruiting season is February–March. For those countries in which the fruits are consumed, a good guide to collection time is when fruits become available in the market. A cost-effective collection method is to purchase good-quality fruits from different vendors; this technique is particularly appropriate when selecting germplasm for planting tava for fruit production. Seed can also be collected from the crown, which is the preferred option, or following natural shed. The seed is sensitive to moisture reduction and is readily damaged by insects or fungi. Seed collected from the ground must be harvested within a day of fruit fall to ensure that immature fruit is not collected. Collected fruits are placed in cloth bags in a cool location (out of the sun) and processed as soon as possible.

Seed processing

Removal of the flesh (pericarp and arillode) promotes seed germination. There are about 300–500 seeds/kg (136–227 seeds/lb).


Mature specimen showing straight trunk clear of branches to about 12 m (40 ft), 'Upolu, Samoa. PHOTOS: C. ELEVITCH

Seed storage

Seeds are recalcitrant and seed moisture content is about 35–55%. Under suitable conditions, including good air ventilation around fruits and cool temperatures (e.g., 10–15°C [50–59°F]), the seed can be stored for up to 6 weeks with the skin intact.

Seed pretreatment

Preferably the seed should be sown immediately after cleaning, and no treatments are necessary.

Growing area

Field Given the large seed, very rapid germination (commencing within 2–3 days), rapid initial seedling growth, and need to grow in large pots, direct sowing into the final field location is an effective and cost-efficient practice. With very fresh seed of high viability, only two seeds need be sown at each planting spot. Direct-sowing locations should be indicated and lightly shaded by living marker stakes of *Gliricidia sepium*, *Hibiscus tiliaceus, Polyscias* spp., or similar species.

Shade house If seeds are sown in a germination tray, transplanting is best done as soon as possible after the seed has germinated.

Germination

Most of the seeds will germinate within 7–10 days of sowing. Fresh seed has a high initial viability (e.g., >90%) but rapidly loses viability in storage.

Media

Seedlings can be grown in most standard potting media, especially the more fertile, loamy types.

Time to outplanting

In the case of nursery-raised seedlings, the period in the nursery may be very short, as short as 6 weeks. Plants need to be grown in large pots if they are to be held in the nursery for more than 2 months.

Guidelines for outplanting

The approximate size at outplanting should be 25 cm (10 in) in height and approximately 4–6 mm (0.16–0.24 in) in diameter. Reasonable maintenance, including regular weeding on an as-needed basis, ensures high survival (e.g., >90%) and good early height growth.

Vegetative propagation

Experiments in PNG have shown that the species can be vegetatively propagated. Initial trials resulted in 50% rooting, but this was increased up to 100% by refining the technique using cutting material taken from older hedge plants (20 months). The most successful results were achieved by using shoot cutting material 3–5 cm (1.2–2 in) in length. The leaf area was reduced to about one third of its original size, and a rooting hormone gel (0.3% IBA) was used.

DISADVANTAGES

A general drawback is lack of availability of germplasm that combines both good fruit characteristics and good stem form for timber production. This reduces the utility of the species for multipurpose plantings. To reach tava's potential as a multipurpose timber/fruit tree will require a moderately intensive, medium-term (up to 10 years) improvement program.

Potential for invasiveness

The species is considered to have a low invasive potential, at least to spread rapidly. In forests remote from human habitation, the majority of the tava fruits/seeds fall near the parent tree. It is likely that dispersal by bats and birds will result in some medium-distance dispersal, i.e., up to several hundred meters away from the parent tree, and infrequently results in long-distance dispersal. In the South Pacific there is a good correlation between the distribution of fruit bats and tava. In areas where its fruits are consumed by humans, it is likely that tava seeds were distributed widely by humans, both inadvertently and deliberately.

Diseases and pests

In parts of the South Pacific, including Vanuatu and Fiji but not Samoa, saplings and mature trees suffer considerable defoliation, with almost all leaves having a heavily shot-holed appearance. Growth rates are reduced where leaf damage is severe, or over an extended period. Witches' brooms, presumed to be of viral origin, are reported to be common. These may develop as malformations of shoots, leaves and inflorescences and may develop into a dense mass of almost 1 m (3.3 ft) diameter before falling from the tree. However, witches broom, while recorded for New Guinea, appears to be infrequent or absent in the South Pacific region. Various galls may develop on the leaves or flowers. *Conopomorpha cramerella* (cocoa pod borer moth) is also listed as a pest.

Host to crop pests/pathogens

Tava is reported to be a common wild host for the beetle *Oxymagis horni*, the larvae of which are a very serious pest of *Eucalyptus deglupta* in the Solomon Islands.

BIODIVERSITY REHABILITATION

Tava may be used as a "framework" species to catalyze the return of biodiversity into degraded Pacific forest ecosystems because:

- in many countries there is an abundance of tava seed for direct-seeding programs
- in many areas there are already large trees that can be liberated through vine cutting
- it grows moderately rapidly
- the tree attracts bats and pigeons that carry and disperse seeds of other Pacific trees and shrubs.

AGROFORESTRY/ENVIRONMENTAL PRACTICES

Mulch/organic matter

In parts of PNG, the dried leaves, the residue of collected fruit-laden branches, are a major source of nutrient-rich mulch in yam cultivation.

Soil stabilization

Mature trees have fairly extensive surface and near-surface lateral roots that aid in soil stabilization.

Crop shade/overstory

The tree provides a moderately dense shade and would not be well suited for interplanting with crops that have a high light requirement.

Homegardens

Good fruiting types are well suited for inclusion in homegardens.

Improved fallows

In parts of PNG the trees are used as a planted fallow, assisting in more rapid return of soil fertility.

Boundary markers

The trees are occasionally planted or retained along property boundaries, serving as markers.

Windbreaks

Tava is infrequently planted specifically as a windbreak, but the trees have a moderately dense canopy and could be incorporated as the upper strata of a multi-tiered windbreak.

Silvopasture

In some parts of the Pacific, such as East Santo, Vanuatu, old trees are retained in pastoral systems to provide shade, fruit, and fuelwood.

Animal fodder

It has not been recorded as an animal fodder.

Woodlot

It is suitable for planting in woodlots, but long rotations and often variable bole form would discourage plantings solely for wood production.

Native animal/bird food

It is an important food tree for animals and birds. The fruits are consumed by fruit bats (*Pteropinae*) and birds, including pigeons.

Wildlife habitat

This tree makes an excellent habitat for wildlife, providing food and shelter and nesting sites (in the form of hollows).

Coastal protection

It is not especially useful for coastal protection, as the canopy is sensitive to salt spray.

Ornamental

Mature trees have a lot of character, with an attractive mottled to smooth bole and red flush of new growth. Most forms develop into large trees that should not be planted adjacent to buildings.

USES AND PRODUCTS

Tava produces a good general-purpose timber and is widely utilized locally throughout its range for a variety of end-uses. It is a commercially important export timber widely used for construction hardwood in PNG, and it is the most important native timber species in Samoa. In parts of the Solomon Islands the leaves are used for chewing with lime, and a canoe putty is extracted from the inner bark.

The fruits are edible, bearing some resemblance to the related lychee (*Litchi chinensis*).

Preparations from the leaves and bark are widely used in the South Pacific and elsewhere in traditional medicines to treat various ailments. Its timber is also considered an excellent firewood.

Fruit

Tava provides a very important seasonal fruit in many parts of the Pacific. The fruits are consumed fresh and sold in local markets and may be readily eaten fresh; the thin skin is removed simply by gripping the fruit around its circumference and twisting. Two shell-like halves come away from the fleshy aril that surrounds the seed. Fruits have a pleasant, sweet taste, reminiscent of a rather bland lychee.

In parts of its natural range it is highly regarded as a seasonal fruit, and its distribution has been expanded by people in Melanesia and Polynesia. In Tonga, the onset of its short fruiting season creates a hive of activity known as lulu tava (literally to “shake down the tava fruit”), before the bats or birds get at it. The greatest utilization of fruits occurs in New Guinea, the Solomon Islands, Vanuatu, and Fiji, which are associated with the selection and domestication of superior fruit types and the absence, until recently, of related Asian fruits trees such as rambutan and lychee. The areas where superior, large fruit types are reported from include the following.

Forma pinnata

PNG New Guinea Islands; Tanga (small island located east of New Ireland) has large, sweet-tasting fruits 3–4 times larger than those around Lae, with very thin, red skin.

Solomon Islands Tevai/Santa Cruz Group, Temotu Province.

Vanuatu Many localities including Banks Group, Santo, Malo, Epi, Aneityum.

Fiji Many localities, including SE Viti Levu, Gau, Kadavu.

Forma glabra

Irian Jaya Near Jayapura—vars. *kablauw* and *iwa* (Sentani language)—thick sweet flesh, tasting like rambutan.

Nut/seed

The seeds are barely edible and need to be roasted and baked prior to consumption. The cooked seeds resemble sour cheese in flavor and smell. The seeds may also be dried and stored.

Medicinal

In Papua New Guinea the masticated bark is applied to burns. In Fiji both leaf and bark extracts are used, either individually or in combination with other plants, to treat a wide range of ailments, including stomach complaints, diarrhea, dysentery, pain relief (bones, muscles, joints, chest, headache), colds, flu, diabetes, and mouth ulcers. In Tonga an infusion of the bark was used to treat diarrhea in children, stomach trouble, serious coughs accompanying fever and constipation, and the leaves were also used medicinally. The bark contains a saponin (an oleanolic acid glycoside), leucoanthocyanidins, and condensed tannins. In parts of Sarawak (Malaysia) it was used as a traditional treatment for chicken pox, with the patient being bathed in an infusion (hot water extract) of the bark. In the Solomon Islands an oral medicine is prepared from the bark to protect babies from the devil.

Near-ripe fruits, 'Upolu, Samoa. PHOTO: C. ELEVITCH

Masticant/stimulant

In parts of the Solomon Islands the leaves are used for chewing with lime.

Timber

The wood is a very good general purpose hardwood suitable for a wide range of uses. Its timber is particularly well suited to light construction, moldings, interior joinery and framing, non-impact tool handles, furniture, and veneers. The sapwood is pale pink or buff, 2.5–5 cm (1–2 in) wide, and not always well demarcated from the red or red-brown heartwood. The grain is usually straight or sometimes strongly interlocked. Wood texture is fine to coarse and uneven. Wood is slightly lustrous with an occasional ribbon or flame on back-sawn faces. It works easily with most machine and hand tools, but wood properties may vary depending on locality/site and taxonomic form.

Air-drying of 12 mm (0.5 in) boards may take 4 months and 40 mm (1.6 in) boards up to 6 months. Considerable degradation may occur during drying unless boards are handled with care. Mild kiln drying schedules will minimize surface checking and twisting of back-sawn material. Final steaming treatment reduces twist but could accentuate surface checking. Timber saws cleanly, producing fair to excellent surfaces. Peeling properties are variable. High-density or waterlogged zones may adversely affect peeling in some logs, with pre-heating advisable. Good quality stock is suitable for face veneer in plywood. The timber glues, screws, and nails well, takes a nice polish, and paints and stains satisfactorily. Shrinkage and density are variable (in the range 464–1025 kg/m^3 [28.9–64.0 lb/ft^3], typically averaging 690–750 kg/m^3 [43.0–46.8 lb/ft^3] at 12% MC), strength properties are intermediate/good, steam-bending properties are generally good, and moisture movement is low to medium. Durability is rather low, but the wood is suitable for outdoor uses not involving ground contact. The heartwood is impermeable, and the sapwood is moderately resistant to preservative impregnation. In service the wood is susceptible to pinhole and marine borer attack, and brown stain. Tava sawdust may cause irritation to nose and throat.

Fuelwood

The wood is an excellent, hot-burning fuel.

Craft wood/tools

In the Solomon Islands the wood is used for making axe handles.

LORE

In Ikutingting, Tanna (Vanuatu), the fruiting time of tava indicates that root crops in gardens are just beginning to store starch and that they are not ready for harvesting. Wild fruits offer alternative foods while allowing garden crops to complete the cycle to harvest.

Canoe/boat/raft making

In the Solomon Islands the wood is used for making canoes and paddles (although these are not especially durable). In Fiji and Tonga, the timber is used in boat building. A canoe putty is extracted from the inner bark.

Tannin/dye

In Fiji an extract of the leaves was formerly used to dye hair black.

COMMERCIAL CULTIVATION

The two main commercial products are timber and fruit.

Timber The species is an important general utility timber throughout much of its native range. It is the major timber species cut in native forests in Samoa and the most important construction timber in PNG.

Fruit Better fruiting types have been selected in Melanesia (southwest Pacific), where it is an important seasonal fruit.

Spacing

Timber

Open, sunny areas are unsuitable for timber plantations of tava, as young trees will break crown early, resulting in a short bole. In secondary or logged-over forest, tava may be planted in enrichment line plantings, with about 8–12 m (26–39 ft) between rows and 2 m (6.6 ft) within rows (for direct-seeding) and 4 m (13 ft) within rows (for seedlings). Tava may also be underplanted in taller forests where the canopy is not too dense (i.e., over 50% shade). The final crop density for timber production would be about 150–200 trees/ha (61–91 trees/ac). For block plantations a closer initial spacing of 3 x 4 m (10 x 13 ft) is recommended in order to reduce weeding. A thinning regime, involving three separate thinnings undertaken every few years and when crowns begin to touch and overlap, is recommended to achieve a final spacing as indicated above. The species is yet to be planted on any large commercial scale for timber. The area needed for timber production would range from 1–2 ha (2.5–5 ac) for local needs up to several hundred hectares to supply or supplement timber supply to a small sawmilling operation.

In parts of lowland Samoa there are large areas of secondary forest, opened due to a combination of cyclones and logging, and now smothered by vines. These forests are in a state of "arrested succession" (unable, or only very slowly able, to develop into lowland closed forest without human assistance); however, with several cycles of vine cutting a tava-rich forest may develop.

Fruit and timber

Closer spacing may be used for smaller-growing varieties, or in cases where fruit type is uncertain, such as for seedlings, and where thinning may be advantageous to produce an orchard of better-fruiting types.

Fruit

A suitable spacing for commercial production of fruit is likely to be 8–9 x 8–9 m (26–30 x 26–30 ft), i.e., 125–150 trees per ha (51–61 trees/ac). The area required for a fruit orchard will usually not be great, e.g., <0.5–1 ha (1.2–2.5 ac), as local markets could easily be over-supplied. With rigorous quality control over selected fruit, attractive packaging, and good marketing, it may be possible to develop a boutique industry supplying and exporting bottled tava fruits in syrup. In this case a larger area, of several to tens of hectares of good fruiting types, would need to be established.

Management objectives and design considerations

Timber

Periodic pruning of lower branches should be undertaken

Vines covering forest of tava trees arrests tree growth, Samoa. Trees can recover if vines are controlled over several years. PHOTO: C. ELEVITCH to prevent them from developing into coarse branches which may even compete with the apical leading shoot. No more than one third of the crown should be removed at any one time.

Fruit and timber

For direct-seeded plantings, there is the option (if large quantities of seed are available) of establishing plantings at high densities and thinning out undesirable phenotypes, i.e., poorly formed stems in the case of timber plantations and trees that produce limited amounts of fruit or small fruits. Good weed control is essential, especially in the first 2–3 years, including regular removal of vines.

Fruit

Fertilizer application is not required, but tava fruit orchards may be kept more productive by periodic application of a complete fertilizer or interplanting with nitrogen-fixing trees and shrubs, such as *Calliandra, Casuarina*, *Gliricidia*, and *Flemingia*. Topping may be used to produce shorter, more spreading trees for fruit production.

Plantings for fruit production should be located near local markets (within 10–20 km [6–12 mi]) to keep transportation costs down and because fruits spoil easily during transport. Likewise, plantations for timber production should preferably be located near existing sawmilling facilities, e.g., within about 50 km (30 mi).

Yields

There is no documented information on timber and fruit yields. A monocultural plantation of better forms for timber production is likely to grow at about 5–10 m^3/ha/yr (72–144 ft^3/ac/yr) on fertile sites. Fruit yields for mature plantations of good fruiting types are estimated to be 2–8 mt/ha/yr (0.9–3.6 t/ac/yr).

Growing in polycultures

The species is very well suited to polyculture, growing together with other tree species to provide a wide range of products for local needs. An advantage of growing in polyculture is that trees develop better stem form for timber, compared to those grown under open conditions.

On-farm processing

It is important to sort and remove any damaged or rotting fruits, as these may cause more rapid spoilage of adjacent fruits.

Markets

Established local markets exist in many Pacific islands for

Tava fruits bottled in syrup, a product developed by University of the South Pacific, Fiji. PHOTO: L. THOMSON

both timber and fruits of tava, but the size of these markets is not well documented. There is potential to expand the local market for timber (and to provide timber for import replacement). Fruit markets are already mostly well supplied; varieties that produce larger, better-tasting fruits and/or those that extend the fruiting period will have better market potential.

The University of the South Pacific (Institute of Applied Sciences and Food and Textiles Department) has developed a "dawa in syrup" product that appears to have export potential. A major UK retail chain has indicated they could market the product for about US$1 per fruit.

INTERPLANTING/FARM APPLICATIONS

Example system 1

Location

Lowlands of northwest Papua New Guinea.

Description

This traditional system consists of mixed food gardens, especially yam (*Dioscorea* spp.), banana, taro (*Colocasia esculenta*), and sugarcane. The cropping cycle is short, typically 18 months, followed by a fallow cycle of up to 30 years. During the cropping cycle, tava and breadfruit (*Artocarpus altilis*) are also planted and tended. Regular cutting back or light pruning during fruit collection from tava trees appears to stimulate subsequent fruiting.

The tava trees serve as both planted fallow, assisting in more rapid return of soil fertility, and in providing fruit. The dried leaves of tava, the residue of collection of fruit-laden branches, are heavily used as fertilizer mulch in yam cultivation.

Crop/tree interactions

There is minimal interaction between the trees and crops, as the trees are still small when crops are being grown. Planting seedlings among crops ensures good weed control during the establishment phase.

Spacing

Although there is no data available, the density of tava trees is estimated at 50 trees/ha (20 trees/ac).

Example system 2

Location

Tonga

Description

Tava is a very important component of the traditional agroforestry system in Tonga. The five most important trees in Tonga's rural allotments are coconut palm (*Cocos nucifera*), koka (*Bischofia javanica*), mango (*Mangifera indica*), citrus trees (*Citrus* spp.), and tava. In this system a lower stratum of root and other crops, characterized by mixed and staggered planting, is closely integrated with a dense mosaic of mixed tree species, including many different fruit trees and other useful multipurpose species, and fallow vegetation in various stages of regeneration.

Yields/benefits

Increased and more sustainable yield of a wide range of products, including food, wood, medicines, and cultural products.

Crop/tree interactions

Trees provide shelter and varying levels of shade for crops, and assist with cycling of soil nutrients that are below the crop root zone.

Eighteen-month-old tava sapling in rainforest regeneration plot, Falelima, Savai'i, Samoa. PHOTO: L. THOMSON

Spacing/density of species

Generally there are 1–3 trees per rural allotment (estimate).

PUBLIC ASSISTANCE AND AGROFORESTRY EXTENSION

Extension offices for agroforestry and forestry in the Pacific: http://www.traditionaltree.org/extension.html

INTERNET

CIRAD Forestry Department's wood quality page for tava: <http://www.cirad.fr/activites/bois/en/syst/asia/kasai.pdf>.

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Traditional Tree Initiative—Species Profiles for Pacific Island Agroforestry (www.traditionaltree.org)

Pometia pinnata (tava)

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Acknowledgments: The authors and publisher thank Dale Evans, Brian Gunn, Diane Ragone, and Art Whistler for their input.

Recommended citation: Thomson, L.A.J., and R.R. Thaman. 2006. *Pometia pinnata* (tava), ver. 2.1. In: Elevitch, C.R. (ed.). Species Profiles for Pacific Island Agroforestry. Permanent Agriculture Resources (PAR), Hōlualoa, Hawai'i. <http://www.traditionaltree.org>.

Sponsors: Publication was made possible by generous support of the United States Department of Agriculture Western Region Sustainable Agriculture Research and Education (USDA-WSARE) Program; SPC/GTZ Pacific-German Regional Forestry Project; USDA Natural Resources Conservation Service (USDA NRCS); State of Hawai'i Department of Land & Natural Resources Division of Forestry & Wildlife; and the USDA Forest Service Forest Lands Enhancement Program. This material is based upon work supported by the Cooperative State Research, Education, and Extension Service, U.S. Department of Agriculture, and Agricultural Experiment Station, Utah State University, under Cooperative Agreement 2002-47001-01327.

Series editor: Craig R. Elevitch

Publisher: Permanent Agriculture Resources (PAR), PO Box 428, Hōlualoa, Hawai'i 96725, USA; Tel: 808-324-4427; Fax: 808-324-4129; E-mail: par@agroforestry.net; Web: <http://www.agroforestry.net>. This institution is an equal opportunity provider.

Species Profiles for Pacific Island Agroforestry

www.traditionaltree.org

April 2006
ver. 2.1

Pterocarpus indicus (narra)

Fabaceae (legume family)

***bluwota* (Vanuatu); *liki* (Solomon Islands); narra, amboyna, rosewood, Burmese rosewood (trade names); narra, rosewood (English); New Guinea rosewood (Papua New Guinea); *pinati* (Samoa); *santal rouge amboine* (French)**

Lex A. J. Thomson

IN BRIEF

Distribution Native to Southeast and East Asia and to the northern and southwest Pacific region; now distributed widely throughout the tropics.

Size Typically reaches 25–35 m (82–115 ft) in height with a broad canopy when grown in the open.

Habitat Grows at elevations of 1–1300 m (3.3–4300 ft) with annual rainfall of 1300–4000 mm (50–160 in).

Vegetation Thrives best in riverine, closed, and secondary forests.

Soils Adapted to a range of soils, growing best on deep, fertile, loamy, alluvial soils.

Growth rate In optimal conditions, height growth may be 2 m/yr (6.6 ft/yr) for the first 3–4 years, slowing to about 1 m/yr (3.3 ft/yr) thereafter.

Main agroforestry uses Soil stabilization, windbreaks, ornamental.

Main products Timber.

Yields Estimated at 5–10 m^3/ha/yr (72–144 ft^3/ac/yr) over a 30–40 year rotation, on optimal sites.

Intercropping Planted as boundary and windbreak around food crops or as a living fence around pastures.

Invasive potential Has limited potential to invade undisturbed native plant communities.

Large tree, Thurston Gardens, Fiji.

INTRODUCTION

Narra (*Pterocarpus indicus*) is a briefly deciduous, majestic tree typically growing to 25–35 m (82–115 ft) in height. Grown under open conditions, the canopy diameter is similar to the tree height. It has a very wide natural distribution in Southeast and East Asia extending eastward to the northern and southwest Pacific region. It may be found in various plant communities but attains its best development in riverine, tropical, closed and secondary forests, including those near to the coast and fringing tidal waterways. Narra is widely planted for amenity and ornamental purposes throughout the humid tropics.

Narra is adapted to subtropical and tropical (mean annual temperature 22–32°C [72–90°F]), subhumid/humid lowlands. In tropical regions it can grow well at higher elevations. A few populations are able to cope with a prolonged dry season of six or more months. Narra is also well adapted to strong winds, and established trees usually stand up well in cyclones, suffering only branch breakage.

The species occurs on a very wide range of soils, attaining its best development in deep, fertile, loamy alluvial soils. It is normally found growing in well drained, sandy to clay loams of mildly acidic to mildly alkaline pH.

It is one of the most promising multipurpose tree species in the Pacific islands for reforestation, village-level woodlots, living fencing, and large amenity trees. It is traditionally one of the most important multipurpose trees for timber and medicine. It fixes nitrogen and reproduces readily, both by seed and from cuttings. On good sites and when open grown it is moderately fast growing, but closely spaced plantings on less fertile sites are likely to grow slowly and not be economically viable for timber production. It is considered very unlikely to become an invasive weedy species. It is in decline in most parts of its natural range due to excessive and often illegal exploitation for timber, and it has been considered for exclusion from international trade (CITES nomination).

It has limited potential for interplanting with crops due to its large size and heavy shade. However, due to its ease of establishment through branch cuttings, it could be managed in an alley farming configuration. It is generally regarded as a useful tree for bordering food gardens due to its inputs of nitrogen-rich leaf fall and its valuable windbreak function.

DISTRIBUTION

Native range

Narra has a wide distribution in Southeast and East Asia, including southern Myanmar, Cambodia, southern China, Vietnam, Philippines, Brunei, Malaysia, and Indonesia. It extends east to the northern Pacific (Ryukyu Islands/Japan, Yap and Pohnpei [Federated States of Micronesia], and Palau) and southeast to New Guinea, New Britain, New Ireland and Manus, the Solomon Islands, and Vanuatu.

Current distribution

The species has been introduced to other tropical regions and countries including the Caribbean and the tropical Americas (Cuba, southern Florida/USA, Granada, Guyana, Honduras, Jamaica, Panama, Puerto Rico, Trinidad), Africa (Congo, Sierra Leone, Tanzania), Asia (India, Sri Lanka, Taiwan), and some Pacific islands (Guam, Hawai‘i, Fiji, and Samoa).

BOTANICAL DESCRIPTION

Preferred scientific name

Pterocarpus indicus Willd.

The genus name is derived from the Greek *pteron*, which means wing, and *karpos*, which means fruit, referring to the flat, winged pods characteristic of the genus.

Family

Fabaceae (legume family)

Subfamily

Faboideae

Non-preferred scientific names

Pterocarpus carolinensis Kaneh.
Pterocarpus draco sensu auct.
Pterocarpus indica Willd.

Common names

Pacific islands

bluwota (Vanuatu)
liki (Solomon Islands)
narra, amboyna, rosewood, Burmese rosewood (trade names)
narra, rosewood (English)
New Guinea rosewood (Papua New Guinea)
pinati (Samoa)
santal rouge amboine (French)

Solomon Islands

Kwara'ae, To'oabaita	*liki*
Ngini, Kwaio, Bugotu	*ligi*
Ayiwo	*nyia neli*
Vaiakau	*na*
Graciosa Bay	*noi'eni*
Roviana	*ringi*
Morovo	*rigi*
Kusage	*dandara*
Varisi	*nakumu*
Maringa	*grigi*
Santa Ana	*riki*

Vanuatu

Bislama language	*bluwota*
Torres Island: Loh/Lungharagi	*neniera*
Banks Group: Vanua Lava/Mosina	*narara*
Banks Group: Gaua/Lambot	*nar*
Maewo: Naone	*nanara*
Santo: Petawata	*navilae*
Santo: Penour	*navulae*
Santo: Valpei	*vulae*
Santo: Narango	*philai*
Santo: Sarete	*philae*
Santo: Hog Harbour	*nula*
Malo: Naviaru	*vuvilae*
Malekula: Larevat	*nakambis*
Malekula: Potindir	*weiwuli*
Malekula: Bubar	*nusmar*
Epi: Moriu	*burmeia, purmeia*
Erromango: Ipota	*vohovati*
Tanna: Ikutingting	*nakautufe*
Tanna: Greenhill	*kautufa*
Aniwa: Kaokao	*kautora*
Aneityum: Port Patrick	*kautofa*
Aneityum: Anelghowat	*nakautefa*

Size and form

A briefly deciduous, majestic, large tree typically growing to 25–35 (–48) m (82–115 [–160] ft) tall and about the same canopy width in open situations. Trees have a large, rather dense canopy. The semi-pendulous lower branches may extend to near ground level in open sites.

Flowers

Flowering is often initiated before the new leaf flush but continues after leaf flushing. Flowering takes place in several short bursts of about 1–2 days duration. The pea-shaped flowers are bright yellow to orange-yellow, about 1.5 cm (0.6 in) long, fragrant, and arranged in branched axillary racemes. The flowers are borne in profusion, adding to the ornamental appeal of trees when in full flower. Seasonality of flowering varies geographically.

Flowering seasons:

Country/Area	Flowering period
Papua New Guinea	May–October
Solomon Islands	
Western Province	(March–) June–July (–August)
Malaita Province	(May–) Oct.–Nov. (–Dec.)
Makira Province	(July–) Oct.–Dec. (–Jan.)
Choiseul/Santa Isobel	June–July
Santa Cruz Group	September–December
Vanuatu	
Torres and Banks Is.	(June–) October–December (–Mar.)
Santo, Malo, Maewo	(July–) August–October (–Nov.)
Malekula, Ambrym, and Epi	October–December (–April)
Tanna and Aneityum	December–January (–April)
Philippines	(January–) April–May (–July)

Leaves

The bright green, imparipinnate leaves are arranged alternately on the branchlets. Trees are either briefly fully deciduous or may be evergreen in uniformly humid zones. The new flush of leaves is light green, turning dark mid-green. Each leaf has (5–) 7–9 (–11) alternately arranged, ovate leaflets; each leaflet is about 6–12 cm (2.4–4.8 in) long by 3–7 cm (1.2–2.8 in) wide, with an entire margin. The terminal leaflet is larger, with the smallest leaflets in the lowest pair on the rachis.

Fruit

The pods are thin, papery winged, disc-shaped, about 5–6 cm (2–2.4 in) across, and borne in clusters. They are light green, turning dull brown when fully mature.

The short bursts of flowers are very showy. PHOTO: C. ELEVITCH

Pods are indehiscent: internally the pod is divided by cross-walls into four or five seed chambers, of which one or two (rarely three) may contain developed seeds.

The seeds mature about 3–4 (–5) months after flowering. The fruiting period varies geographically. In Papua New Guinea (PNG) the pods ripen from early December to March. Some pods fall while others remain on the tree up to the end of May. In the Solomon Islands seeds mature sometime during the period from July to January. The main fruiting period in northern Vanuatu is November to January, while in central and southern Vanuatu it is from January to March. In Fiji, seeds mature around March–April.

The time to bearing fruit depends on the planting material. Plants established from large branch cuttings taken from mature trees typically flower and fruit within 2–3 years. Trees established from seedlings may take many years (e.g., probably more than 5–7 years) before producing useful quantities of seed.

Mature pods can often be found on trees. PHOTO: C. ELEVITCH

Seeds

The seeds are flattened, bean-shaped, 6–8 mm (0.2–0.3 in) long with a leathery, although rather brittle, seed coat. Pod/seed dispersal is mainly by wind. Pods can float, and water dispersal is likely to also be significant for riverine populations.

Rooting habit

Trees have a well developed near-surface lateral rooting structure. Young plants compete poorly with *Imperata* and other tall, vigorous grasses and need to be regularly weeded on grassy sites. For establishment on grassy sites, good pre-planting control of grasses is essential, and a once-only treatment with glyphosate herbicide is recommended for this purpose. Because roots can grow large near the surface, it is best to grow the tree well away from sidewalks and pavement.

Similar species

Narra is a very distinctive tree in terms of its general appearance, leaves, flowers, and fruits, and there are no similar species, either naturally occurring or planted, in the Pacific islands (aside from recent small trials of *Pterocarpus macrocarpus* and *P. dalbergioides* on Kolombagara in the Solomon Islands).

GENETICS

Variability of species

Morphological variation was well documented by Rojo (1972). There is considerable intraspecific variation in morphological characteristics, such as leaflet, flower, and fruit size, shape, and hairiness, as expected for a species with a wide geographic and ecological range. Larger-fruited forms are found in Melanesia (PNG, Solomon Islands, and Vanuatu). There is also considerable variation in wood properties. In different parts of Vanuatu, two folk varieties are often distinguished on the basis of wood characters (such as width of sapwood, color of heartwood).

Known varieties

The only formally named variety is forma *echniatus* (Pers.) Rojo from Southeast Asia (including Philippines and Lesser Sunda Islands, Indonesia). This form is distinguished from the type form by its spiny or prickly fruits.

Culturally important related species in the genus

Pterocarpus macrocarpus (in Southeast Asia, Indochina) and *P. dalbergioides* (Andaman Islands, India, and Burma) are highly valued local timber trees, with the former being very important for furniture and wooden articles for Buddhist temples in Thailand and Vietnam.

ASSOCIATED PLANT SPECIES

Its best development is in riverine, tropical, closed, and secondary forests. In these situations it may occur in small patches of nearly monospecific stands. It also occurs in seasonally dry, semi-deciduous hill forests and fringing mangrove swamps.

Associated native species commonly found

On Santo, Vanuatu, it occurs naturally with *Antiaris toxicaria*, *Barringtonia* spp., canarium nut (*Canarium indicum*), *Castanospermum australe*, *Dendrocnide* spp., *Dracontomelon vitiense*, whitewood (*Endospermum medullosum*), and *Pangium edule*. In PNG it commonly occurs with *Kingiodendron alternifolium*. In the Philippines it occurs with *Calophyllum blancoi*, *Intsia bijuga*, *Syzygium simile,* and *Vitex parviflora.*

Species commonly associated as aboriginal introductions in Pacific islands

The tree appears to have been introduced to Pacific islands after European contact.

Species commonly associated in modern times or as recent Pacific island introduction

Narra is a large amenity tree grown in association with other commonly planted trees such as *Adenanthera pavonina*, candlenut (*Aleurites moluccana*), breadfruit (*Artocarpus altilis*), ylang-ylang (*Cananga odorata*), *Citrus* spp., coconut (*Cocos nucifera*), *Delonix regia*, *Dracontomelon vitiense, Ficus* spp., Tahitian chestnut (*Inocarpus fagifer*), mango (*Mangifera indica*), tava (*Pometia pinnata*), *Spathodea campanulata*, *Spondias dulcis,* mahogany (*Swietenia macrophylla*), and Malay apple (*Syzygium malaccense*).

Left: Extensive shallow root system presumably exposed by erosion. PHOTO: C. ELEVITCH **Right: Lower trunk of large tree.** PHOTO: L. THOMSON

ENVIRONMENTAL PREFERENCES AND TOLERANCES

Narra is adapted to the subtropical and tropical, subhumid/humid lowlands (up to 600 m [1970 ft]). In tropical regions it can grow well at higher elevations (up to about 1300 m [4300 ft]). Some populations, e.g., in East Nusa Tengarra, Indonesia are well adapted to prolonged dry seasons of six or more months.

Climate

Elevation range

1–1300 m (3.3–4300 ft)

Mean annual rainfall

1300–4000 mm (50–160 in)

Rainfall pattern

It favors environments with summer, bimodal, and uniform rainfall patterns.

Dry season duration (consecutive months with <40 mm rainfall)

0–6 months

Mean annual temperature

22–32°C (72–90°F)

Mean maximum temperature of hottest month

29–34°C (84–93°F)

Mean minimum temperature of coldest month

18–24°C (64–75°F)

Minimum temperature tolerated

5–8°C (41–46°F)

Soils

Narra is adapted to a very wide range of soils, attaining its best development on deep, fertile, loamy, alluvial soils. It is most commonly found growing in well drained, sandy to clay loams of slightly acid to slightly alkaline pH. However, particular populations may be adapted to different soil types, e.g., infertile, alkaline, stony soils on Sumba and East Nusa Tenggara (Indonesia). In the Philippines it is mainly found on alkaline soils.

Soil texture

It can grow in light and medium-textured soils (sands, sandy loams, loams, and sandy clay loams).

Soil drainage

It requires free drainage for best growth.

Soil acidity

The tree tolerates acid to neutral soils (pH 4.0–7.4).

Special soil tolerances

Narra tolerates shallow, sodic, and infertile soils.

Tolerances

Drought

The ability to tolerate drought is expected to vary considerably between provenances, with the most drought-resistant sources originating from eastern Indonesia (Sumba, East Nusa Tengarra). Established trees from Melanesian sources are likely to tolerate a dry season of many months (e.g., 4–6 months), especially on deeper soils.

Full sun

The species grows best in full sun, and mature specimens will be present in the upper canopy or as canopy emergents.

Shade

It can tolerate up to 25% shade.

Fire

The tree is likely to have limited fire tolerance due to thin bark, except possibly for sources from regularly-fired grassy woodland communities in eastern Indonesia.

Frost

It is expected to be severely damaged or killed by low temperatures (i.e., less than 5–8°C [41–46°F]).

Waterlogging

It grows best on freely draining soil types, but its riverine distribution suggests it must be able to at least tolerate short periods (several weeks duration or more) of shallow inundation very well.

Salt spray

Narra is expected to be damaged (including some leaf scald and drop) by salt-laden winds, and it is not recommended for planting in the most exposed seaside locations. However, it often occurs near to the sea and presumably has a moderate level of tolerance of foliar salt spray.

Wind

Trees have overall good tolerance of both steady and storm winds; e.g., mature trees planted in Fiji suffered minor damage during a particularly severe cyclone (Kina, January 1993).

Abilities

Fix nitrogen
Narra is a nitrogen-fixing tree that nodulates readily.

Self-prune
The species generally has a poor self-pruning habit, at least in open areas.

Coppice
The coppicing ability is not well known, but cut and fallen trees are reported to coppice well in Vanuatu and PNG.

Pollard
The species regrows fairly well after moderately heavy pruning, but the longer-term responses to occasional or regular pollarding are unknown.

Narra nodulates readily with nitrogen-fixing bacteria. PHOTO: J. B. FRIDAY

GROWTH AND DEVELOPMENT
Plants have an intermediate but highly variable growth rate: initially growth is directed toward shoot elongation, especially in more shaded situations, and then later into stem diameter growth. Rapid diameter growth is dependent on plants having sufficient space and light for development of an extensive crown. Plants established from large branch cuttings have the fastest growth, e.g., averaging 2.5 cm (1 in) diameter at breast height (dbh) growth per annum (up to a 4 cm [1.6 in] dbh annual increment). In Cebu (Philippines) the mean annual diameter increment increased with age, such that for the first 11–12 years the diameter increment averaged less than 0.5 cm (0.2 in) per year, but by 26 years it was averaging 1.1 cm/yr (0.4 in/yr). Initiation of heartwood may not begin to occur until many years after planting; e.g., about 18–19 years in the Philippines.

Growth rate
Height growth is highly dependent on site. On deep, well watered, fertile, lightly shaded sites, height growth may reach 2 m/yr (6.6 ft/yr) in the first 3–4 years, before slowing to about 1 m/yr (3.3 ft/yr). In open areas plants have a plagiotrophic growth habit with poor apical dominance. The shoot leader grows 1.5–3 m (5–10 ft) before bending over, growing almost laterally before another more upright leader emerges and takes over. Through this process the bole self-straightens to a large extent. In the open, however, plants may develop a multi-stemmed, branchy habit, and height growth may only be 0.5–0.75 m (1.6–2.5 ft) per year. The only growth data for the f. *echniatus* indicated an average height growth increment of 0.6–1.2 m (2–4 ft) per year.

Reaction to competition
Weed control is important for at least the first 2–4 years to reduce competition until the trees grow large enough to cast enough shade to suppress undergrowth.

PROPAGATION
Narra can be propagated from seeds, cuttings, grafting, and tissue culture. Seedlings and large branch cuttings are the most common methods of propagation.

Seedlings

Seed collection
The time for collection of ripe fruits varies by region. Pod maturity is indicated by a color change from light green to brown. Some pods fall or disperse soon after maturing, but most remain on the tree for several months. It is preferable to collect mature fruits by climbing into the canopy and lopping fruit-laden branches or else shaking and/or beating with long poles to dislodge fruits onto tarpaulins on the ground.

Seed processing
Fruits may be de-winged in order to reduce bulk and improve storability. Dewinging is done using a hammer mill or brushing machine fitted with hard brushes. There are about 1500–3000 (Av=2300) air-dried pods per kg (3300–6600 [Av=5000] pods/lb). Typically about 50% of fruits contain one healthy seed, but the percentage of viable

seed may be as low as 10–20%. With about 50% of fruits containing one healthy seed, there are 1200–1300 seeds/kg (2640–2860 seeds/lb) of air-dried pods. There are about 13,000 extracted seeds/kg (28,600 seeds/lb).

Seed storage

Storage behavior is orthodox, with seed being able to be safely dried down to 4% moisture content. The initial moisture content of seeds was found to be around 16–17% on a fresh weight basis. The most suitable method for longer-term storage, i.e., several years, is to store de-winged fruits at low temperature and moisture content.

Seed pretreatment

Seeds are typically sown still encased in their indehiscent pod into either open nursery beds, seed trays, or directly into individual containers (especially if extracted seed is used). The germination rate is improved if seeds are extracted from the pod before sowing; however, no pretreatment is required for germination. Seed extraction is not recommended for routine sowing, as it is a slow, manual process, often resulting in some damage to extracted seeds (and reducing their viability and/or storage life).

Growing area

It is preferable to germinate seeds in a sheltered area, such as a shade house. Seedlings should also be kept in sheltered areas with light shade (25–50%) for 2–4 weeks after transplanting. They may then moved into an open nursery situation and should be grown and hardened in full sunlight for at least 6–8 weeks prior to field planting. Seedlings derived from direct-sown fruits may be grown in the open if nursery infrastructure is unavailable.

Germination

The fruits are pushed, on the flattened side, into soil to a depth of about 10 mm (0.4 in), and then covered with a thin layer of soil. If extracted seeds are used, they should be laid flat and shallowly covered with 2–3 mm (0.08–0.12 in) of media/soil. Light shade should be provided, and the seedbed mulched. Seeds begin to germinate 3–4 days after sowing. The germination rate is about 24–40% at 4–15 days after sowing. Transplant germinants into individual pots at the cotyledon or four-leaf stage.

Media

A freely-draining, standard nursery potting medium is recommended.

Approximate size at outplanting

Seedlings take about 4 months to reach a suitable size for field planting; i.e., about 25 cm (10 in) tall.

Guidelines for outplanting

Seedlings need to be planted into well weeded and maintained areas, preferably with light to moderate shade to encourage apical dominance and better stem form.

Direct-seeding

Direct-seeding is often the best method for outplanting. It eliminates any transplant trauma. It also allows planting multiple seeds, so that the best-formed, most vigorous seedling can be selected at each planting site. The drawbacks of direct-seeding include risk of predator damage (e.g., rats, pigs, cattle), lack of rains to sustain the newly germinated seeds, and the mandatory frequent maintenance that must be done to ensure weeds do not smother the small seedlings.

In direct-seeding, an area is prepared for each planting spot, cleared of weeds, and cultivated to a depth of 50 cm (20 in) if the soil is compacted. It is recommended that 5–10 pods be sown in the final planting location, in order to ensure at least one healthy, vigorous germinant per position. Ideally, direct-sown fruits should be sown early in the wet season and fairly soon after the first good rains have been received. Fruits are planted at a depth of 2 cm (0.8 in).

Other propagation methods

Stem cuttings can be taken from trees of any age and size, but cuttings of diameter 6 cm (2.2 in) or larger will root better than cuttings of smaller diameter. In the Philippines, 30-cm-long (10 in) cuttings taken from trees approximately 20 years old were planted in plastic bags and placed under shade. They developed shoots and roots and became established. Trees established from large branch cuttings have a greater tendency to be affected by heart rot, and this propagation method should be avoided if timber production is a major objective of planting.

Grafting is also possible. Buds on scions were observed to develop 5 days after grafting, at which time callus formation at the point of stock-scion union was also obvious.

The species can be successfully propagated through tissue culture, but there is minimum need for this method given ease of propagation by seed and conventional vegetative cuttings.

DISADVANTAGES

The species' main drawbacks are

- poor adaptability to less fertile and drier sites, including slow growth
- late onset of heartwood formation

- lack of knowledge concerning best seed sources
- its large, spreading, and dense canopy and poor stem form in open situations limit its potential for inclusion in most agroforestry systems.

Potential for invasiveness

The species has low potential to invade undisturbed native plant communities and has not been reported to become widely naturalized when planted outside of its native habitats. The exceptionally high value and demand for its timber further mitigate against its spread, as larger trees capable of producing sizable fruit crops would likely be cut and utilized for timber.

Pests and diseases

The species is variously affected by pests and diseases in its native habitats. The most serious insect pests include an unidentified leaf miner in Solomon Islands and Vanuatu (possibly *Hyloconis*, which is recorded from Malaysia) and a caterpillar (*Melipotis diversipennis*) in Sumatra, Indonesia. Plants may also be damaged by sap-sucking psyllids. Seeds may be infected by the fungus *Phomopsis*. Fungal damage has been reported on seedlings, including anthracnose (*Glomerella cingulata/Colletotrichum gloeosporioides*) and leaf spots (*Cyllindrocladium quinoseptatum, Phyllcora pterocarpii, Pestalotia* sp., *Guignardia* sp., *Phyllosticta* sp., and *Aldora stella-nigra*). A soft scale (*Coccus longulus*) has been noted in Fiji. An insect pest (*Agrilus* sp.) has been recorded in the Solomon Islands.

Root fungal diseases can be reduced in the nursery through use of sterilized and freely draining media, avoiding dense sowing of seeds, and early sanitary disposal of diseased seedlings.

Larger trees may be affected by potentially serious root and stem rots including *Fomes lamaoensis*, *Ganoderma lucidum*, and *Phellinus noxius*. An unknown disease caused extensive dieback and death in street trees in Malaysia in the late 1800s to the early 1900s.

Host to crop pests/pathogens

No data available.

AGROFORESTRY/ENVIRONMENTAL PRACTICES

Mulch/organic matter

It has excellent potential to provide surface mulch and build soil organic matter due to its nitrogen-fixing capacity and its annual leaf fall (deciduous) habit.

Soil stabilization

The tree has excellent potential for soil stabilization, especially along drainage lines and flood plains, due to its adaptation to such sites, large buttresses, and extensive, spreading, near-surface root system.

Crop shade/overstory

The large canopy and heavy shade make the species unsuitable as a crop shade for all but the most shade-tolerant species. It has been used as shade tree for coffee.

Alley cropping

Narra might have potential for alley cropping given its nitrogen-fixing potential and ease of propagation by branch cuttings. However, there are generally other better-proven leguminous tree species available for this role, such as *Calliandra calothyrsus, Gliricidia sepium*, and *Leucaena* spp.

Homegardens

It is unsuitable for homegardens due to its large size and spread.

Improved fallows

The tree has some potential for planting as improved fallow, including for short rotations by using branch cuttings to quickly establish plantation. In a short-rotation improved fallow, branch cuttings enable a rapid and cheap establishment and a shorter weeding period.

Living fences

It is widely used as a living fence due to ease of establishment by large branch cuttings.

Boundary markers

Has some potential as a boundary marker due to its longevity and cyclone resistance and is sometimes planted for this purpose, e.g., in the Reef Islands (Solomon Islands), where it is believed to benefit gardens through fall of N-rich leaf litter and cycling of mineral nutrients from deep soil layers. Neighboring farmers may not always appreciate narra being used as a boundary marker due to its canopy spread and possible excessive shading of crops and/or pastures.

Windbreaks

The species is wind-firm, often with branches drooping to near ground level, and is well suited for windbreak planting where space permits.

Silvopasture

A few trees might be included in each paddock in silvopastoral systems to provide shade for livestock.


Left: The broad canopy is too dense for most understory crops. Right: The drooping branches are advantageous for shade in many public situations. PHOTOS: C. ELEVITCH

Animal fodder

No data available.

Woodlot

Has potential for woodlot planting, especially due to the high value of its timber, although it is not suitable for short-term rotations.

Native animal/bird food

No data available.

Wildlife habitat

Considered to be an important wildlife habitat tree in the Philippines.

Bee forage

The scented flowers are regularly visited by a large number of bee species, including honeybees, and the tree is considered to be important source of nectar and/or pollen.

Fish/marine food chain

It grows in the lower reaches of major rivers, including tidal creeks, and is likely to be important for stabilizing soils and maintaining water quality in these sensitive habitats that are vital to the marine food chain.

Coastal protection

It often grows near to the sea and is useful for coastal protection, but is not recommended for planting in the most exposed sites.

Ornamental

Narra is an outstanding ornamental tree for large public parks and avenue plantings.

USES AND PRODUCTS

Narra produces a beautifully figured and richly colored timber with excellent working and technical properties. It has been traditionally used throughout South and Southeast Asia and western Pacific islands for a wide range of products, including light construction purposes, furniture, and tools. In some parts of its range, such as Vietnam, the species has been extinct for several centuries as a result of over-exploitation. Some trees produce strongly figured wood known as Ambonese gnarl wood, or amboyna, that is highly sought after for craftwood and face veneers for high-value end uses. Narra wood is durable in salt water, particularly the wood obtained from trees growing near the sea, and is a preferred species for canoes and boats and their accessories. Narra is one of the Asia-Pacific region's finest timbers, and it is highly favored for use in interior joinery, paneling, decorative flooring, musical instruments, precision tools, and handicrafts.

Throughout its native range it is an important trees for use in preparation of traditional herbal medicines. Different parts of the tree, notably bark extracts, are used in the treatment of a wide range of ailments and illnesses, particularly those pertaining to the digestive system and skin. In recent times it has been claimed in the Philippines (Research Centre for Tropical Medicine) to have amazing healing properties for diverse and major illnesses, but further trials are needed to verify such claims.

The species is widely planted for amenity purposes due to its

- ornamental appeal (large spreading habit, excellent shade tree, and masses of fragrant yellow flowers)
- stability and wind-firmness
- ease of establishment and quick landscape impact through use of large branch cuttings
- longevity.

It is widely planted as a street tree in the Philippines, Malaysia, and Singapore and is used for living fences in the Solomon Islands and Vanuatu.

Leaf vegetable

The young leaves and flowers are eaten, but only rarely.

Medicinal

Narra has a vast number of traditional medicinal uses reported, especially from bark extracts. In several regions the shredded bark is boiled and the fluid taken orally for treatment of dysentery and diarrhea. In PNG it is used to treat tuberculosis, headaches, and sores, and as a purgative. In the Solomon Islands it is used to treat dysentery, heavy menstruation, and gonorrhea. In Vanuatu it is used to treat cuts and wounds, and stomachache and diarrhea in infants. In Malaysia juice extracted from the roots has been used to treat syphilitic sores and mouth ulcers. In Indonesia the young leaves have been used in the treatment of boils, ulcers, and prickly heat rashes.

In recent years, herbal teas and pills made from narra extracts have been popularized in the Philippines for treating a wide range of diseases and ailments including leprosy, menstrual pain, flu, rheumatoid arthritis, and diabetes.

Beautiful/fragrant flowers

The bright yellow flowers are both ornamental and sweetly fragrant.

Timber

Narra produces one of the world's most highly prized cabinet timbers—decorative with excellent working and technical properties. The wood is moderately hard and heavy (550–900 kg/m^3 [34–56 lb/ft^3] at 15% moisture content), and easily cut and worked by saws, planes, and other tools. The heartwood is streaked, light yellowish-brown to reddish-brown, and readily distinguished from the pale, yellowish sapwood.

The wood is highly durable in low-decay situations, such as interior uses. The sapwood is susceptible to lyctid (powder-

Left: Bees and other pollinators frequent narra when it is in blossom. Right: When pruned, the tree can even be used in tight landscaping areas. PHOTOS: C. ELEVITCH post beetles), while the heartwood is only infrequently attacked by termites. Durability in ground contact is reportedly extremely variable, lasting from 2–3 up to 20–25 years. It is an important commercial timber species wherever it occurs, and it has been overexploited and has become rare or extinct in parts of Southeast Asia.

Fuelwood

The wood is an excellent, hot fuel but is only rarely used for this purpose.

Craft wood/tools

The wood is valued for making craft items, being highly decorative and easily turned and worked by hand tools. Some trees, especially from the island of Seram (Indonesia), produce strongly figured wood known as Ambonese gnarl wood, or amboyna, that is highly sought after for craftwood. In the Solomon Islands and Vanuatu the large plank buttresses are cut into doors and seats, while burls are favored for making ornate bowls and for slicing into decorative face veneers for high-value end uses.

Canoe/boat/raft making

In Melanesia it is important for canoes, paddles, and outrigger beds. It is considered a very good boat-building timber due to its durability in seawater, including good resistance to marine borers.

Tannin/dye

The heartwood contains various red compounds, and in the Philippines the heartwood is used to make a red dye. The bark extract can be used for tanning.

In contact with water the wood/bark imparts a blue fluorescence, which gives rise to the common name in Vanuatu Bislama, bluwota.

Cosmetic/soap/perfume

An infusion from the leaves is sometimes used as shampoo in the Philippines.

COMMERCIAL CULTIVATION

The principal commercial product is timber, both for local uses and for export. The timber is used for high-class furniture and cabinets, decorative sliced veneer, interior wall paneling, feature flooring (including strip and parquet), musical instruments, gun stocks and rifle butts, turned articles, knife handles, boat building, and specialized joinery. It is also used for light building construction purposes including posts.

In Papua New Guinea, narra is an important commercial timber that fetches high prices. The export of logs is banned, and only processed wood is exported.

In the Philippines, export of narra wood was 3 million kg (6.6 million lb) in 1985, declining to 2.3 million kg (5 million lb) in 1986 (57% processed) and 430,000 kg (950,000 lb) in 1987 (all processed). From that time, export has been

Top: Trunk with burl. Bottom: High-end products made from narra burl. PHOTOS: J. NAUPA negligible, and at present there is a total cutting ban on the species.

Due to supply shortages there is relatively limited international trade in narra at present. The price (in 2004) for sawn boards from Papua New Guinea, the Solomon Islands and Vanuatu was US$600–800/$m^3$ (US$17–23/$ft^3$) FOB.

Spacing

The recommended initial plantation density is about 400 trees/ha (162 trees/ac), or a spacing of 8 x 3 m (26 x 10 ft). One or more selective thinnings reduces the density down to a final crop density of 100–150 trees per ha (40–60 trees/ac). Closer initial spacings, e.g., 2.5–3 x 2.5–3 m (8–10 x 8–10 ft), may be employed in order to gain more rapid site control and provide greater choice for selecting well formed trees for retention as final crop trees.

The area required for commercial production of narra timber depends on factors such as distance to processing facilities, markets, and the number of other growers. For a smallholder an area of as little as 1 ha (2.5 ac), or 100 trees, may provide worthwhile financial returns. The plantation area of commercial timber species required to supply a viable larger sawmill is considered to be around 10,000–12,000 ha (25,000–30,000 ac).

Management objectives and design considerations

The key management objective is to obtain an adequate or high stocking of well formed trees. Management approaches include

- use of seed sources with good stem form (but these are yet to be established)
- manipulating remnant and planted vegetation on site to provide appropriate light regimes (including intermediate levels of shade)
- close initial spacing to enable thinning of poorer phenotypes
- regular weeding and vine cutting.

Advantages of polycultures

Narra may naturally occur in near-monospecific stands and is expected to be amenable to growing in a monoculture. Its nitrogen-fixing ability would enable it to be advantageously grown with other moderately fast-growing tree species that have a high nitrogen requirement.

Yields

There is very limited yield data. On the most fertile Pacific islands sites with optimum silviculture the yield is likely to

> Narra is the national tree of Philippines and more than 100,000 ha (247,000 ac) of narra plantations were established there from 1960 to 1990.

be 5–10 m^3/ha/yr (72–144 ft^3/ac/yr) on a 30–40 year rotation. On poorer sites and with longer rotations the yield is likely to be less than 3–4 m^3/ha/yr (43–57 ft^3/ac/yr). In the Philippines a growth rate of 12 m^3/ha/yr (172 ft^3/ac/yr) over a 50-year rotation has been used for plantation planning purposes, which appears optimistic.

Markets

Narra timber is well known in the international timber trade, and there are established markets in Asia, Europe, the USA, and Australia/NZ. These markets would accept large volumes of sawn timber at high prices (e.g., >US$600/$m^3$ [US$17/$ft^3$]) if it were available. Narra is a preferred and highly sought-after timber wherever it occurs, and local markets are also very good.

INTERPLANTING/FARM APPLICATIONS

Example system 1

Location

Reef Islands, Solomon Islands.

Description

The traditional method in which narra is planted as a boundary marker on the edge of food gardens.

Crop/tree interactions

Narra trees provide windbreak and shelter for crops.

Yields

Unknown yield, although more open-grown trees have much faster diameter increment than in close-spaced plantations. Leaf fall from overhanging branches improves the soil fertility and organic matter.

Spacing/density of species

The tree density is estimated at 10–12 trees/ha (4–5 trees/ac).

Example system 2

Location

Santo, Vanuatu.

Description

This system is newly developed over the past 20–30 years. Narra is planted as live fences around pasture paddocks.

Yields

Trees grow moderately fast but have poor bole form and limited value for timber due to high incidence of heart rot and degrade (due to being open-grown plants established by means of large branch cuttings). The main benefits are low-cost, long-lasting fencing and possibly some benefits to pasture in terms of nitrogen inputs through leaf-fall.

Crop/tree interactions

The trees provide useful shade for livestock in situations where the existing forest has been fully removed.

Spacing/density of species

The spacing varies considerably, e.g., 5–10 m (16–32 ft) between larger specimens, and fence lines are often interplanted with other living-fence species such as *Hibiscus tiliaceus*.

PUBLIC ASSISTANCE AND AGROFORESTRY EXTENSION

Extension offices for agroforestry and forestry in the Pacific: <http://www.traditionaltree.org/extension.html>.

INTERNET

Agroforestree database, World Agroforestry Centre (ICRAF): http://www.worldagroforestrycentre.org/Sites/TreeDBS/AFT/AFT.htm

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Species Profiles for Pacific Island Agroforestry (www.traditionaltree.org)

Pterocarpus indicus (narra)

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Acknowledgments: The author and publisher thank John Francis, Diane Ragone, and Jacqui Wright for their input. Photo contributions by J. B. Friday and Jon Naupa are greatly appreciated.

Recommended citation: Thomson, L.A.J. 2006. *Pterocarpus indicus* (narra), ver. 2.1. In: Elevitch, C.R. (ed.). Species Profiles for Pacific Island Agroforestry. Permanent Agriculture Resources (PAR), Hōlualoa, Hawai'i. <http://www.traditionaltree.org>.

Sponsors: Publication was made possible by generous support of the United States Department of Agriculture Western Region Sustainable Agriculture Research and Education (USDA-WSARE) Program; SPC/GTZ Pacific-German Regional Forestry Project; USDA Natural Resources Conservation Service (USDA NRCS); State of Hawai'i Department of Land & Natural Resources Division of Forestry & Wildlife; and the USDA Forest Service Forest Lands Enhancement Program. This material is based upon work supported by the Cooperative State Research, Education, and Extension Service, U.S. Department of Agriculture, and Agricultural Experiment Station, Utah State University, under Cooperative Agreement 2002-47001-01327.

Series editor: Craig R. Elevitch

Publisher: Permanent Agriculture Resources (PAR), PO Box 428, Hōlualoa, Hawai'i 96725, USA; Tel: 808-324-4427; Fax: 808-324-4129; E-mail: par@agroforestry.net; Web: <http://www.agroforestry.net>. This institution is an equal opportunity provider.

Rhizophora mangle, R. samoensis, R. racemosa, R. × harrisonii (Atlantic–East Pacific red mangrove)

Rhizophoraceae (mangrove family)

American mangrove (English, Australia); red mangrove (USA); *mangle rojo* (Central and Latin America, Pacific and Caribbean coasts); *tiri wai* (Fiji); *togo* (Samoa)

Norman C. Duke and James A. Allen

IN BRIEF

Distribution Native to American west and east coasts and African west coast. One species, *Rhizophora mangle*, was introduced to the central Pacific, including Hawai'i and the Society Islands. Closely allied with Indo–West Pacific stilt mangroves whose ranges naturally overlap AEP mangroves only in the southern Pacific.

Size Can reach 30–50 m (100–160 ft) in height, although commonly attains 5–8 m (16–26 ft).

Habitat Inhabits the intertidal wetland zone, 0–6 m (0–20 ft) elevation between mean sea level and highest tides, with variable rainfall.

Vegetation Commonly associated with other mangrove species.

Soils Adapted to a very wide range of soils but thrives best in fine mud sediments of downstream river estuaries.

Growth rate Grows less than 1 m/yr (3.3 ft/yr) in height.

Main agroforestry uses Soil stabilization, coastal protection, wildlife/marine habitat.

Main products Timber, fuelwood, charcoal, dyes, and traditional medicine.

Yields Timber volume was estimated at 100–150 m^3/ha/yr (1400–2100 ft^3/ac/yr).

Intercropping Recommended for planting together with other mangrove species.

Invasive potential These plants are ready colonizers of new mud banks, making them opportunistically invasive with a high potential to invade alien environments; generally not recommended for planting outside of their natural range.

PHOTO: N. C. DUKE

Atlantic–East Pacific red mangrove *Rhizophora mangle* growing along an estuarine shoreline near Braganza, Amazonian Brazil.

INTRODUCTION

Atlantic–East Pacific red mangroves (AEP *Rhizophora* species) are the most important and dominant mangrove species of tropical coastal areas of the Atlantic Ocean, the American Pacific coast, and several islands in the southwestern Pacific Ocean. This species group is one of two that make up the genus *Rhizophora* and consists of three species (two being closely allied) and one hybrid: *R. mangle*, *R. samoensis*, *R. racemosa*, and *R.* × *harrisonii*, respectively.

Red mangroves, notably *R. mangle*, have also been introduced into new sites in the Indo–West Pacific (IWP) region during the past century. In the Hawaiian and Society Islands, no mangroves were present until introductions were made in the 1920s, since which time their presence has become quite noticeable. In the Hawaiian Islands, mangroves have reportedly overgrown channels, reduced tidal flows, and overgrown archeological sites. Red mangroves thrive under a range of intertidal wetland conditions, including high salinity levels from greater than full strength seawater to freshwater (Cintron et al. 1978), and they tolerate a range of flooding, soil types, and other physical site factors. Typically, they are most common in the middle to low intertidal zone above mean sea level, extending often along the seaward margin of mangrove stands.

Many of the values of red mangroves are difficult to separate from the larger role played by mangrove plants. As such, the roles of particular species of *Rhizophora* are often not distinguished from other members of the genus, including the IWP stilt mangroves. Because *Rhizophora* species dominate most tropical mangroves worldwide they are generally believed to play a vital role for mangrove ecosystems including shoreline protection, enhancement of water quality in near-shore environments (plus coral reef areas), and support of estuarine and marine food chains.

Red mangroves are generally considered non-native to the IWP, not withstanding the disjoint but natural occurrence of *R. samoensis* in New Caledonia, New Hebrides, Fiji, Tonga, and Samoa. However, where introductions of *R. mangle* have been made, the uses of such plants need to be weighed carefully against their effects as potentially invasive species. In Hawai‘i, for example, several important negative effects have been documented, including reduction in the habitat quality for endangered water birds such as the Hawaiian stilt (*Himantopus mexicanus knudensi*), colonization of habitats to the detriment of native species (e.g., in anchialine pools), overgrowing native Hawaiian archaeological sites, and causing localized drainage problems by reducing the flow through tidal creeks or drainage channels.

WHAT IS A MANGROVE?

Mangroves form a unique and dominant ecosystem comprised of intertidal marine plants, mostly trees, predominantly bordering margins of tropical coastlines around the world. These halophytic (salt tolerant) plants thrive in saline conditions and daily inundation between mean sea level and highest astronomical tides, and they provide vital structure as habitat and food for similarly adapted resident and transient fauna. Mangrove plants exchange gases from exposed roots using special lenticels, while flooding tides allow uptake of river-borne nutrients and frequent dispersal by their buoyant propagules. The ecological limits defined by the diurnal tidal range explain the setting and why just 70 species around the world are considered to be mangroves (Tomlinson 1986, Duke et al. 1998), compared with adjacent rainforests that may have hundreds of tree species per hectare. Specialized morphological and physiological characteristics largely define and characterize mangrove plants, such as buttress trunks and roots providing support in soft sediments, aboveground roots allowing vital gas exchange in anaerobic sediments, and physiological adaptations for excluding or expelling salt. Fewer than 22 plant families have developed such essential attributes, representing independent instances of co-evolution over millions of years to form today's mangrove habitats.

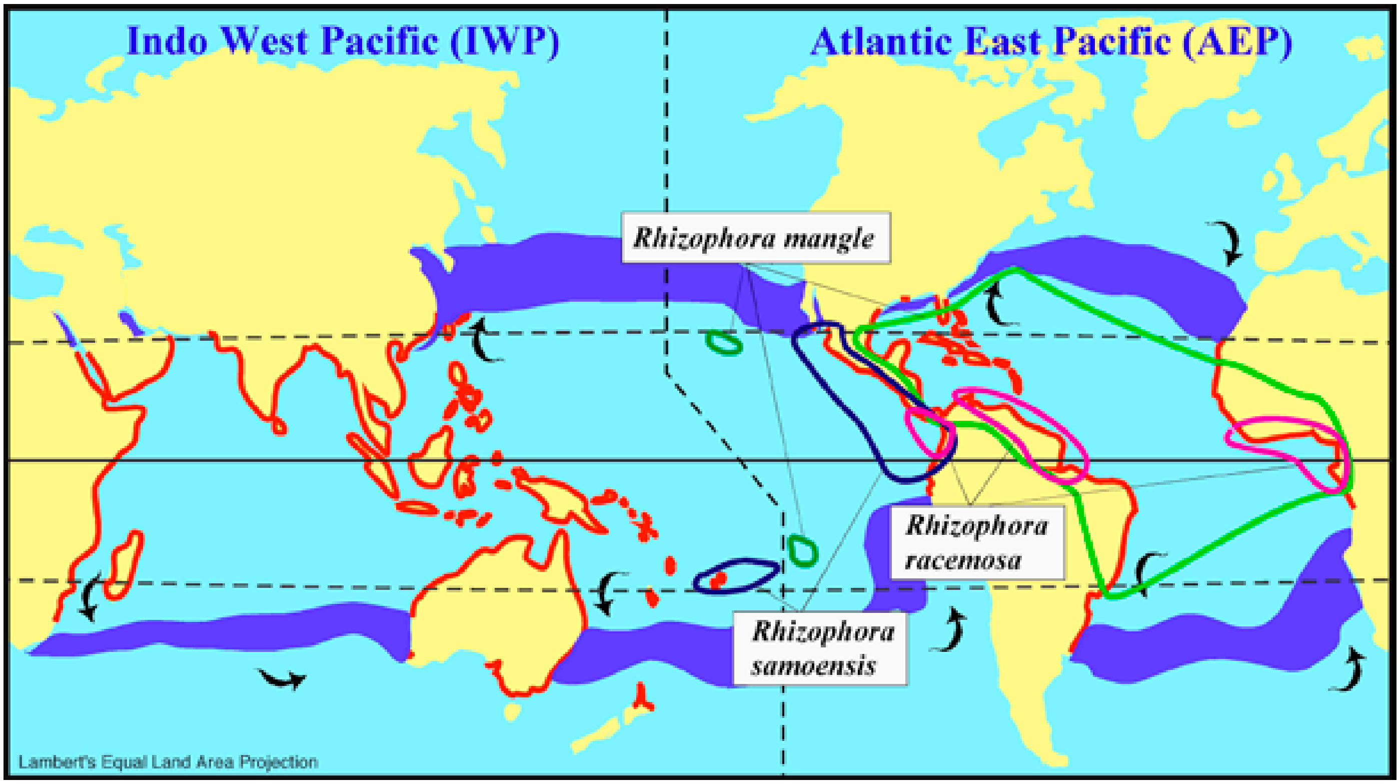
DISTRIBUTION

Native range

Atlantic–East Pacific red mangroves are native to tropical regions along the American east and west coasts to the African west coast, as well as in isolated occurrences in the southwestern Pacific islands.

Rhizophora mangle is the species that most characterizes AEP *Rhizophora*. It occurs naturally and dominates tropical tidal areas along both sides of the Atlantic. The closely related and almost identical "sibling species," *R. samoensis* (=*R. mangle sensu lato* Tomlinson 1986; =*R. mangle* var. *samoensis* Hochr.), is native to the American west coast and islands in the southwestern Pacific, notably New Caledonia, New Hebrides, Fiji, Tonga, and Samoa. The taxonomic status of these sibling taxa is arguable based on morphological data alone. The status of observed differences in like forms *R. mangle* and *R. samoensis,* however, will only be resolved in genetic studies and selected breeding programs.

Rhizophora racemosa is less common than *R. mangle* and *R. samoensis* but occurs as a distinct co-inhabitant of man-



World distribution of red mangroves, the AEP *Rhizophora* species. Given the apparent hybrid status of *R. × harrisonii*, its distribution is likely where the distributions *R. racemosa* and *R. mangle*/*R. samoensis* overlap. Coastlines marked in red indicate the distribution of all mangroves. IMAGE: N.C. DUKE

grove stands in wetter areas and larger catchment estuaries of the Atlantic. The species favors riverine estuaries, and it is restricted in the AEP to a few stands along the Pacific coast of the Americas and does not occur in the IWP. At least one other possible species, *R. × harrisonii*, occurs across the same range. Given this and its intermediate characters, the taxon is considered the putative hybrid of *R. mangle* and *R. racemosa*. The distribution of *R. racemosa* and the putative hybrid *R. × harrisonii* appears restricted mostly to equatorial estuaries of larger river systems with more continuous freshwater flows.

Of great interest also is the natural presence of red mangrove in the southwestern Pacific islands. Also occurring in this region is another hybrid taxon, *R. selala* (Salvoza) Tomlinson, whose putative parents include *R. samoensis* (=*R. mangle* var. *samoensis*) and *R. stylosa* (=*R. mucronata* var. *stylosa*). This hybrid taxon is special because *R. stylosa* is a dominant member of the IWP stilt mangroves. The occurrence of this hybrid means that there appears to be very little genetic separation between these defining and most divergent of *Rhizophora* species.

Current distribution

Because red mangroves are recognized as valuable timber producers, beneficial to shoreline stabilization and fisheries, it is feasible that their dispersal westward in the Pacific may have been assisted by aboriginal travelers in the past. However, there is no evidence for this happening, so currently there is no agreed explanation for the presence of *R. samoensis* in the southwestern Pacific. In the absence of human intervention, and accepting that long-distance dispersal was not possible, one explanation is island-hopping by natural dispersion across an ancient archipelago of seamounts that crossed the southeastern Pacific during early formation of the Pacific Plate in the Late Cretaceous period (Duke 1992, 1995). Any migration would have been westward, with distances between the putative ancient islands large enough to restrict all mangrove species except the dispersal-specialist red mangroves. In support of this theory, there are tantalizing similarities in cross-ocean linkages for several shallow-water reef fish.

Red mangroves extend notably beyond their native range. *Rhizophora mangle* has been introduced to the Hawaiian and Society Islands from Atlantic populations in Florida. In each case, founder populations have increased and expanded dramatically, especially in the Hawaiian Islands. Plants introduced in the early 1900s to Moloka‘i and O‘ahu now extend to most islands of the group, and the expectation is that they will spread further. Accordingly, *R. mangle* is treated as an invasive species in these islands.

Similar introductions of *R. mangle* elsewhere are apparently less invasive, possibly because other mangroves that already occupy the habitat reduce establishment opportunities for any new introductions. In the Townsville, Australia, area, local authorities were not prepared to take the risk, however, so when a small introduced stand of *R. mangle* was discovered in the upper part of Ross River, it was destroyed.

BOTANICAL DESCRIPTION

Preferred scientific names

Rhizophora mangle L.
Rhizophora samoensis (Hochr.) Salvoza (=*R. mangle* var. *samoensis* Hochr.)
Rhizophora racemosa G.F.W. Meyer
Rhizophora × *harrisonii* Leechman (=*R. mangle* × *R. racemosa*)

Family

Rhizophoraceae (mangrove family)

Common names

Atlantic–East Pacific red mangroves, American mangrove (English)
red mangrove (USA)
mangle rojo (Central and Latin America, Pacific and Caribbean coasts)
tiri wai (Fiji)
togo (Samoa)

Size

Atlantic–East Pacific red mangroves are medium to tall trees. They may reach 30–50 m (100–160 ft) in height, although they are commonly much shorter, around 5–8 m (16–26 ft). Stem diameters are about 15–35 cm (6–14 in) taken just above the highest prop root. This method of measurement differs fundamentally from the standard diameter at breast height (dbh) used for most forest surveys, as diameter height above the substrate varies from 0.5–7 m (1.5–23 ft) (consider the tree in the photo on the first page).

Form

Red mangroves are often multi-stemmed rambling to columnar trees with distinct aboveground prop roots. They tend to be of shorter stature and more spreading in shape on the seaward edge of stands or in sites of higher salinity. Taller, single-stemmed trees are often found just behind the seaward edge of stands downstream in major river estuaries. Multi-stemmed trees occur in frontal areas but are more common in upper intertidal regions. Prop roots are sturdy even when relatively thin.

Flowering

Flowers are perfect, containing both male and female parts. Inflorescences have few to many joints with 1,2,3,4–chotomous branching and one to many buds possible per inflorescence. Open flowers are located within or below leaf axils at leaf nodes below the apical shoot, depending on species. For *R. mangle*, *R.* × *harrisonii*, and *R. racemosa*, mature buds and flowers are located at 1–2, 3–5, and 7–9 nodes down from the apical shoot, respectively. The calyx is typically waxy yellow to creamy white and green at maturity, with four lobes. Buds elongate to ovate, green when immature to lighter colors as they mature, smooth, dimensions 1–2 cm (0.4–0.8 in) long, ~0.5 cm (0.2 in) wide. Petals, usually four, are lanceolate to linear, creamy white, with woolly to sparsely hairy margins, ~12 mm (0.5 in) long and ~4 mm (0.16 in) wide. Stamens number eight, pale yellow, to golden brown at maturity. Style is pale green, terete, filiform, 0.5–4 mm (0.02–0.16 in) above ovary base, 1.5–3 mm (0.06–0.12 in) wide, dichotomous tip, pale yellow. Bracts and bracteoles are distinct. Peduncle is 3–4 cm long (1.2–1.6 in), ~0.3 cm (0.01 in) wide. Flowering period is chiefly (but not exclusively) August–December in the southern hemisphere and February–June in the northern hemisphere.

Leaves

Leaves are opposite, simple, bright green, obovate, leathery, margins revolute, generally curved surface, obtuse blunt apex with a minute lip folded under. Cork wart spots occur on most species' leaf undersurfaces, scattered evenly, not raised, reddish brown (may be distinguished from infections and wounds by their uniform cover). Note that non-spotted leaves are found on an unusual form of *R. racemosa* in northern Brazil. Leaf emergence occurs chiefly during November–February in the southern hemisphere and May–August in the north. Leaf fall occurs chiefly over the wet summer period, October–February in the southern hemisphere and April–August in the northern hemisphere.

Fruit

Fruits, when mature, are pear-like, elongate, waist constriction, smooth brown surface, calyx lobes elongate spreading (when the hypocotyl is ready to emerge). For *R. mangle*, *R.* × *harrisonii*, and *R. racemosa* mature fruit located in leaf

Top left: The blunt apex of leaves is characteristic of all AEP red mangroves, as in this *R. samoensis* from Fiji. Top right: Leafy rosette of *Rhizophora mangle* (similar to *R. samoensis*) showing open flowers with elongate, reflexed calyx lobes. Bottom left: Open flower of *Rhizophora racemosa* showing flat, slightly hairy petals and stiff-erect, non-reflexed calyx lobes. Bottom right: Mature fruit of *Rhizophora mangle* (similar to *R. samoensis*) showing its elongate pear-shape, prior to emergence of the hypocotyl. Note the persistent style at the distil tip of the fruiting body. Atlantic Panama. PHOTOS: N.C. DUKE

axils 3, 7 (rare) and 10–11 nodes down from apical shoot, respectively.

Seeds/hypocotyls

Like all *Rhizophora* species, red mangroves are viviparous, meaning that they produce seeds hidden in the mature fruit, and these germinate while the fruit is still attached to the parent plant. The dispersal unit, a viviparous seedling, is called a hypocotyl. One hypocotyl is usually produced from each fruit, although on rare occasions twins may be observed.

Hypocotyls are narrowly cylindrical, elongate, green, smooth with irregular small brown lenticels, distal half wider, distal tip pointed. *Rhizophora mangle* and *R. samoensis* both have distinct brown distal portions of otherwise green, relatively short hypocotyls (see photo). For *R. mangle*, *R.* × *harrisonii*, and *R. racemosa*, mature hypocotyls are located in leaf axils 3–8, ~8 (rarely observed), and 13–15 nodes down from the apical shoot, respectively.

"Fruiting," when mature hypocotyls fall, occurs chiefly (but not exclusively) in November–January in the southern hemisphere and May–July in the northern hemisphere.

Bark

Bark is smooth and red-brown in seaward and exposed locations (rocky and sandy substrates), to gray-fissured with smooth, red-brown prop roots in sheltered locations (mud substrates). There is total coverage of gray-fissured bark in some localities.

Mature hypocotyls of *Rhizophora mangle* (similar to *R. samoensis*), showing distinctive brown distal end, Hawai'i. PHOTO: N.C. DUKE

Expended fruits of *Rhizophora samoensis* (left) and *R. stylosa* (right), Fiji. PHOTO: N.C. DUKE

Rooting habit

Mature trees have distinctive, sturdy, aboveground prop roots surrounding the stem base that anchor only shallowly in the sediments to 1–2 m (3.3–6.6 m) depth. This conforms to the anoxic conditions commonly observed in mangrove sediments.

Similar species

Red mangroves are distinguished from IWP stilt mangroves principally by the leaf apex: red mangroves have a blunt leaf apex and lack the spiked, mucronate leaf tip present in stilt mangroves.

Rhizophora mangle and *R. samoensis*, with mostly 0–3 inflorescence joints, are distinguished from *R. racemosa* and *R.* × *harrisonii*, which have 3–8 inflorescence joints.

Rhizophora racemosa is distinguished from *R.* × *harrisonii* by the node position of mature buds and flowers in leaf axils, down from the apical shoot, being 7–9 nodes and 3–5 respectively. The possible hybrid character is shown in *R.* × *harrisonii*, where it has characters intermediate between *R. racemosa* and *R. mangle*.

Rhizophora mangle and *R. samoensis*, the sibling species, are distinguished by minute/absent bracts on pedicles at the calyx base in *R. mangle*, while *R. samoensis* has bracts twice as wide as the pedicle. As noted, *R. mangle* and *R. samoensis* appear very closely related and are likely to be the same species. Discriminating between them reliably is not possible in many instances without detailed examination of key morphological and genetic characteristics.

GENETICS

Variability of species

Atlantic–East Pacific red mangroves are those *Rhizophora* species that occur naturally along the east and west coasts of the Americas, as well as along the west African coast and those island populations in the southwestern Pacific. In this group there appear to be four relatively distinct taxa, although at times their morphological and taxonomic differences are questionable. The uncertainty is chiefly based on: 1) the presence of one intermediate individual that is recognized as a distinct hybrid, namely *R.* × *harrisonii*, and 2) the occurrence of two sibling species, *R. mangle* and *R. samoensis*, which may, on closer examination, be shown to be the same species.

The relationship of *R. mangle* and *R. samoensis* is perhaps the most contentious. They appear very closely related, as they are distinguished by only a few morphological characters, as well as their distinct geographic ranges. The sibling species separate naturally across the American land barrier, with *R. mangle* in the Atlantic and *R. samoensis* in the Pacific. The situation became more complex during the 1900s when *R. mangle* (mostly from around Atlantic Florida) was introduced to the Pacific in several isolated instances, notably to Hawai'i, the Society Islands, and northeastern Australia. The Australian introduction was eradicated a few years ago, but in both other locations the spread of *R. mangle* has proceeded unchecked, and the species now dominates most intertidal wetland areas of each location. In Hawai'i changes in shoreline ecology have been dramatic, especially because no mangroves grew in this isolated location previously. A similar situation is expected in the Society Islands, but no detailed reports are available.

These introductions highlight the unexplained discontinuity of *R. samoensis* in the southwestern Pacific islands. This is the only example where AEP and IWP *Rhizophora* species naturally co-exist. Curiously, the human introductions of *R. mangle* demonstrate that island habitats without mangroves existed between Samoa and South America, and that these are suitable for mangrove colonization. The question raised by this natural discontinuity remains unresolved. This observation emphasizes the profound limitations of long-distance dispersal for this mangrove group of otherwise long-distance dispersal specialists.

Recognizing the morphological differences between *R. mangle* and *R. samoensis* is considered useful in distinguishing between introduced populations of *R. mangle* in the Hawaiian and Society Islands, as compared with natural populations of *R. samoensis* where they occur elsewhere in the Indo–West Pacific.

By contrast, *R. racemosa* is readily distinguished from *R. mangle* and *R. samoensis*. This species appears more common in estuaries influenced by larger and more continuous freshwater flows in equatorial regions of three distinct regions: the east Pacific (Costa Rica to Ecuador), west Atlantic (Venezuela to Brazil), and east Atlantic (western Africa). There are no reports of differences within this taxon between these areas, but recently (N.C. Duke, pers. obs.), two forms of *R. racemosa* were found to co-exist in northern Brazil. One fits the type description in every respect including the presence of cork wart spots on leaf undersurfaces, while the other form lacked these spots. This was particularly notable since all red mangroves until now have been reported to possess such spots on their leaf undersurfaces. This character is present in IWP stilt mangroves and in a similar way defines the two forms of *R. apiculata* occurring in Australasia and the northwestern Pacific.

Known varieties and hybrids

Rhizophora harrisonii is the apparent hybrid of *R. mangle* and *R. racemosa* based on its intermediate and shared morphological characteristics. Further investigations are needed to adequately describe *Rhizophora* taxa and their distributions throughout the AEP region. Current evidence indicates the situation may be more complex, with another possible hybrid where *R. racemosa* apparently occurs on the eastern Pacific coast of the Americas with *R. samoensis*, the allied partner to *R. mangle*.

Furthermore, as noted above, two forms of *R. racemosa* were observed in Brazil. The same recent investigation also discovered two intermediate forms, recognized as potential hybrids between the two *R. racemosa* forms and *R. mangle*. Key questions arise from these new observations including: what is the distribution of the two forms of *R. racemosa*, and how do these compare with populations in western Africa? There are clearly more questions than answers concerning genetic variation in red mangroves.

Aberrant individuals are reported to produce chlorophyll-deficient propagules, called albinos. This is particularly notable and common in *R. mangle* stands throughout the Caribbean area to northern Brazil. Yellow or red propagules can be observed hanging in affected trees alongside normal green propagules. Their relative numbers on an individual tree are believed to quantify the amount of outcrossing that occurs among neighboring normal trees. Other trees have also been observed with variegated foliage.

Culturally important related species

All *Rhizophora* species are closely similar in tree form, and cultural groups in the Pacific region may not always distinguish between them. Other mangrove genera, such as *Bruguiera*, are considered close in form and value also, and these together are often used in similar ways by indigenous peoples.

ASSOCIATED PLANT SPECIES

AEP red mangroves can be found growing with other mangrove species, preferably within intertidal wetland conditions above mean sea level elevations in tropical regions. *R. mangle* and *R. samoensis* grow in marine saline conditions, while *R. racemosa* forms and hybrid grow in proximity to a regular freshwater source. *R. racemosa* are commonly found in lower to middle tidal reaches of rivers and streams with regular, frequent freshwater runoff, while *R. mangle* and *R. samoensis* occur in coastal embayments and coral islands. In Fiji, however, *R. samoensis* occurs together with *R. stylosa* (a stilt mangrove). In this case, *R. samoensis* occurs more frequently in upstream locations of the freshwater dominated streams, while *R. stylosa* remains the marine specialist, preferring downstream and exposed coastal locations.

Red mangroves often extend up the tidal profile to the terrestrial fringe in areas of higher rainfall. In lower-rainfall areas, red mangroves occur on estuarine margins just above mean sea level. Best development has been observed in lower tidal reaches and on soft, fine, muddy sediment substrates.

Associated species commonly found

In Atlantic and east Pacific populations, red mangroves occur commonly with *Avicennia germinans* and *Laguncularia racemosa*. In the southwestern Pacific, *R. samoensis* is associated with IWP mangroves, including *R. stylosa* and *Bruguiera gymnorrhiza* predominantly. In other locations, red mangroves are associated with other mangrove species. The types of associated species are notably variable where this species has been introduced to the IWP region. In Hawai'i, while the species frequently occurs in nearly mono-specific stands, it does sometimes occur alongside a mangrove introduced from the IWP (*Bruguiera sexangula*) and species that typically occur in lower-salinity environments, such as *Hibiscus tiliaceus*.

ENVIRONMENTAL PREFERENCES AND TOLERANCES

Climate

Atlantic–East Pacific red mangroves thrive in tropical and subtropical environments characterized by moderately high and well distributed rainfall. Mangrove plants appear to depend on groundwater to sustain optimal growth, especially during drier months. In drier locations, such as the Baja Peninsula on the northern Pacific coast of Mexico, the stunted but dense thickets of *R. samoensis* (=*R. mangle*?) attest to the great adaptability of red mangroves to a wide range of climatic types.

Elevation range

0–6 m (0–20 ft), in reference to mean sea level.

Mean annual rainfall

These mangroves grow in all rainfall conditions. Their extent, form, and biomass reflect the different rainfall conditions.

Rainfall pattern

They grow in climates with summer or uniform rainfall patterns.

Dry season duration (consecutive months with <40 mm [1.6 in] rainfall)

Because of access to groundwater, red mangroves grow in regions with up to 8 months of drought. Across a wide variety of climatic regions, mangrove cover expands and contracts through time. This has been evident in correlations between El Niño events and reduced growth as possible causes of some damage to mangroves, presumably due to decreases in freshwater availability.

Mean annual temperature

20–30°C (68–86°F) (estimate)

Mean maximum temperature of hottest month

32–38°C (90–100°F) (estimate)

Mean minimum temperature of coldest month

0–5°C (0–41°F)

Minimum temperature tolerated

0°C (32°F) (estimate)

Soils

Trees develop greatest stature and columnar growth form in estuaries of larger tropical rivers, characterized by fine clay, black mud sediments with relatively high loads of organic carbon. They are also anaerobic with high concentrations of sulfide. Trees also grow well in sites with aerobic sediments consisting of fine sands to coarse stones and rocks, and coral ramparts.

Soil texture

Plants grow in light, medium, and heavy texture soils (sands, sandy loams, loams, and sandy clay loams, sandy clays, clay loams, and clays).

Soil drainage

The trees grow in soils with free and unimpeded drainage, as well as waterlogged soils.

Soil acidity

pH 6–8.5

Special soil tolerances

Plants grow best in saline soils but survive well in fresh water. The optimal salinity range is reported to be from 8 to 26 ppt (parts per thousand), compared with approximately 34–36 ppt for seawater.

Tolerances

Drought

Red mangroves can tolerate drought periods well, although trees have apparently been killed by drought in some sites on Molokaʻi, Hawaiʻi where groundwater sources appear to be limited. Drought conditions presumably cause soil salinity to increase in excess of tolerable limits for these plants.

Full sun

They grow best in full sun.

Shade

They appear to have low tolerance of shade. However, recent evidence shows this more likely due to weevils that infest and kill cooler, shaded seedlings (Brook 2001, Sousa et al. 2003).

Fire

Red mangroves have no tolerance of fire in close proximity.

Frost

Tolerance of sub-freezing temperatures is low to none.

Waterlogging

Red mangroves are tolerant of daily tidal flooding up to depths of up to 1.5 m (5 ft). While tolerating permanently saturated soils, they are intolerant of drying soils.

Salt spray

The trees are highly tolerant of salt spray.

Wind

Red mangroves are typically found in seaward areas subject to wind and salt spray but largely protected from waves. Planting in such highly wind-prone locations is recommended, but only where required and within the tree's native range.

Waves

In general, exposed, wave-prone coastlines are inhospitable to mangroves. In areas where wave action is infrequent, red mangroves are believed to provide significant buffering of coastal areas during storm and tsunami surge events (Dahdouh-Guebas 2005).

Abilities

Self-prune

Red mangroves self-prune well in dense stands, but they commonly maintain lower branches in more open-growing locations.

Coppice

The trees have notably poor coppice ability. Generally, if 50% or more of the leaves are removed from a tree, it will die.

MANGROVES AND CLIMATE CHANGE

Atlantic–East Pacific red mangroves, like other mangrove species, are affected by climate change. The unique physiological characteristics of each species define its capacity for survival in the face of change. Mangroves are expected to respond rapidly and decisively to shifts in key factors, like temperature, rainfall, and sea level, as each species has defined ranges of tolerance for each factor. For instance, because mangroves are characteristically restricted to elevations between mean sea level and highest tides, as sea level rises their communities must move upland to survive. Since mangroves have narrow optimal temperature ranges, rising temperatures will cause their distributions to shift north or south to areas where temperature conditions are most suitable, and they will die off in areas where they are not suited. Of course, their success in making these shifts depends on their successful dispersal and re-establishment, and the availability of suitable new space. Clearly, such changes have occurred throughout history, so the distribution of mangroves today represents the survivors of all past changes.

Key indicators of change can be identified and mapped as incremental shifts and responses of mangrove communities. These might be observed as shifts in vegetation, for example: 1) in the total tidal wetland habitat zone, as expected with changes in sea level; and 2) in the salt marsh–mangrove ecotone, as expected with changes in longer-term rainfall patterns as this affects moisture stress in saline environments. In both cases, the response zones will follow elevation contours. Changes along contours can be quantified from long-term spatial assessments over decade- and century-long time periods, depending on the rates of change. Knowledge of these changes and their causes allows better prediction of future change.

GROWTH AND DEVELOPMENT

Growth rates vary with age. They generally grow less than

1 m/yr (3.3 ft/yr) but can exceed this in favorable circumstances. Height growth is rapid shortly after establishment while food reserves are taken up from the hypocotyls of established seedlings. Growth rate slows when trees approach a site-specific maximum canopy height. When near maturity and maximum height, trees broaden their canopies and increase stem diameter rather than grow taller.

Flowering and fruiting

Flowering and fruiting periods of red mangroves are distinctly seasonal. Peak pheno-events are expected to shift into later months with cooler temperatures and higher latitudes. Trees have notable and relatively long periods of reproductive development, taking 18–30 months from first emergence of flower bud primordia until maturation and drop of mature hypocotyls. The duration depends on species, with the longest being *R. racemosa* with an expected period of around 30 months for each reproductive cycle.

Yields/growth rates

Growth rates vary with species, spatial position in the stand, competition, vigor, and age. For northern Pacific sites in Costa Rica, Jimenez (in Chong 1988) reported annual diameter growth increments for *R. mangle* and *R. racemosa* trees of 0.14–0.19 cm (0.06–0.07 in) for diameter size classes less than 10 cm (4 in), and 0.08–0.17 cm (0.03–0.07 in) for diameter size classes greater than 10 cm.

Chong (1988) provides information on potential yields from Playa Garza Pilot Area in an investigation of the feasibility of managing mangrove forests the Terraba-Sierpe Forest Reserve on the southern (wetter) Pacific coast of Costa Rica. The estimated mean annual increment (MAI) was 6 m^3/ha/yr (86 ft^3/ac/yr) with some stands as high as 11–14 m^3/ha/yr (157–200 ft^3/ac/yr).

Reaction to competition

Rapid early growth of red mangrove seedlings in full sunlight ensures their success and dominance in preferred estuarine and intertidal conditions. Newly established seedlings grow best in close proximity with their same species cohort. This affords them maximal protection from physical damage by drift logs and erosive waves. Since competition is high between neighboring seedlings, slower plants die and decompose quickly, leaving faster competitors the benefit of not only the space they occupied but also their nutrients.

PROPAGATION

Although natural regeneration is generally relied upon from Pacific to Atlantic regions, these species are relatively easy to propagate. Propagation is simple and relies on the special feature of the genus in having large viviparous propagules. Planting simply entails gently pushing the distal end of the 20–60 cm (8–24 in) long hypocotyl one third of its length into the sediment, spaced at about 1–1.5 m (3.3–5 ft) intervals. No holes need be dug, and neither nursery preparation nor stakes are needed. Low maintenance is generally sufficient for maximizing seedling establishment success in sheltered areas. However, substantial protection is required in more exposed coastal locations during the first decade of establishment. Such protection methods may include encasement of individual seedlings in PVC piping (Riley and Kent 1999), or installation of temporary structures to dampen wave action and reduce debris drift across restoration sites, as observed in Vietnam and China (Field 1996).

Propagule collection

Propagules may be available throughout the year, but peak production occurs around July–August in northern parts of the range and around January–February in the southern hemisphere. Propagule maturation occurs later in relatively higher latitude locations north or south beyond the tropic zone (e.g., July–October in Hawai'i).

Mature propagules may be collected from the ground after they have fallen or picked directly from trees. Only healthy looking propagules should be selected. Propagules that are shrunken or desiccated in appearance or that exhibit significant physical damage should be rejected. Although propagules with only minor borer damage may survive and grow, selection of propagules with no signs of borer or crab damage are strongly preferred. Propagules that already have some root or leaf development can be used in most cases, but should not be stored for long.

Propagule processing

Processing of mature propagules is not required for red mangroves, although damaged and insect-infested individuals should be removed. The following pretreatment section gives possible additional steps. Propagules can be sown in nursery beds, or preferably planted directly in the field soon after collection.

Propagule storage

Propagules can be kept viable for at least 6–7 days by storing them in brackish water or by wrapping them in wet burlap bags and keeping them out of direct sunlight. Pretreatment is considered essential if considering such storage (see below). It is likely that propagules can be kept

Mature hypocotyl of *Rhizophora racemosa* showing distinctive, slender, smooth propagule, Brazil. PHOTO: U. MEHLIG

longer, but storage beyond 2 weeks is not recommended, and long-term storage is not feasible.

Propagule pretreatment

Pretreatment of propagules is generally considered unnecessary. However, a study of scolytid beetle larvae (*Coccotrypes fallax*) infections on *Rhizophora* propagules in Australia found at least 18% were heavily infested (Brook 2001). Infested propagules were established under canopy-shaded areas. The study went further to find that pretreatment in a 50°C (122°F) water bath for 5 minutes killed the beetles and removed the risk of establishment losses due to borer damage. Heat treatment might be easily achieved by leaving the collected propagules in the sun for a short period (a few hours) before planting.

Growing area

Red mangroves should be grown in full sunlight.

Seedling establishment

Leaves and roots may begin to develop within a week or two of sowing.

Media

Although a wide variety of soil media are acceptable, a mix of sand and peat in equal parts has been recommended for mangrove nurseries.

Time to outplanting

Seedlings are ready for outplanting at the six-leaf (three-node) stage if grown up in nursery conditions, which can take up to 6 months to achieve. Older seedlings up to 0.5 m (1.5 ft) tall have also been successfully transplanted, but this is not recommended. Direct planting of large numbers of propagules is restricted by their peak seasonal availability, as propagules do not keep for extended periods.

Guidelines for outplanting

Outplanting anytime of the year is suitable. Propagules or nursery-grown seedlings usually have excellent survival in sites correctly selected and, if appropriate, protected from disturbance. Survival rates of 90% or greater are reasonable in such circumstances.

On the other hand, survival may be zero on sites exposed to excessive wave action, on sites with inappropriate hydrologic or salinity regimes, or (rarely) subjected to disturbance by grazing animals (e.g., goats, sheep, cattle, horses). A method of encasing propagules in PVC pipe has been used in Florida and the Caribbean to protect seedlings in places with a high likelihood of disturbance.

DISADVANTAGES

In general, red mangroves pose few significant disadvantages when planted within their native range. They are not especially susceptible to pests or pathogens and have not been reported to host major pests or pathogens of important crop species.

Potential for invasiveness

The very successful introduction and rapid spread of red mangroves in the Hawaiian Islands clearly demonstrates the potential for invasiveness of mangroves in areas where suitable habitat is available. The plants are readily opportunistic due to their relatively wide tolerance for salinity and soil conditions. Also, their floating propagules are spread widely by ocean currents over great distances.

The species *R. mangle* has unfortunately now taken on the public status of invasive weed and pest species in Hawai'i. To alleviate public concern, eradication efforts have been carried out in several locations on O'ahu and Hawai'i. It is not clear about the success or effectiveness of this campaign, as it appears to have been based on subjective information and no monitoring.

Pests and diseases

Susceptibility to pests and diseases is believed to be low, with the exception of insect borers and crabs that prey on propagules. For introduced stands in the Hawaiian islands, damage to propagules and leaves is notably lower than within the species' native range, and productivity (as expressed in litter fall) is higher.

Host to crop pests/pathogens

No reports are found of red mangroves serving as hosts for known major crop pests or pathogens. In Hawai'i, however, *R. mangle* stands have served as ideal sites for the non-native cattle egret (*Bubulcus ibis*) and also sometimes harbor significant populations of rats.

AGROFORESTRY/ENVIRONMENTAL PRACTICES

Mulch/organic matter

Mulch in *Rhizophora* forests is hidden from view. If it were not for the small mangrove crabs, fallen leaves would be washed away with each tide. The crabs actively take leaves into underground burrows and chambers. The resulting mulch is rapidly colonized by bacteria and consumed by other burrowing fauna to release nutrients that appear to further enhance the forest.

Soil stabilization

Red mangrove forests stabilize soils with their network of sturdy overlapping prop roots, which dampen water movement and promote sedimentation in areas that might otherwise be eroded. A major reason that red mangrove was introduced into Hawai'i was to stabilize mud flats that were expanding as a result of sugarcane production and resultant erosion. *Rhizophora mangle* has proven quite effective for this purpose and has been shown to improve water clarity in near-shore environments, presumably due to its role in sediment trapping and stabilization.

Fence posts

Red mangrove stems make good posts, as the wood is generally hard and resistant to insect borers.

Windbreaks

Red mangrove forests provide a windbreak along coastal margins generally, and places to seek sanctuary during typhoons and hurricanes.

Woodlot

Mangroves adjacent to peoples' homes throughout the Pacific frequently serve as informal woodlots, particularly on islands with clear tenure systems that include mangrove areas. Red mangrove timber is very useful for small construction and for fuel for cooking. Converting the wood to charcoal can further enhance the timbers' calorific value. This is done commercially in SE Asia and Central America with various *Rhizophora* species.

Native animal/bird food

Red mangrove is a known source of native animal foods. Several observations demonstrate the diversity and quantity, and it is thought to be extremely important in mangrove ecosystems. Numerous insects, crabs, and mollusks graze on green leaves in the forest canopy and on fallen leaves on the forest floor. Where present, sesarmid crabs consume a large quantity of fallen leaves and propagules. Organic matter processed by these herbivores is believed to broadly support aquatic food chains in coastal regions. Few mammals (probably none in introduced Hawaiian stands) appear to use red mangrove as a major food source.

Wildlife habitat

In addition to aquatic marine organisms (see Fish/marine food chain), red mangroves serve as habitat for a wide range of terrestrial and arboreal wildlife. In various locations throughout the region, these mangrove forests provide shelter and food for a number of associated fauna, including birds, small mammals, shellfish, and other marine life.

Bee forage

Rhizophora species have no nectar, but they do produce copious pollen that is usually distributed by wind. Interestingly, one reason stated for the introduction of red mangrove to Hawai'i was as a "pasture plant for bees" (Cooke 1917). Clearly, it wasn't the best choice for this purpose!

Fish/marine food chain

Mangroves in general are believed to play a vitally important role in protecting and supporting marine food chains. Many fish species use red mangroves during part of their

BENEFITS OF MANGROVE TIDAL WETLAND

Benefits include, in no particular order (adapted from Tomlinson 1986):

- visual amenity and shoreline beautification
- nutrient uptake, fixation, trapping, and turnover
- habitat use by fauna
- mesoclimate, where forests moderate evapotranspiration to create a specialized niche climate
- nursery habitat for young fauna, where mangroves provide a source of food and physical protection from predation
- sanctuary niche for mature fauna, including migratory birds and fish, where mangroves provide protection and a food resource
- primary production based on photosynthesis, giving rise to forest growth and forest products, notably timber
- secondary production, including microbial and faunal production, as well as grazers, and via decomposition
- fishery products, including both estuarine and coastal
- shoreline protection, based on general mangrove tree and root structure, as well as edge trees, which reduce erosion and provide stand protection from waves and water movement
- carbon sequestration and a sink where carbon is bound within living plant biomass
- sediment trapping, based on mangroves being a depositional site for both water and airborne sediments, which in turn reduces turbidity of coastal waters.

life cycles, as do species of shrimp and crabs. As mentioned above, senescent leaves that have fallen from *Rhizophora* trees are taken by grapsid (small mangrove) crabs into their burrows. In Hawaiian populations, there appears to be excessive leaf accumulation in some locations, suggesting that normal associated fauna and other decompositional biota are lacking.

Coastal protection

Red mangrove forests and mangroves in general play an important role in protection of coastlines, fishponds, and other coastal infrastructure. Red mangroves are planted for coastal or fishpond protection in some areas (e.g., in Terraba-Sierpe Forest Reserve, Costa Rica), and there are laws in many locations aimed at protecting mangroves in large part because of this important function.

USES AND PRODUCTS

Red mangroves are probably of greatest value for their environmental benefits, because they (and mangroves generally) are believed to play a vital role in supporting marine food chains, protecting coastal areas, and improving water quality.

In terms of direct benefits to people, the most widespread use of red mangroves is for wood used for a range of purposes from cooking fuel to construction of homes and canoe parts. Other uses of the tree include dyes, medicines, and tannin for tanning leather. It seems likely that red mangroves may have several other uses (e.g., as cattle feed) that to date have not been fully explored.

Staple food

Leaves and hypocotyls are edible but not widely used for food.

Medicinal

Red mangrove bark has reportedly been used to treat angina, boils, and fungal infections. The leaves and bark have been used as an antiseptic and to treat diarrhea, dysentery, fever, malaria, and leprosy, although it is not clear how effective the treatments have been in these cases.

Animal fodder

One report (Morton 1965) concluded that red mangrove leaves might serve as a valuable source of cattle feed, but this potential has yet to be realized.

Timber

The wood of red mangroves is widely used for structural components of traditional homes (e.g., poles, beams, flooring, wall-cladding, rafters) and other components including underground mine supports, fencing, cabinet works, tool handles, and boat anchors. The wood is also used for other purposes, ranging from traditional uses such as fishing stakes, spears, and copra huskers to use as a source of chips for pulp production.

The heartwood of *R. mangle* is light red to dark red or reddish brown or purplish, with uniform or more or less striped grain. The sapwood is yellowish, grayish, or pinkish. The wood texture is fine to medium; grain straight to irregular; low-luster; without distinctive odor or taste. The specific gravity (oven-dry weight/green volume) is 0.89.

Fuelwood

Red mangrove wood is used for fuelwood in many places along the American Pacific coast (e.g., Panama, Costa Rica, Nicaragua). The wood is also made into charcoal in many Central American countries, including Panama and Costa Rica.

Canoe/boat/raft making

The wood has been used to make canoe parts.

Tannin/dye

The bark and hypocotyls are used to tan leather and to produce dyes ranging from red-brown to black (the latter with repeated dying). Tannin content of the bark is high for most *Rhizophora* species.

COMMERCIAL CULTIVATION

Red mangrove timber is harvested commercially for charcoal production through much of its range, including Central and Latin America. The calorific value of the timber is significantly enhanced by converting it to charcoal. This is done with all local *Rhizophora* species, as well as *Pelliciera* and *Laguncularia*.

Rehabilitation and replanting

Projects to replant and rehabilitate mangrove forests have been conducted where they have been damaged in a significant way. For example, in Bahia las Minas, Atlantic Panama, a large oil spill killed around 50 ha (124 ac) of mangroves in 1986 (Duke et al. 1997), and Refineria Panama lead a project to replant the damaged areas. Because the soils were oiled it was decided to plant *R. mangle* seedlings using clean terrestrial sediments. Total plantings eventually amounted to in excess of 100,000 seedlings. A subsequent investigation (Duke 1996) found natural recruitment was 40 times greater than planted numbers, and natural seedlings grew equally as well as, or better than, planted seedlings. It was of great importance that naturally recruited sites recovered more quickly than planted sites, possibly because of site damage during planting. Furthermore, damage to exposed and damaged mangrove areas increased after 5–6 years when dead standing timber dramatically deteriorated and was moved by wave action with each tide and storm.

Top: Charcoal treatment plant established with the DANIDA Mangrove Project in Pacific Costa Rica, supported by IUCN and CATIE. Bottom: Typical earthen kiln used to convert stacked red mangrove poles into charcoal for local heating needs, Pacific Panama. PHOTOS: N.C. DUKE

Spacing

Mangrove plantations in general are typically planted at spacings of about 1.0–1.5 m (3.3–5 ft). Spacing wider than about 2.5 m (8 ft) tends to result in a high proportion of multiple stemmed and/or shorter trees. Wider spacing and therefore spreading trees may be desired for coastal protection projects but not for timber production. In the absence of significant natural mortality, timber plantations should be thinned to spacing of 2.5 to 3.5 m (8–11 ft) between trees as the stand develops and becomes crowded.

Management objectives and design considerations

Some published guidelines for mangrove silviculture exist and are referenced below, but specific guidelines on thinning, fertilizing, etc., are lacking.

Growing in polycultures

Red mangroves naturally occur in mixed-species stands, and each species has its own ecological and economic values. It is also important to plant associated buffer areas, particularly along the shoreline where mangroves grow better adjacent to banks stabilized by shoreline upland plants. Together they will complement and enhance the richness and stability of the planted environment.

Estimated yield

For the southern (wetter) Pacific coast of Costa Rica, Chong (1988), in an FAO-sponsored project, provided information on potential yields from the 240 ha (590 ac) Playa Garza Pilot Area in an investigation of the feasibility of managing around 5200 ha (12,800 ac) of mangrove forests in the surrounding Terraba-Sierpe Forest Reserve. It was reported that yields resulting from uncontrolled felling of 100 ha/yr (250 ac/yr) could be achieved by felling just 10 ha/yr (25 ac/yr) if conducted more systematically.

Chong estimated that each hectare of mangrove in this reserve could produce US$619 ($250/ac) annually. A detailed management plan was proposed in the report. The average stand volume for red mangroves was 163 m^3/ha (2330 ft^3/ac), with a total mangrove forest stand volume around 280 m^3/ha (4000 ft^3/ac). Estimated yields of timber volume under bark were 100–150 m^3/ha/yr (1400–2100 ft^3/ac/yr) for red mangroves, and for the co-dominant mangrove *Pelliciera,* yields are estimated at 60 m^3/ha/yr (860 ft^3/ac/yr).

Markets

Markets for red mangrove products are local in nature, with little available except for firewood and charcoal in most places, other than indirect products such as mangrove crabs and fruit bats. In Central America, large quantities of red mangrove wood chips and charcoal may be moved greater distances and in greater volumes than other wood products. In Panama there is a strong trade in red mangrove poles around 3 m (10 ft) in length (around 10–15 years old) for construction of *bohio*, the locally popular outdoor recreation shelters for barbecues and parties.

INTERPLANTING

Some interplanting systems include:

Example 1—Bahia las Minas oil spill (Duke 1996, Duke et al. 1997)

Location

Bahia las Minas, Panama Atlantic coast

Description

Planting was undertaken in 1988 and 1989. Around 40 ha (100 ac) were planted with *Rhizophora mangle*, sponsored and implemented by Refineria Panama.

Crop/tree interactions

Not applicable.

Spacing/density of species

Spacing was about 1.5 m (5 ft).

Planting of red mangroves in an attempt to replace around 50 ha of tree loss following a major oil spill in Bahia las Minas, Atlantic Panama. PHOTO: N.C. DUKE

Example 2— Terraba-Sierpe Forest Reserve
(Chong 1988)

Location

Costa Rica, Terraba-Sierpe.

Description

Planned project. This project reached the planning stages only and was sponsored by FAO with IUCN and CATIE. The species to be planted included *R. racemosa*, *R. mangle*, and *Pelliciera rhizophorae*.

Crop/tree interactions

Not applicable, as there were no crops.

Spacing/density of species

Spacing was planned to be 1.5 m (5 ft) for all species.

PUBLIC ASSISTANCE

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Species Profiles for Pacific Island Agroforestry (www.traditionaltree.org)

Rhizophora mangle, R. samoensis, R. racemosa, R. × *harrisonii* (Atlantic–East Pacific red mangroves)

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Acknowledgments: The authors and publisher thank Tom Cole, Farid Dahdouh-Guebas, Dale Evans, Kathy Ewel, Ariel Lugo, and Diane Ragone for their input. A photo contribution by Ulf Mehlig is greatly appreciated. Norm Duke acknowledges a host of people who have over the years supported his journey into *Rhizophora* and who share the passion for this group of plants. Collaborators and friends include: Jim Allen, Uta Berger, John Bunt, Molly Crawford, Farid Dahdouh-Guebas, Otto Dalhaus, Kathy Ewel, Candy Feller, XueJun Ge, Gina Holguin, L.P. Jayatissa, Kandasamy Kathiresan, Ken Krauss, Eugenia Lo, Ulf Mehlig, Jaime Polania, Jurgenne Primavera, Ute Steinicke, Mei Sun, and Nick Wilson.

Recommended citation: Duke, N.C., and J.A. Allen. 2006. *Rhizophora mangle*, *R. samoensis*, *R. racemosa*, *R.* × *harrisonii* (Atlantic–East Pacific red mangroves), ver. 2.1. In: Elevitch, C.R. (ed.). Species Profiles for Pacific Island Agroforestry. Permanent Agriculture Resources (PAR), Hōlualoa, Hawai'i. <http://www.traditionaltree.org>.

Sponsors: Publication was made possible by generous support of the United States Department of Agriculture Western Region Sustainable Agriculture Research and Education (USDA-WSARE) Program; SPC/GTZ Pacific-German Regional Forestry Project; USDA Natural Resources Conservation Service (USDA NRCS); State of Hawai'i Department of Land & Natural Resources Division of Forestry & Wildlife; and the USDA Forest Service Forest Lands Enhancement Program. This material is based upon work supported by the Cooperative State Research, Education, and Extension Service, U.S. Department of Agriculture, and Agricultural Experiment Station, Utah State University, under Cooperative Agreement 2002-47001-01327.

Series editor: Craig R. Elevitch

Publisher: Permanent Agriculture Resources (PAR), PO Box 428, Hōlualoa, Hawai'i 96725, USA; Tel: 808-324-4427; Fax: 808-324-4129; E-mail: par@agroforestry.net; Web: <http://www.agroforestry.net>. This institution is an equal opportunity provider.

Rhizophora apiculata, R. mucronata, R. stylosa, R. × annamalai, R. × lamarckii (Indo–West Pacific stilt mangrove)

Rhizophoraceae (mangrove family)

mangle hembra **(Guam: Chamorro);** ***tebechel*****,** ***bngaol*****,** ***agpat*****,** ***apgal*** **(Palau);** ***raway*****,** ***roway*****,** ***ravey*** **(Yap Islands, FSM);** ***chia*****,** ***cia*** **(Chuuk, FSM);** ***aak*****,** ***akelel*****,** ***akapah*** **(Pohnpei, FSM);** ***kahrak*****,** ***suhkasrik*****,** ***sakasrik*** **(Kosrae, FSM);** ***petu rogha*****,** ***ngochango-chara*** **(Marovo, Solomon Islands);** ***tiri tambua*** **(Fiji);** ***koriki*** **(Daru and Kiwai, PNG);** ***totoa*** **(Motu, PNG); spotted leaved red mangrove (Western Australia); red mangrove, tall-stilted mangrove, prop root mangroves (Queensland)**

Norman C. Duke

IN BRIEF

Distribution Native to tropical and subtropical coastal areas from the African east coast, throughout Asia to Australia and to most islands of the eastern Pacific Ocean. Closely allied with Atlantic–East Pacific red mangroves whose ranges naturally overlap only in a small number of southern Pacific islands.

Size Can reach 30–40 m (100–130 ft) in height, although commonly reaches 5–8 m (16–26 ft).

Habitat Inhabits the intertidal wetland zone, 0–6 m (0–20 ft) elevation between mean sea level and highest tides, with variable rainfall.

Vegetation Mangrove communities.

Soils Adapted to a wide range but thrives best in fine mud sediments of downstream river estuaries.

Growth rate Grows <1 m/yr (3.3 ft/yr) in height.

Main agroforestry uses Soil stabilization, coastal protection, wildlife/marine habitat for marine fauna.

Main products Timber, fuelwood, charcoal, dyes, and traditional medicine.

Yields In Malaysia, the 30-year rotation harvested yield of green wood has been about 136–299 mt/ha (61–133 t/ac).

Intercropping Recommended for planting together with other mangrove species.

Invasive potential Has potential to invade new environments; not recommended for planting outside of the natural range. These plants are ready colonizers of new mud banks, making them opportunistically invasive.

Rhizophora mucronata **trees showing stilt roots, Chuuk, Federated States of Micronesia.**

INTRODUCTION

Indo–West Pacific stilt mangroves (IWP *Rhizophora* species) are widespread throughout most tropical coastal areas of the western Pacific region to east Africa. This group is one of two that make up the genus *Rhizophora* and consists of three species (two being closely allied), *R. mucronata*, *R. stylosa*, and *R. apiculata*, and two hybrids, *R.* × *lamarckii* and *R.* × *annamalai*.

Stilt mangroves thrive under a range of intertidal conditions, including a range of salinity levels from near freshwater to full strength seawater. They tolerate a range of flooding regimes, soil types, and other physical site factors. Typically, these mangroves are common in the mid-intertidal zone, and particularly along the seaward margin of tropical mangrove stands.

Rhizophora are considered the most important of all mangrove genera across the Pacific tropical region. However, the benefits provided by stilt mangroves are difficult to separate from the larger role of mangroves and mangrove ecosystems in general. Mangroves are known to play a vital role in shoreline protection, enhancement of water quality in nearshore environments (including coral reefs), and in supporting estuarine and marine food chains. In most parts of the Pacific, trees are harvested for firewood, so the trunk is the main part of the tree considered for direct use.

DISTRIBUTION

Native range

Indo–West Pacific stilt mangroves occur widely throughout the western Pacific. Specifically, they occur in tropical and subtropical, intertidal wetlands from the east coast of Africa, through Asia to Micronesia extending east in the northwestern Pacific through the Federated States of Micronesia to the Marshall Islands, and south to northern Australia extending east in the southern Pacific as far as Samoa. Distributions appear continuous, but separate species have different preferred locations where they dominate:

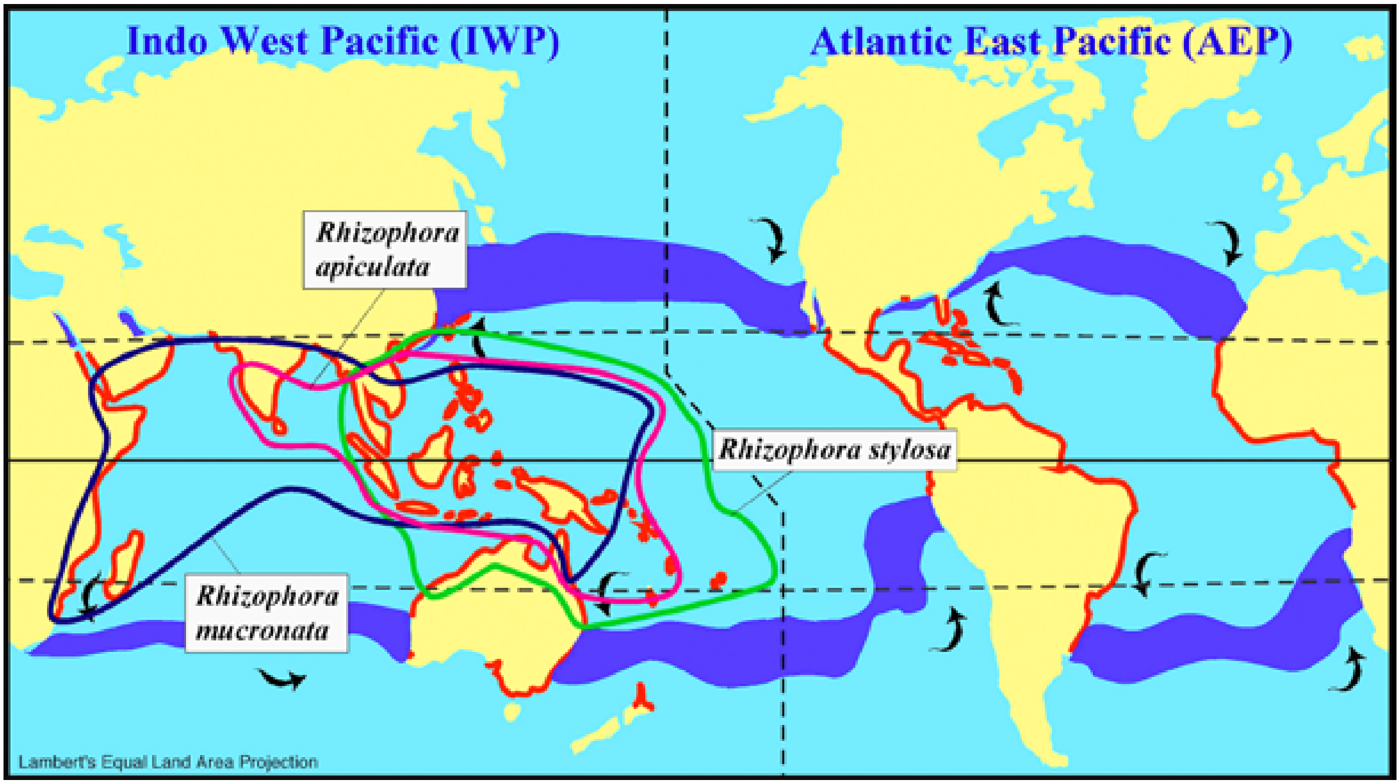
- *R. mucronata* occurs mostly in areas subject to regular freshwater flows (at least in the eastern part of its range)
- *R. stylosa* occurs in marine situations often preferring more exposed offshore sites
- *R. apiculata* is often found mid–lower estuary in larger riverine estuaries and embayments
- the hybrid *R.* × *lamarckii* is found downstream in middle to higher intertidal locations.

Rhizophora mucronata and *R. stylosa* are sibling species (i.e., possibly *R. stylosa* =*R. mucronata* var. *stylosa* (Griff.) Salvoza), and together they characterize most stands of IWP stilt mangroves. The range of *R. mucronata* is the widest of all IWP species, extending from east Africa, where it occurs as the sole *Rhizophora*, to the western Pacific, where it overlaps with all other IWP species. In contrast, *R. stylosa* extends exclusively east, notably into the southwestern Pacific. The range of *R. apiculata* also extends further east in the south Pacific than *R. mucronata*, but otherwise its range mostly fits within the ranges of other IWP *Rhizophora*. The status of observed differences in similar forms, *R. mucronata* and *R. stylosa,* will only be resolved in genetic studies and selected breeding programs.

The two hybrid taxa presumably have distributions in keeping with their hybrid status. As such, they are located wherever the ranges of their putative parents overlap. Confirmed records of hybrid distributions show *R.* × *lamarckii* to be widespread in the western Pacific, while *R.* × *annamalai* was found in India and Sri Lanka along the western limits of *R. apiculata*. However, considerable confusion is expected in the field distribution records, because these hybrids

WHAT IS A MANGROVE?

Mangroves form a unique and dominant ecosystem comprised of intertidal marine plants, mostly trees, predominantly bordering margins of tropical coastlines around the world. These halophytic (salt tolerant) plants thrive in saline conditions and daily inundation between mean sea level and highest astronomical tides, and they provide vital structure as habitat and food for similarly adapted resident and transient fauna. Mangrove plants exchange gases from exposed roots using special lenticels, while flooding tides allow uptake of river-borne nutrients and frequent dispersal by their buoyant propagules. The ecological limits defined by the diurnal tidal range explain the setting and why just 70 species around the world are considered to be mangroves (Tomlinson 1986, Duke et al. 1998), compared with adjacent rainforests that may have hundreds of tree species per hectare. Specialized morphological and physiological characteristics largely define and characterize mangrove plants, such as buttress trunks and roots providing support in soft sediments, aboveground roots allowing vital gas exchange in anaerobic sediments, and physiological adaptations for excluding or expelling salt. Fewer than 22 plant families have developed such essential attributes, representing independent instances of co-evolution over millions of years to form today's mangrove habitats.



World distributions of stilt mangroves, the IWP Rhizophora species. Given the hybrid status of *Rhizophora* × *lamarckii* (= *R. stylosa* × *R. apiculata*) and *R.* × *annamalai* (= *R. mucronata* × *R. apiculata*), their distribution is likely where the distributions of their respective parent trees overlap. Coastlines marked in red indicate the distribution of all mangroves. IMAGE: N.C. DUKE

are difficult to distinguish based on morphological characters alone.

Of great interest also in the southwestern Pacific islands is the only occurrence of another hybrid taxon, *R.* × *selala* (Salvoza) Tomlinson, derived from putative parents *R. samoensis* (=*R. mangle*?) and *R. stylosa* (=*R. mucronata* var. *stylosa*?). This hybrid taxon is special because *R. samoensis* is a key member of the AEP red mangrove *Rhizophora* species. The occurrence of this hybrid means there appears to be very little genetic separation between these defining and most divergent of *Rhizophora* species.

Current distribution

There are no reports of any stilt mangroves occurring outside their natural range. However, these species are recognized as valuable timber producers, so it is possible that their dispersal east in the Pacific and elsewhere may have been assisted by indigenous peoples in the past.

BOTANICAL DESCRIPTION

Preferred scientific names

Rhizophora mucronata Lamk.
Rhizophora stylosa Griff. (= *R. mucronata* var. *stylosa* (Griff.) Salvoza)
Rhizophora apiculata Bl.
Rhizophora × *lamarckii* Montr. (= *R. stylosa* × *R. apiculata)*
Rhizophora × *annamalai* K. Kathiresan. (= *R. mucronata* × *R. apiculata)*

Family

Rhizophoraceae (mangrove family)

Common names

aak, *akelel*, *akapah* (Pohnpei, FSM)
abat (Ceram, Indonesia)
ailave, *kailau* (Aru, Indonesia)
bakau (Malay Peninsula, Singapore, Borneo, Sumatra)
bakauan, *bakau, bakhaw* (Philippines)
bako (Java, Indonesia)
bangka (Acheh, Indonesia)
chia, *cia* (Chuuk, FSM)
Indo–West Pacific stilt mangroves (English)
kahrak, *suhkasrik*, *sakasrik* (Kosrae, FSM)
koriki (Daru and Kiwai, PNG)
lolaro, *belukap* (Sulawesi, Indonesia)
mangle hembra (Guam: Chamorro)
ngochangochara, petu rogha (Marovo, Solomon Islands)
prop root mangroves (northeastern Australia)

raway, *roway*, *ravey* (Yap Islands, FSM)
red, tall-stilted mangrove (Queensland)
spotted leaved red mangrove (Western Australia)
tebechel, *bngaol*, *agpat*, *apgal* (Palau)
tiri tambua (Fiji)
totoa (Motu, PNG)

Size

Indo–West Pacific stilt mangroves are medium to tall trees that may reach 30–40 m (100–130 ft) in height, although they are commonly much shorter, around 5–8 m (16–26 ft). Stem diameters are often about 15–35 cm (6–14 in) taken just above the highest prop root. This measure differs fundamentally from the standard diameter at breast height (dbh) used for most forest surveys, as diameter height above the substrate varies from 0.5 to 7 m (1.6–23 ft) (consider the tree in the photo on the first page).

Form

Stilt mangroves are rambling to columnar trees with distinct aboveground prop roots. Trees tend to be of shorter stature and more spreading in shape on the seaward edge of stands or in areas of higher salinity. Taller, single-stemmed trees are found most often just behind the water's edge of stands midstream in major riverine estuaries. Multi-stemmed trees are common in more arid or marginal habitats.

Flowering

Flowers are perfect. Inflorescences have few to many joints with 1,2-chotomous branching and one to many buds possible per inflorescence. Open flowers are located within or below leaf axils at leaf nodes below the apical shoot, depending on species. For *R. mucronata*, *R. stylosa*, *R.* × *annamalai*. *R.* × *lamarckii*, and *R. apiculata* mature buds and flowers are located at 1–3, 1–5, 3–5, 3–6, and 6–11 nodes down from apical shoot, respectively. Calyces are typically pale yellow at maturity with 4 lobes, rarely 3. Buds are obovate, green when immature to pale yellowish green as they mature, dimensions 1–2 cm (0.4–0.8 in) long and ~1 cm (0.4 in) wide. Petals, usually 4, are lanceolate to linear, creamy white, woolly to hairless, ~10 mm (0.4 in) long and ~2 mm (0.08 in) wide. Stamens number 7–12, pale yellow. Style is pale green, terete, 0.5–6 mm (0.02–0.24 in) above base, dichotomous tip. Bracts and bracteoles are variable depending on species. Mature bud bracts are slender green (*R. mucronata, R. stylosa*), swollen green (*R.* × *annamalai, R.* × *lamarckii*) and swollen corky green (*R. apiculata*). Peduncles are 1–7 cm (0.4–2.8 in) long, and ~3 mm (0.12 in) wide. Flowering period is chiefly during August–December in the southern hemisphere, and during February–June in the northern hemisphere.

Leaves

Leaves are opposite, simple, light or dark green, obovate, leathery, margins revolute, bluntly acute apex with a distinct mucronate tip, 1–7 mm (0.04–0.3 in) long. Upper leaf surface is smooth, shiny. Cork wart spots occur on undersurface, scattered evenly, not raised, present in most species in most locations, but absent only from *R. apiculata* and *R.* × *lamarckii* in southern New Guinea and Australia. Mature leaf dimensions are 6–19 cm (2.4–7.5 in) long, and 3–10 cm (1.2–3.9 in) wide. Petiole 1–4 mm (0.04–0.16 in) long.

Leaf emergence is mostly around November–February in the southern hemisphere and May–August in the northern hemisphere. Leaf fall occurs mostly during the wet summer period from October to February in the southern hemisphere and April–August in the northern hemisphere.

Fruit

Fruits, when mature, are pear-shaped, elongate, waist constriction, smooth brown surface, calyx lobes elongate spreading (when hypocotyl ready to emerge). For *R. mucronata*, *R. stylosa*, *R.* × *annamalai*, *R.* × *lamarckii*, and *R. apiculata* mature fruit located in leaf axils 3–5, 4–7, 5 (rare), 7 (rare), and 8 nodes down from apical shoot, respectively.

Seeds/hypocotyls

Like all *Rhizophora* species, stilt mangroves are viviparous, meaning that the trees produce seeds hidden in the mature fruit, and these germinate on the parent tree. The dispersal unit, a viviparous seedling, is called a hypocotyl. One hypocotyl is usually produced from each fruit, although on rare occasions twins may be observed.

Hypocotyls are narrowly cylindrical, elongate, green, smooth with irregular small brown lenticels, distal half is slightly wider, distal tip is pointed in most taxa, but rounded to blunt for *R. apiculata*. For *R. mucronata*, *R. stylosa*, *R.* × *annamalai*, *R.* × *lamarckii*, and *R. apiculata* mature hypocotyls are located in leaf axils 4–10, 4–9, none, 8–9 (rarely observed), and 9–13 nodes down from the apical shoot, respectively. Hypocotyl dimensions are variable and not consistently species-specific, 14–80 cm (6–31 in) long, 1–2 cm (0.4-0.8 in) at the widest point, and 0.5–1.5 cm (0.2–0.6 in) wide at the "collar," the fruiting structure that envelops the plumule (embryonic leaves).

"Fruiting," when mature hypocotyls fall, occurs chiefly (but not exclusively) from November to January in the southern hemisphere and May to July in the northern hemisphere.

Bark

The bark is gray to dark gray and heavily fissured, occa-

Top left: The distinct mucronate (abrupt, pointed) tip at the apex of leaves is characteristic of all IWP stilt *Rhizophora*. The coloration of the mucronate tip shown in this image of *R. stylosa* is variably red or green. Northeastern Australia. Top right: Inflorescence of *Rhizophora mucronata* (similar to *R. stylosa*) showing open flowers with distinctive woolly petals and slender smooth bract beneath the calyx. Bottom left: Inflorescence of *Rhizophora apiculata* showing open flowers with distinctive hairless petals, non-reflexed calyx lobes, and corky bract beneath the calyx. Bottom right: Leafy rosette of *Rhizophora mucronata* (similar to *R. stylosa*) showing mature buds and mature fruit. PHOTOS: N.C. DUKE

sionally red-brown and smooth. Prop roots are sturdy even when relatively thin.

Rooting habit

Mature trees have distinctive, sturdy, aboveground prop roots surrounding the stem base that anchor only shallowly in the sediments to 1–2 m (3.3–6.6 ft) depth. This conforms to the oxygen deficient (anoxic) conditions commonly measured in mangrove sediments.

Similar species

Stilt mangroves are distinguished from Atlantic–East Pacific red mangrove species principally by the spiked, mucronate tip at the leaf apex of stilt mangroves that is absent in red mangroves.

Rhizophora mucronata and *R. stylosa* have slender (i.e., length much greater than the width) bracts at the base of mature buds as distinguished from *R. apiculata, R.* × *lamarckii*, and *R.* × *annamalai* that have bracts almost as wide, or wider than the length.

Rhizophora apiculata is distinguished from *R.* × *lamarckii* and *R.* × *annamalai* plus other IWP species by swollen (wider than long), corky brown bracts, one inflorescence joint, and node position of mature buds and flowers in leaf axils at 6–11 nodes down from apical shoot, well below leaves in the leafy shoot.

Hybrid characteristics are shown in *R.* × *lamarckii* where

Mature hypocotyls of *Rhizophora stylosa* (similar to *R. mucronata*). Great Sandy Straits, NE Australia. PHOTO: N.C. DUKE

Left to right: Mature flower buds of *Rhizophora apiculata*, *R.* × *lamarckii*, *R. stylosa,* and *R. mucronata*. These samples were collected in NE Australia, where the four species grow side by side in several estuaries. PHOTO: N.C. DUKE

it has key characters intermediate between *R. apiculata* and *R. stylosa*. Similarly, hybrid characteristics are shown in *R.* × *annamalai*, which has key characters intermediate between *R. apiculata* and *R. mucronata*. Hybrids can often be larger and taller than neighboring parent trees.

Rhizophora × *lamarckii* is distinguished from *R.* × *annamalai* by style length <1.7 mm (0.07 in).

Rhizophora mucronata and *R. stylosa*, the sibling species, are distinguished by short styles (<2 mm [0.08 in] long) in *R. mucronata*, while *R. stylosa* has long styles (>2 mm [0.08 in] long). As noted, *R. mucronata* and *R. stylosa* appear closely related and are possibly the same species. If genetic studies show them to be the same, then *R. stylosa* would be renamed *R. mucronata* var. *stylosa*. Discriminating between them reliably is not possible in many instances without detailed examination of key morphological and genetic characteristics. Individuals with intermediate length styles occur in several locations.

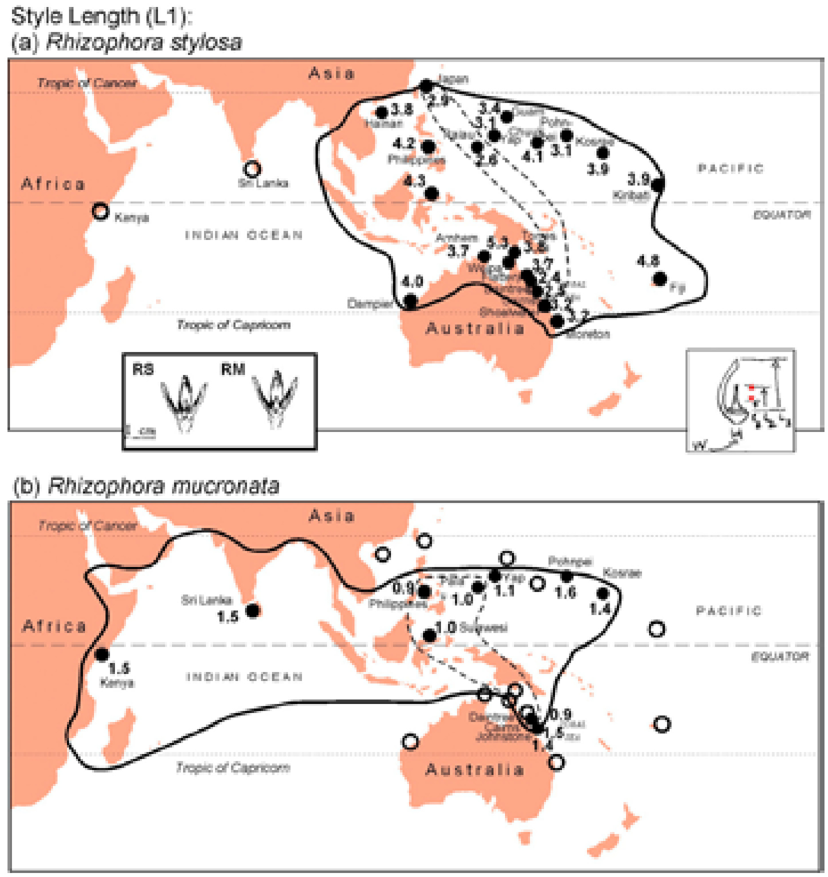
GENETICS

Variability of species

Indo–West Pacific stilt mangroves are those *Rhizophora* species that occur naturally from east Africa to the western Pacific Ocean (see the map). This group comprises five relatively distinct taxa, although at times their morphological and taxonomic differences appear questionable. The uncertainty is chiefly based on: 1) the presence of two intermediate individuals that are recognized as distinct hybrids, namely *R.* × *lamarckii* and *R.* × *annamalai*, and 2) the occurrence of two sibling species, *R. mucronata* and *R. stylosa*, which may, on closer examination, be shown to be the same species.

The relationship of *R. mucronata* and *R. stylosa* is perhaps the most contentious. They appear closely related because they are distinguished only by one key character, namely style length. The sibling species are largely not separated geographically, with a significant portion of the range of each overlapping the other. However, their ranges do include areas of exclusivity in the west and east, respectively. There are also indications that morphological and ecological characteristics vary for each taxon across their wide ranges. For instance, *R. mucronata* in east Africa has the same exposed water edge habit as *R. stylosa* in northern Australia. By contrast, *R. mucronata* in Australia and Asia occurs in upstream locations of freshwater dominated estuaries. There are also subtle but distinct differences in morphological characteristics in *R. mucronata* for bud shape, inflorescence structure, and leaf dimensions that may be related to differences in habitat. It is clear that *R. stylosa* is the taxon best adapted to marine exposed locations wherever it occurs.

It is of great interest to fully evaluate the relative and precise distributions of *R. mucronata* and *R. stylosa*, because these are likely to explain the way species have naturally evolved and dispersed. In some island groups to the north of Australia, for instance, there is a curious pattern in separate sympatric occurrences where these species are easily distinguished in some populations (Philippines, Sulawesi) while in others (Federated States of Micronesia, Palau) their style lengths overlap, making it impossible to always tell them apart using this character. This may be explained by a progressive lengthening of the style in *R. stylosa*, corresponding possibly with its more recent introduction in locations with longer styles. If this is correct, *R. stylosa* has spread from Australia and Federated States of Micronesia both westward and eastward; for example, in Sulawesi and Fiji where style lengths are the longest recorded. This idea concurs with the specialized marine habit of this species.



Variation in style length of *Rhizophora stylosa* and *R. mucronata* in the IWP region. Note that for each species, but especially for *R. stylosa*, larger styles occur in eastern and western populations. IMAGES: N. C. DUKE

By contrast, *R. apiculata* is readily distinguished from *R. mucronata* and *R. stylosa*. This species appears more prevalent in estuaries influenced by larger and more continuous freshwater flows, and it is found in a continuous distributional range, from India to the western Pacific and northern Australia. Across this range there are also two forms of *R. apiculata*, and their occurrences do not overlap. One form, found north and west from the northern New Guinea coast, fits the type description in every respect including the presence of cork wart spots on leaf undersurfaces. The other form lacking these spots occurs south and east from the southern New Guinea coast. This character was thought to be unique to *R. apiculata* until recently, when trees of *R. racemosa* (an AEP red mangrove) without spots were discovered in Brazil. This character helps define two forms of *R. apiculata* in Australasia and the western Pacific.

Known varieties and hybrids

Rhizophora mucronata and *R. stylosa* are both known to hybridize with *R. apiculata*, giving rise to morphologically distinct and geographically widespread hybrid forms, *R.* × *annamalai* and *R.* × *lamarckii*, respectively. Their hybrid status was initially based on intermediate morphological characters but has since been confirmed in genetic investigations.

As discussed above, *R. mucronata* and *R. stylosa* are sibling species with few diagnostic characters to separate them and a corresponding lack of genetic separation. This clearly makes it difficult to separate respective hybrid forms with *R. apiculata*, although this may be done by also using the style length character. The situation is more complex, however, when it must be considered further that there are the two forms of *R. apiculata*. These each have hybrids with *R. stylosa* based on occurrences north and south of New Guinea.

IWP stilt mangroves are also characterized by a number of notable genetic, morphological, and growth variants. Aberrant traits are observed in a small number of individuals throughout the range. Perhaps the most consistent aberrant trait, however, is "albino" hypocotyls (i.e., those lacking any green pigment, leaving them red or yellow) observed in Australia, Federated States of Micronesia, Palau, and other places. Yellow or red propagules can be observed hanging in affected trees alongside normal green propagules of all IWP species. Their relative number on an individual tree is thought to quantify the amount of outcrossing that occurs with neighboring normal trees. On rare occasions, other trees have also been observed with variegated foliage.

Culturally important related species

All *Rhizophora* species are closely similar in tree form, and different cultural groups in the Pacific region may not always distinguish between them. Other mangrove genera, like *Bruguiera*, are considered close in form and value also, and these are often used in similar ways by indigenous peoples.

Foliage of *Rhizophora mucronata* showing a tree with a rare yellow "albino" form of hypocotyls among the normal green hypocotyls. Johnstone River, NE Australia. PHOTO: N. C. DUKE

ASSOCIATED PLANT SPECIES

IWP stilt mangroves are naturally associated with a number of other mangrove and non-mangrove species across their wide range of tidal and estuarine locations. Planting with other species is highly recommended, particularly terrestrial and beach strand associates growing naturally above mean sea level elevations. The idea is to establish and achieve whole-of-bank stabilization as soon as possible. Since stilt mangroves also occupy a range of substrate types, including coral, rocks, gravel, sand, and mud, it is important to choose associated species best suited to the particular local conditions.

Associated species commonly found

The associated species vary with geographic location, latitude, soil type, estuarine upstream location, and tidal position.

In frontal stands, IWP stilt mangroves may be associated with *Sonneratia alba* and *Avicennia marina* downstream. Where downstream stands of stilt mangroves are backed by sand ridges and beach margins, the associated species include *Calophyllum* spp., *Thespesia* spp., *Casuarina* spp., *Barringtonia asiatica,* and *Cocos nucifera*.

Upstream in riverine estuaries of tropical coastlines of larger islands and continental margins, associated species include *Sonneratia caseolaris*, *S. lanceolata*, and *Aegiceras corniculatum*. In such upstream locations, stilt mangroves are commonly backed by *Bruguiera* and other higher intertidal mangrove species, as well as associated upland species including *Barringtonia racemosa* and *Hibiscus tiliaceus*.

ENVIRONMENTAL PREFERENCES AND TOLERANCES

Climate

IWP stilt mangroves thrive in tropical and subtropical environments characterized by moderately high and well distributed rainfall. However, in drier locations, like in northern areas of Western Australia, the stunted but dense thickets of *R. stylosa* attest to the great adaptability of stilt mangroves to a wide range of climatic types.

Elevation range

0–6 m (0–20 ft), in reference to mean sea level.

Mean annual rainfall

These mangroves grow in all rainfall conditions. Their extent, form, and biomass reflect the different rainfall conditions.

Rainfall pattern

Grows in climates with summer or uniform rainfall patterns.

Dry season duration (consecutive months with <40 mm [1.6 in] rainfall)

Mangrove plants appear to depend on groundwater to sustain optimal growth, especially during drier months. Across a wide variety of climatic regions, mangrove cover expands and contracts through time. This has been evident in correlations between El Niño events and reduced growth as possible causes of some damage to mangroves, presumably due to decreases in freshwater availability.

Mean annual temperature

20–30°C (68–86°F) (estimate)

Mean maximum temperature of hottest month

23–38°C (73–100°F) (estimate)

Mean minimum temperature of coldest month

13–18°C (55–64°F)

Minimum temperature tolerated

10°C (50°F) (estimate)

Soils

Trees develop greatest stature and columnar growth form in estuaries of larger tropical rivers, characterized by fine clay, black mud sediments with relatively high loads of organic carbon, and anaerobic soils with high concentrations of sulfide. Trees also grow well in sites with aerobic sediments consisting of fine sands to coarse stones and rocks, as well as coral ramparts.

Soil texture

Plants grow best in light, medium, and heavy texture soils (sands, sandy loams, loams, sandy clay loams, sandy clays, clay loams, and clays).

Soil drainage

Plants grow best in soils with free and un-impeded drainage, as well as waterlogged soils.

Soil acidity

pH 6–8.5

Special soil tolerances

Plants grow best in saline soils but can survive well in fresh water. The optimal salinity range is reported to be 8–26 ppt (parts per thousand), compared to approximately 34–36 ppt for seawater.

Tolerances

Drought

Stilt mangroves usually grow best in wetter conditions. However, *R. stylosa* and western range *R. mucronata* can tolerate drought periods well.

Full sun

They usually grow best in full sun.

Shade

Stilt mangroves are usually considered to have a very low tolerance of shade. However, in eastern Australia at its southern latitudinal limit, *R. stylosa* trees commonly grow under a closed canopy of *Avicennia marina*. This may be

MANGROVES AND CLIMATE CHANGE

Indo–West Pacific stilt mangroves, like other mangrove species, are affected by climate change. The unique physiological characteristics of each species define its capacity for survival in the face of change. Mangroves are expected to respond rapidly and decisively to shifts in key factors, like temperature, rainfall, and sea level, as each species has defined ranges of tolerance for each factor. For instance, because mangroves are characteristically restricted to elevations between mean sea level and highest tides, as sea level rises their communities must move upland to survive. Since mangroves have narrow optimal temperature ranges, rising temperatures will cause their distributions to shift north or south to areas where temperature conditions are most suitable, and they will die off in areas where they are not suited. Of course, their success in making these shifts depends on their successful dispersal and re-establishment, and the availability of suitable new space. Clearly, such changes have occurred throughout history, so the distribution of mangroves today represents the survivors of all past changes.

Key indicators of change can be identified and mapped as incremental shifts and responses of mangrove communities. These might be observed as shifts in vegetation, for example: 1) in the total tidal wetland habitat zone, as expected with changes in sea level; and 2) in the salt marsh–mangrove ecotone, as expected with changes in longer-term rainfall patterns as this affects moisture stress in saline environments. In both cases, the response zones will follow elevation contours. Changes along contours can be quantified from long-term spatial assessments over decade- and century-long time periods, depending on the rates of change. Knowledge of these changes and their causes allows better prediction of future change.

due to the absence of scolytid beetle larvae that usually infect shaded propagule-seedlings in the tropics (Brook 2001). If this is the case, it implies *Rhizophora* seedlings might be more shade tolerant than originally thought (Sousa et al. 2003). This is supported further by the observation that *Bruguiera* species, the apparent shade specialists of tropical areas, had few scolytid infections.

Fire

The trees have no tolerance of fire in close proximity.

Frost

They have low tolerance of sub-freezing temperatures.

Waterlogging

Stilt mangrove trees are tolerant of daily tidal flooding up to depths of 2.5 m (8 ft). While tolerating permanently saturated soils, they are intolerant of drying soils.

Salt spray

They are highly tolerant of salt spray.

Wind

Some species of stilt mangrove trees are typically found on the exposed water's edge of large riverine estuaries.

Trunk of *Rhizophora mucronata* showing distinctive stilt roots. Kenya, E Africa. PHOTO: N. C. DUKE

Abilities

Self-prune

Stilt mangroves self-prune well in dense stands, but they commonly maintain lower branches in more open locations.

Coppice

The trees have notably poor coppice ability. Generally, if greater than 50% or more of the leaves are removed from a tree, they will die. There appears to be a variant of *R. apiculata* in the Philippines and in some islands of the Federated States of Micronesia (Pohnpei and Kosrae) that is used by local people for sustainable firewood collection. These trees regrow from regular cutting, which keeps them stunted.

GROWTH AND DEVELOPMENT

Growth rates vary with age. The tree generally grows less than 1 m/yr in height but can exceed this in favorable circumstances. Height growth is rapid shortly after establishment while food reserves are taken up from the hypocotyls of established propagules. The growth rates appear to slow when trees approach a site maximal canopy height, dependant on specific site/location conditions. When near maturity, trees tend to spread and broaden their canopy and stem diameter rather than grow taller.

Flowering and fruiting

Flowering and fruiting periods of stilt mangroves are distinctly seasonal. Furthermore, peak pheno-events shift later with cooler temperatures and higher latitudes. Trees have notable and relatively long periods of reproductive development, taking 18–30 months from first emergence of flower bud primordia until maturation and drop of mature hypocotyls. The duration depends on species, with the longest being *Rhizophora apiculata*, with around 30 months for each reproductive cycle.

Yields/growth rates

Growth rates vary with species, spatial position in the stand, competition, vigor, and age. In the Matang Mangrove Forest Reserve in Malaysia, Putz and Chan (1986) reported that diameter growth rates of *R. apiculata* trees were 0.24–0.29 cm (0.09–0.11 in) for diameter size classes from 10 to 60 cm (4–24 in).

Watson (1928) estimated that under Malaysian conditions mean annual increment (MAI) of stilt mangroves culminated at around 10.6 m^3/ha/yr (152 ft^3/ac/yr) at 39–40 years.

Reaction to competition

Rapid early growth of seedlings of stilt mangroves in full sunlight ensures their success and dominance in preferred estuarine and intertidal conditions. Newly established seedlings grow best in close proximity with their same species cohort. This affords them maximal protection from physical damage by drift logs and erosive waves. Since competition is high between neighboring seedlings, slower plants die and decompose quickly, leaving faster competitors the benefit of not only the space they occupied but also their nutrients.

PROPAGATION

IWP stilt mangroves are readily propagated by direct planting of their propagules. Although natural regeneration is generally relied upon around the Pacific region, these species are relatively easy to propagate. Propagation is simple and relies on the special feature of the genus in having large viviparous propagules. Planting simply entails gently pushing the distal end of the 20–80 cm (8–31 in) long hypocotyl one third of its length into the sediment, spaced at about 1–1.5 m (3.3–5 ft) intervals. No holes need be dug, and neither nursery preparation nor stakes are needed. Low maintenance is generally required for maximizing seedling establishment success in sheltered areas. However, substantial protection is required in more exposed coastal locations during the first decade of establishment. Such protection methods may include encasement of individual seedlings in PVC piping (Riley and Kent 1999), or installation of temporary structures to dampen wave action and reduce debris drift across restoration sites as observed in Vietnam and China (Field 1996).

Propagule collection

Propagules may be available throughout the year, but peak production occurs around July–August in northern parts of the range and around January–February in the southern hemisphere. Mature propagules may be collected after they have fallen or been picked directly off trees. Only healthy looking propagules should be selected. Propagules that are shrunken or desiccated in appearance or that exhibit significant physical damage should be rejected. Although propagules with only minor borer damage may survive and grow, selection of propagules with no signs of borer or crab damage is strongly preferred. Propagules that already have some root or leaf development can be used in most cases but should not be stored for long.

Propagule processing

Processing of mature propagules is not required for stilt mangroves, although damaged and insect infested individuals should be removed. Also see the following pretreatment section for possible additional steps. Propagules can be sown in nursery beds, or preferably planted directly in the field soon after collection.

Propagule storage

Propagules can be kept viable for at least 6–7 days by storing them in brackish water or by wrapping them in wet

Left: Mature hypocotyl and fruits of *Rhizophora mucronata* showing distinctive collar on attached propagule and expended fruit. PHOTO: N. C. DUKE
Right: A sectioned wilting seedling of *Rhizophora stylosa* shows the extent of scolytid infection marked by brown frass. PHOTOS: B. M. BROOK

burlap bags and keeping them out of direct sunlight. Pretreatment is considered essential if considering such storage (see below). It is likely that propagules can be kept longer, but storage beyond 2 weeks is not recommended, and long-term storage is not feasible.

Propagule pretreatment

Pretreatment of propagules is generally considered unnecessary. However, a study of scolytid beetle larvae (*Coccotrypes fallax*) infections on *Rhizophora* propagules in Australia found at least 18% that were heavily infested (Brook 2001). Infested propagules were established under canopy-shaded areas. The study went further, finding that pretreatment in a 50°C (122°F) water bath for 5 minutes killed the beetles and removed the risk of establishment loses due to borer damage. Heat treatment might be easily achieved by leaving the collected propagules in the sun for a short period (a few hours) before planting.

New planting on seaward edge of *R. apiculata* at Ao Khung Krabaen Mangrove Forestry Center, Som Lek, Thailand. PHOTO: C. ELEVITCH

Growing area

Stilt mangroves should be grown in full sunlight.

Seedling establishment

Leaves and roots may begin to develop within a week or two of sowing.

Media

Although a wide variety of soil media are acceptable, a mix of sand and peat in equal parts has been recommended for mangrove nurseries.

Time to outplanting

Anytime during the year is suitable. Seedlings are ready for outplanting at the 6-leaf (=3 node) stage if grown up in nursery conditions. Older seedlings up to 0.5 m (20 in) tall have also been successfully transplanted, but this is not considered beneficial.

Direct planting of large numbers of propagules is restricted by their peak seasonal availability, as propagules do not keep for extended periods unless planted out in nursery conditions.

Guidelines for outplanting

Propagules or nursery-grown seedlings usually have excellent survival in sites correctly selected and, if appropriate, protected from disturbance. Survival rates of 90% or greater are not unreasonable in such circumstances.

On the other hand, survival may be zero on sites exposed to excessive wave action, on sites with inappropriate hydrologic or salinity regimes, or (rarely) disturbance by grazing animals (e.g., goats, sheep, cattle, and horses). A method of encasing propagules in PVC pipe has been used in Florida and the Caribbean to protect seedlings in places with a high likelihood of disturbance.

DISADVANTAGES

In general, the planting of stilt mangroves poses few significant disadvantages when planted within their native ranges. They are not especially susceptible to pests or pathogens and they have not been reported to host major pests or pathogens of important crop species.

Potential for invasiveness

Although the invasiveness of stilt mangroves has not been demonstrated, they are likely to be opportunistic due to their relatively wide tolerance for salinity and soil conditions. The spread of the closely allied AEP red mangrove species *R. mangle* when introduced into Hawai'i has clearly demonstrated the potential for invasiveness of these mangroves. Although they were not native, suitable growing conditions existed, demonstrating that the global distribution of *Rhizophora* spp. is currently limited by their natural

BENEFITS OF MANGROVE TIDAL WETLAND

Benefits include, in no particular order (adapted from Tomlinson 1986):

- visual amenity and shoreline beautification
- nutrient uptake, fixation, trapping, and turnover
- habitat use by fauna
- mesoclimate, where forests moderate evapotranspiration to create a specialized niche climate
- nursery habitat for young fauna, where mangroves provide a source of food and physical protection from predation
- sanctuary niche for mature fauna, including migratory birds and fish, where mangroves provide protection and a food resource
- primary production based on photosynthesis, giving rise to forest growth and forest products, notably timber
- secondary production, including microbial and faunal production, as well as grazers, and via decomposition
- fishery products, including both estuarine and coastal
- shoreline protection, based on general mangrove tree and root structure, as well as edge trees, which reduce erosion and provide stand protection from waves and water movement
- carbon sequestration and a sink where carbon is bound within living plant biomass
- sediment trapping, based on mangroves being a depositional site for both water and airborne sediments, which in turn reduces turbidity of coastal waters.

dispersal range. This also means geographically isolated populations are vulnerable to introductions of genotypes from elsewhere.

Susceptibility to pests/pathogens

Susceptibility to pests and diseases is believed to be low, with the exception of insect borers and crabs that feed on propagules.

Host to crop pests/pathogens

No reports were found of stilt mangroves serving as hosts for known major crop pests or pathogens. The scolytid beetles are specific to the genus *Rhizophora*.

AGROFORESTRY/ ENVIRONMENTAL PRACTICES

Mulch/organic matter

Mulch in *Rhizophora* forests is hidden from view. If it were not for the small mangrove crabs, fallen leaves would be washed away with each tide. The crabs actively take leaves into underground burrows and chambers. The resulting mulch is rapidly colonized by bacteria and consumed by other burrowing fauna to release nutrients that appear to further enhance the forest.

Soil stabilization

Stilt mangrove forests stabilize soils with their network of sturdy overlapping prop roots dampening water movement and promoting sedimentation in areas that might otherwise be eroded.

Rhizophora mucronata **tree growing on the edge of an estuarine channel. While the stem leans out over the water to get the most light, the stilts both support the tree and stabilize the bank.** PHOTO: N. C. DUKE

Fence posts

Stilt mangrove stems make good posts since they are generally hard wood and resistant to insect borers.

Windbreaks

Rhizophora forests provide a windbreak along coastal margins, generally, and as places to seek sanctuary during typhoons and cyclones. Planting in highly wind-prone locations is not recommended unless the location has some history, or reasonable expectation, that mangrove survival is likely.

Woodlot

Mangroves adjacent to peoples' homes throughout the Pacific frequently serve as informal woodlots, particularly on islands with clear tenure systems that include mangrove areas. Stilt mangrove wood is very useful for small construction, and for cooking fuel. Converting it to charcoal can further enhance the timbers' calorific value. This is done commercially in SE Asia and Central America with various *Rhizophora* species.

Native animal/bird food

IWP stilt mangroves are largely an unknown source of native animal foods. However, several observations demonstrate that the diversity and quantity of the source is thought to be extremely important in mangrove ecosystems. Numerous insects, crabs, and mollusks graze on green leaves in the forest canopy. Sesarmid crabs consume a large quantity of fallen leaves and propagules. Organic matter processed by these herbivores is believed to broadly support aquatic food chains in coastal regions. Few mammals appear to use stilt mangroves as a major food source, although native rats often chew into the wood in search of boring insect larvae.

Wildlife habitat

In addition to aquatic marine organisms (see Fish/marine food chain), stilt mangroves serve as habitat for a wide range of terrestrial and arboreal wildlife. In various locations throughout the region, these forests provide shelter and food for a number of associated fauna, including birds, fruit bats, small mammals, shellfish, and other marine life.

Bee forage

Rhizophora species have no nectar, but they do produce copious pollen that is usually distributed by wind.

Fish/marine food chain

Mangroves in general are believed to play a vitally important role in protecting and supporting marine food chains. Many fish species use stilt mangroves during part of their life cycles, as do species of shrimp and crabs. Species such as the mangrove mud crab (*Scylla serrata*) are common in IWP mangroves, and these are important sources of food and income on many islands in the region. Populations of some smaller species may exceed 10 crabs/m^2 (1 crab/ft^2) in parts of the Pacific. Senescent leaves having fallen from *Rhizophora* trees are taken by grapsid (small mangrove) crabs into their burrows. Buried leaves decompose and contribute to nutrient recycling in mangrove forests. Nutrients also feed directly and indirectly to associated estuarine and marine food chains.

Rhizophora stylosa **sprouted propagules for sale in Iriomote, Japan.** PHOTO: N. C. DUKE

Coastal protection

Stilt mangrove forests, and mangroves in general, play an important role in protection of coastlines, fishponds, and other coastal infrastructure. Stilt mangroves are planted for coastal or fishpond protection in some areas (e.g., in Kalibo Bakhawan Eco Park, the Philippines) and there are laws in many locations aimed at protecting mangroves in large part because of this important function.

Ornamental

No significant ornamental trade is known. However, as an apparently isolated example, a small number of plants are sold as souvenirs to departing tourists from Iriomote and other southern islands of Japan. Sprouted hypocotyl seedlings are used to make bonsai "forest gardens."

USES AND PRODUCTS

IWP stilt mangroves are probably of greatest value for their environmental benefits, because they (and mangroves generally) are believed to play a vital role in supporting marine food chains, protecting coastal areas, and improving water quality.

In terms of direct benefits to people, the most widespread use of stilt mangroves is for wood for a range of purposes from cooking fuel to construction of homes and canoe parts. Other uses of the stilt mangroves include tannin and dyes. A less lauded benefit has been derived from some ecotourism ventures. The dual benefit in this practice comes from both a moderate economic return combined with a substantial longer-term educational value in raising environmental awareness in the community.

Staple food

Leaves and hypocotyls are edible but not widely used for food.

Medicinal

Stilt mangrove bark has reportedly been used to treat angina, boils, and fungal infections. The leaves and bark have been used as an antiseptic and to treat diarrhea, dysentery, fever, malaria, and leprosy, although it is not clear how effective the treatments have been in each of these cases.

Timber

The wood of stilt mangroves is widely used for structural components (e.g., poles, beams, flooring, wall-cladding, and rafters) of traditional homes and other structures like underground mine supports, fencing, cabinet works, tool handles, and boat anchors. The wood is also used for other purposes, ranging from traditional uses such as fishing stakes, spears, and copra-huskers to use as a source of chips for pulp production. However, pulp from *Rhizophora* species does not have good strength properties, so these species are not often sought after for this purpose (Percival and Womersley 1975).

Fuelwood

Stilt mangrove wood is used for fuelwood on many Pacific islands (e.g., Kosrae and Chuuk). The wood is also made into charcoal in countries such as the Philippines, Indonesia, and Malaysia (Ong et al. 1980, 1995).

Canoe/boat/raft making

The wood has been used to make canoe parts.

Top: Mangrove tourism in Hainan, China, complete with *Rhizophora* motifs on the jetty handrail panels. PHOTO: N. C. DUKE **Bottom: Boardwalk and signage for visitors (*R. mucronata* on left and *R. apiculata* on right), Ao Khung Krabaen Mangrove Forestry Center, Som Lek, Thailand.** PHOTO: C. ELEVITCH

Tannin/dye

The bark and hypocotyls are used to produce dyes ranging from red-brown to black (the latter with repeated dying). *Rhizophora* species are the best producers of tannins of all the mangroves with 20–25% of bark weight (Percival and Womersley 1975). Chopped bark is treated by continuous countercurrent extraction with first cold then warm water producing an extract called "cutch." The cutch can be exported for processing and final tannin extraction. Tannins were used extensively for preserving cotton ropes and netting. Mangrove tannins can be used to prepare tannin formaldehyde adhesives. These adhesives are recognized for their high moisture resistance and waterproof grades in plywood and particleboard production. *Rhizophora* tannins are also known to impart a red color to finished leather tanning, but this is considered undesirable since blending with other tannin extracts is needed.

Ecotourism

The mangrove environment is attractive and interesting to both local people and to visiting tourists. In China, for example, facilities have been provided to assist and regulate this form of ecotourism, including a dedicated hotel and restaurants. Simple boardwalks in other places (e.g., Australia, Thailand) are relatively low key but the intention is the same, to provide public access for those wanting to see and learn about this fascinating environment. The boardwalks are there to make the mangrove experience as effortless as possible while protecting the mangroves from direct damage. Walks are often also accompanied with informative and educational signage.

Eleven-year-old plantation of *Rhizophora apiculata* in the 63 ha (156 ac) Bakhawan Eco Park at Kalibo, northern Panay, Philippines. PHOTO: N. C. DUKE

COMMERCIAL CULTIVATION

Stilt mangrove timber is harvested commercially for charcoal production in SE Asia. The calorific value of the timber is significantly enhanced by converting it to charcoal. This is done with various *Rhizophora* species. Charcoal production has been conducted in a sustainable way on the Malay Peninsula for over 100 years using silvicultural practices developed for *Rhizophora* species, especially *R. apiculata* (Ong et al. 1980, 1995). In addition, forests in Malaysia, New Guinea, and the Solomon Islands have been clear-felled for wood chips using unsustainable harvesting practices.

Spacing

Mangrove plantations in general are typically planted at spacings of about 1.0–1.5 m (3.3–5 ft). Spacing wider than about 2.5 m (8 ft) tends to result in a high proportion of multiple-stemmed and/or shorter trees. Wider spacing and the resulting spreading trees may be desired for coastal protection projects, but not for timber production. In the absence of significant natural mortality timber plantations should be thinned to spacing of 2.5 to 3.5 m (8–11 ft) between trees as the stand develops and becomes crowded.

Management objectives

In areas where the mangrove fern (*Acrostichum speciosum*) is common, it may need to be controlled to promote early growth of stilt mangroves. Some published guidelines for mangrove silviculture exist and are referenced below, but specific guidelines on thinning, fertilizing, etc., are currently unavailable.

Growing in polycultures

Stilt mangroves naturally occur in mixed-species stands, and each species has its own ecological and economic values. Mixed-species plantings are recommended together with large-leaf mangrove, *Bruguiera gymnorrhiza*. It is also important to plant associated buffer areas, especially along the shoreline where mangroves grow better adjacent to banks stabilized by shoreline upland plants. Suitable upland tree genera include *Calophyllum*, *Casuarina*, *Hibiscus*, *Thespesia*, and *Barringtonia*. Within the mangrove forest, natural recruitment will often bring additional mangroves such as *Bruguiera* species, but these might be planted as well. Together they will complement and enhance the richness and stability of the planted environment.

Estimated yield

Snedaker and Brown (1982) state that mangrove forest products in Bangladesh have an annual value of US$36,000,000. Ong (1982) reports that the Matang Reserve in Malaysia with 35,000 ha (86,000 ac) of productive, almost monospecific, forests of *R. apiculata*, the value of mangrove wood alone is close to US$9,000,000 per year.

The Matang Mangrove Forest Reserve in Malaysia has been managed for timber production of chiefly *Rhizophora apiculata* since the beginning of the century and is reputedly the best managed mangrove forest in the world (Khoon and Ong 1995, Ong et al. 1995). The average stand volume for these stilt mangroves was 153 m^3/ha (2190 ft^3/ac). Stand volumes up to 226 m^3/ha (3230 ft^3/ac) have been reported from Thailand.

The present management plan for the Matang Reserve is a 30-year rotation period with two thinnings, at 15 and 20 years. The 30-year rotation harvested yields have been around 136–299 mt/ha (61–133 t/ac) of green wood. However, there has been a decline in yield from 299 mt/ha (133 t/ac) from virgin stands to the second-generation yields of 158 mt/ha (70 t/ac) in 1967–69 to an even lower 136 mt/ha (61 t/ac) in 1970–77. Because the standing biomass of the trees did not increase from 23 years (155 mt/ha [69 t/ac]) to 28 years (153 mt/ha [68 t/ac]), it was suggested that a rotation of 25 years be used instead of the previous recommendation of 30 years.

Markets

Markets on most Pacific islands are local in nature, with little in the way of stilt mangrove products (other than indirect products like mangrove crabs and fruit bats) being exported from one island to another. The exception is probably firewood and charcoal, which is available from local markets in most places. In Southeast Asia, large quantities of stilt mangrove wood chips and charcoal may be moved greater distances and in greater volumes than wood products on smaller islands.

INTERPLANTING/FARM APPLICATIONS

Some interplanting systems include:

Example 1—Bakhawan Eco Park (Primavera et al. 2004)

Location

Aklan, New Buswang, and Kalibo, Philippines

Description

Planting was undertaken in 1989 and 1993. Species planted included *R. apiculata* and *R. mucronata* on a total area planted of 63 ha (156 ac). Sponsors and implementers were DENR, PACAP AusAID, USWAG, and KASAMA.

Crop/tree interactions

Not known.

Spacing/density of species

Spacing was about 1.5 m (5 ft) for both species.

Example 2 (Primavera et al. 2004)

Location

Guimaras and Nueva Valencia, Philippines

Description

The planting was undertaken in 1994. Species planted included *R. apiculata* and *R. mucronata* on a total area of 149 ha (368 ac). Funding source and implementers were DENR-CEP.

Crop/tree interactions

Not known.

Spacing/density of species

Spacing was around 1.5 m (5 ft) for both species.

Example 3 (Primavera et al. 2004)

Location

Iloilo and Carles, Philippines

Description

The planting was done in 2001. Species planted included *R. apiculata* and *R. mucronata* on a total area of 530 ha (1300 ac). Funding source and implementers were DENR Forestry Sector Program: MACABATA-ARM Federated People's Organisation.

Crop/tree interactions

Not known.

Spacing/density of species

Spacing was around 1.5 m (5 ft) for both species.

PUBLIC ASSISTANCE

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Species Profiles for Pacific Island Agroforestry (www.traditionaltree.org)

Rhizophora apiculata, R. mucronata, R. stylosa, R. × annamalai, R. × lamarckii (Indo–West Pacific stilt mangroves)

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Acknowledgments: The author and publisher thank Tom Cole, Farid Dahdouh-Guebas, Dale Evans, Ariel Lugo, and Diane Ragone for their input. Photo contributions by Beth Brook and Craig Elevitch are greatly appreciated. The author acknowledges a host of people who have over the years supported his journey into *Rhizophora* and who share the passion for this group of plants. Collaborators and friends include: Jim Allen, Uta Berger, John Bunt, Molly Crawford, Farid Dahdouh-Guebas, Otto Dalhaus, Kathy Ewel, Candy Feller, XueJun Ge, Gina Holguin, L.P. Jayatissa, Kandasamy Kathiresan, Ken Krauss, Eugenia Lo, Ulf Mehlig, Jaime Polania, Jurgenne Primavera, Ute Steinicke, Mei Sun, and Nick Wilson.

Recommended citation: Duke, N.C. 2006. *Rhizophora apiculata*, *R. mucronata*, *R. stylosa*, *R.* × *annamalai*, *R.* × *lamarckii* (Indo–West Pacific stilt mangroves), ver. 2.1. In: Elevitch, C.R. (ed.). Species Profiles for Pacific Island Agroforestry. Permanent Agriculture Resources (PAR), Hōlualoa, Hawai‘i. <http://www.traditionaltree.org>.

Sponsors: Publication was made possible by generous support of the United States Department of Agriculture Western Region Sustainable Agriculture Research and Education (USDA-WSARE) Program; SPC/GTZ Pacific-German Regional Forestry Project; USDA Natural Resources Conservation Service (USDA NRCS); State of Hawai‘i Department of Land & Natural Resources Division of Forestry & Wildlife; and the USDA Forest Service Forest Lands Enhancement Program. This material is based upon work supported by the Cooperative State Research, Education, and Extension Service, U.S. Department of Agriculture, and Agricultural Experiment Station, Utah State University, under Cooperative Agreement 2002-47001-01327.

Series editor: Craig R. Elevitch

Publisher: Permanent Agriculture Resources (PAR), PO Box 428, Hōlualoa, Hawai‘i 96725, USA; Tel: 808-324-4427; Fax: 808-324-4129; E-mail: par@agroforestry.net; Web: <http://www.agroforestry.net>. This institution is an equal opportunity provider.

Species Profiles for Pacific Island Agroforestry
www.traditionaltree.org

April 2006
ver. 2.1

Samanea saman (rain tree)

Fabaceae (legume family)

filinganga (Northern Marianas); *gouannegoul*, *saman* (French); *gumorni spanis* (Yap); *kasia kula*, *mohemohe* (Tonga); *marmar* (New Guinea); *'ohai* (Hawai'i); rain tree, monkey pod, saman (English); *tamalini*, *tamaligi* (Samoa); *trongkon-mames* (Guam); *vaivai ni vavalangi*, *sirsa* (Fiji)

George W. Staples and Craig R. Elevitch

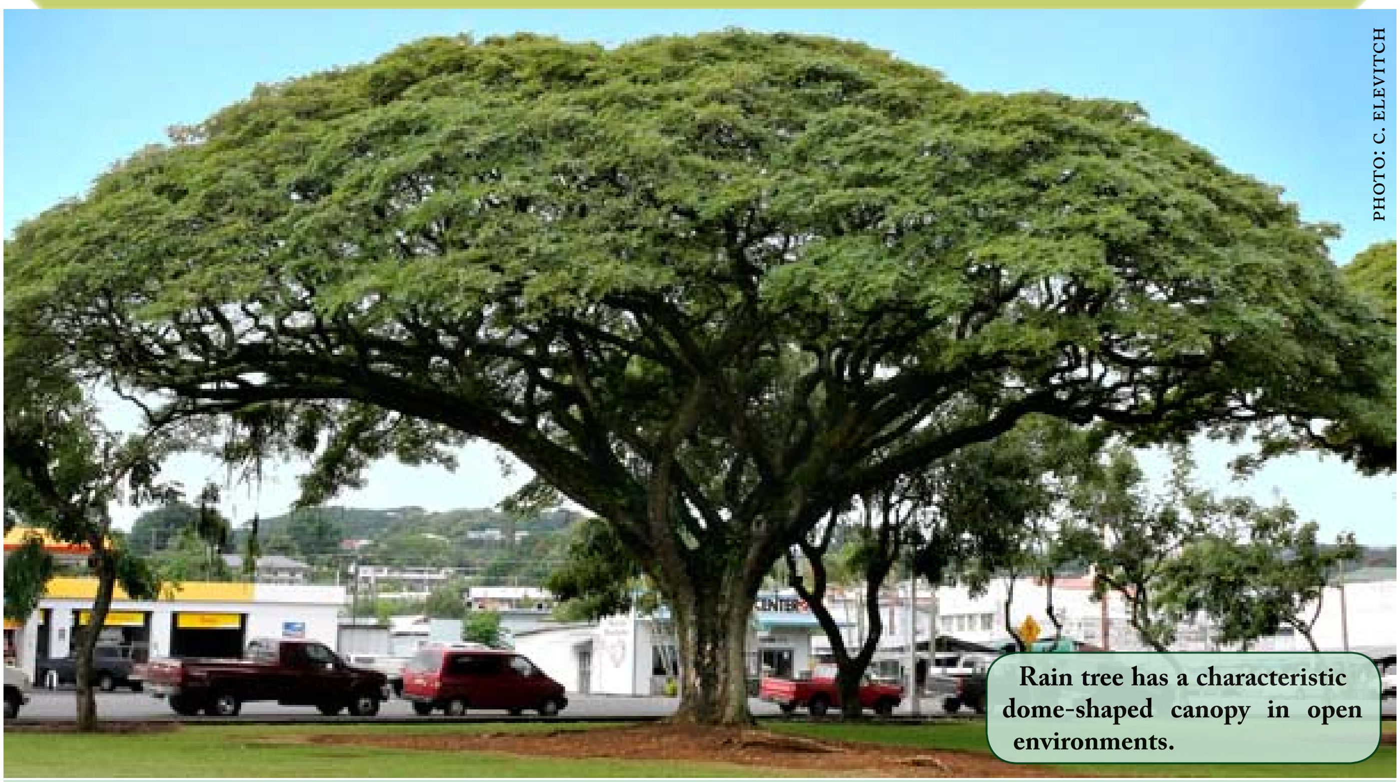

PHOTO: C. ELEVITCH

Rain tree has a characteristic dome-shaped canopy in open environments.

IN BRIEF

Distribution Native to northern South America, and now naturalized throughout the tropics.

Size Typically reaches 15–25 m (50–80 ft) tall with a broad crown typically 30 m (100 ft) in diameter.

Habitat Grows best in the lowlands from sea level to 300 m (1000 ft) with rainfall 600–3000 mm (24–120 in).

Vegetation Naturally occurs on savannahs (grasslands) and in deciduous forests and riparian corridors.

Soils Adapts to a wide range of soil types and pH levels.

Growth rate Moderately fast growing with growth rates of 0.75–1.5 m/yr (2.5–5 ft/yr) per year.

Main agroforestry uses Silvopasture, crop shade.

Main products Fodder, timber.

Urban forestry Well suited for large public areas such as parks, school grounds, etc., and large homesteads.

Yields A 5-year-old tree can produce 550 kg (1210 lb) of green forage; timber yields of 10–25 m^3/ha/yr (1715–4290 bf/ha/yr) under a 10–15 year rotation.

Intercropping Interplanted as a shade tree with coffee, cacao, and other crops.

Invasive potential Considered invasive in Fiji and Vanuatu, elsewhere in the Pacific it is naturalized but rarely considered to be problematic.

INTRODUCTION

Rain tree (*Samanea saman*) is easily recognized by its characteristic umbrella-shaped canopy. When grown in the open, the tree usually reaches 15–25 m (50–80 ft) in height with a canopy diameter wider than the tree is tall. Rain tree is most important in the Pacific as a shade tree on small farms, along roads, in parks and pastures. The wood has limited use for carved bowls in local markets; it could be developed more widely as a commercial timber, comparing favorably to black walnut. A multitude of minor uses is documented for rain tree, most of them of purely local significance, but all could be explored for wider applicability. Rain tree naturalizes freely almost everywhere it has been introduced and is considered an invasive pest in Vanuatu and Fiji. In many other places naturalized rain tree is not considered a problem.

DISTRIBUTION

Native range

Extensive cultivation has obscured the native range of rain tree. It is believed to be native in northern South America (Colombia, the Caribbean slope and the Orinoco drainage of Venezuela), and in Central America as far north as El Salvador. It is now widespread from Mexico south to Peru, Bolivia, and Brazil. In these areas, it occurs in low-elevation dry forests and grassland/savannah habitats.

Current distribution

Rain tree is cultivated and naturalized throughout the tropics. In the Pacific, rain tree is known to occur on the following islands: American Samoa (Tutuila), Commonwealth of the Northern Mariana Islands (Saipan, Rota), Federated States of Micronesia (Chuuk, Kosrae, Pohnpei), Fiji (Kanacea, Taveuni, Vanua Levu, Viti Levu), French Polynesia (Îles Tubuai [Rurutu], Tahiti, Marquesas, Moorea, Raiatea), Guam, Hawai‘i, Marshall Islands (Jaluit, Kwajalein), Niue, Palau (Koror), Papua New Guinea, the Philippines, Pitcairn, Rotuma, Samoa (‘Upolu), and Tonga (Tongatapu, ‘Eua, Vava‘u, Lifuka/Foa). The species is also naturalized in a number of the Caribbean Islands including Puerto Rico. It is almost certainly even more widespread than the foregoing list indicates.

BOTANICAL DESCRIPTION

Preferred scientific name

Samanea saman (Jacquin) Merrill

Family

Fabaceae (alt. Mimosaceae), legume family

Subfamily

Mimosoideae

Non-preferred scientific names

Albizia saman (Jacquin) F. Mueller
Enterolobium saman (Jacquin) Prain ex King
Inga salutaris Kunth.
Inga saman (Jacquin) Willd
Mimosa saman Jacquin
Pithecellobium saman (Jacquin) Bentham

Common names

Pacific islands

filinganga (Northern Marianas)
gouannegoul, *saman* (French)
gumorni spanis (Yap)
kasia kula, *mohemohe* (Tonga)
marmar (New Guinea)
‘ohai (Hawai‘i)
rain tree, monkey pod, saman (English)
tamalini, *tamaligi* (Samoa)
trongkon-mames (Guam)
vaivai ni vavalangi, *sirsa* (Fiji)

Other regions

acacia, palo de China (Philippines)
algarrobo, *algarrobo del país*, *carreto negro*, *delmonte*, *dormilón*, *guannegoul*, *samán* (Spanish)
gouannegoul, *saman* (French)

Size

Rain tree generally attains maximum heights of 15–25 m (50–80 ft). In rare cases it can reach a height of 50 m (160 ft). The crown typically reaches 30 m (100 ft) in diameter. Very large trees may reach 50–60 m (160–195 ft) in diameter. Rain trees usually have a short, stout trunk of about 1–2 m (3–6.5 ft) in diameter at breast height (dbh), but the trunk can attain 2–3 m (6.5–10 ft) dbh in exceptional cases. Under dense planting conditions, trees may attain greater height (to 40 m, 130 ft) with a narrower crown diameter than when planted in the open.

Form

Rain tree has a distinctive, umbrella-shaped crown. The crown is typically broad and domed; the horizontal spread is greater than the height when grown in spacious, open settings. Under plantation conditions, the crown is more vase-shaped.

RAIN TREE?

The name rain tree has been attributed to:

- The leaflets are light-sensitive and close together on cloudy days (as well as from dusk to dawn), allowing rain to fall through the canopy to the ground below.
- The grass is often much greener under a rain tree than the surrounding grass.
- A steady drizzle of honeydew is often created by sap-sucking insects.
- Nectaries on the leaf petioles excrete sugary juice that sometimes falls from the tree like rain.
- During heavy flowering, stamens can drop from the canopy like rain.

Flowers

The tiny flowers (12–25 per head) are massed in pinkish heads 5–6 cm (2–2.4 in) across and about 4 cm (1.6 in) in height. The long, bicolored stamens (white in lower half and reddish above) give the whole inflorescence the appearance of a powder puff or feather duster held slightly above the foliage. Thousands of heads are borne at the same time, covering the tree in pinkish bloom. The central flower in each head is larger, stalkless, has more petals, and is incapable of forming a fruit; this flower is a nectar-producing organ that attracts pollinators. Usually only one flower per head (rarely two) is pollinated and forms a fruit.

Leaves

Leaves are alternately arranged along twigs and have a prominent swelling (pulvinus) at the petiole base; stipules are present and threadlike; the leaf blades are twice-even-pinnately compound, arranged in 2–6 pairs of pinnae, each pinna bearing 6–16 diamond-shaped leaflets, shiny green above, dull and finely hairy beneath, 2–4 cm (0.8-1.6 in) long and 1–2 cm (0.4–0.8 in) wide, the apical leaflets largest. During dry periods trees are semi-deciduous, losing their leaves for a short period. Where there is a definite dry season, they may remain leafless for a period of weeks but refoliate quickly if there is adequate moisture. This gives the appearance that rain tree is "evergreen" in moister climates.

Fruit

Mature pods are black-brown, oblong, lumpy, 10–20 cm long (4–8 in), 15–19 mm (0.6–0.8 in) wide, ca. 6 mm (0.25 in) thick, straight or slightly curved, not dehiscing but eventually cracking irregularly, and filled with a sticky, brownish pulp that is sweet and edible.

Top: Flowers and new leaves. Bottom: Fruit in varying stages of ripeness. PHOTOS: C. ELEVITCH

Rain tree makes a remarkable habitat for epiphytes such as ferns and orchids, particularly in wetter areas. PHOTO: C. ELEVITCH

Seeds

Seeds are plumply oblong-ellipsoid, 8–11.5 mm (0.3–0.45 in) long, 5–7.5 mm (0.25–0.38 in) wide, slightly flattened from side to side, smooth, dark glossy brown with a slenderly U-shaped yellowish marking (pleurogram) on the flattened sides. There are 15–20 seeds per pod (often only 5–10 seeds per pod in the native range, where seed predation by insects accounts for the rest). One kilogram of seeds averages 4000–6000 seeds (1820–2730 seeds/lb). Seeds are readily dispersed by domestic livestock (cattle, hogs, goats) and to a much lesser extent by wild animals (peccary, tapir, and rodents in the presumed native range), whose feeding habits and digestive capacity permit very few seeds to pass through intact. It has been hypothesized that rain tree fruits evolved for dispersal by large mammals that became extinct in the Americas during the Pleistocene glaciations. Cattle and other herbivorous domestic animals efficiently fill the seed dispersal role today.

Bark

The bark of mature trees is gray, rough, and fissured in long plates or corky ridges. On younger trees the bark is smoother and paler gray to brownish in color. The inner bark is light colored and bitter.

How to distinguish from similar species/look-a-likes

Rain tree is not easily confused with any other tree in the Pacific. The broadly domed, umbrella-shaped crown, squat, thick trunk, pinnately compound leaves with diamond-shaped leaflets that fold up at night or on cloudy or rainy days, pinkish "powder puff" flower heads, and indehiscent blackish pods filled with sticky, pitch-like pulp are distinctive. What appears to be a white-flowered form of rain tree in Hawai'i is a different species, *Pseudosamanea guachapele*. It is rare in cultivation but where it is grown it has been confused with rain tree when flowering. The seedlings and saplings of rain tree can be confused with those of *Albizia lebbeck*.

GENETICS

Variability of species

Rain tree is remarkably uniform in appearance throughout its distribution and shows little local variability. No taxonomic varieties have been recognized among wild *Samanea saman*, nor have foresters or plant breeders named any cultivars.

Culturally important related species in the genus

There are two other species of *Samanea* (*S. tubulosa* and *S. inopinata*); neither has any reported cultural importance in the Pacific islands.

Genetic resources where collections exist

The Oxford Forestry Institute includes *Samanea saman* in its germplasm conservation program. However, neither germplasm collections nor breeding programs are known to exist for rain tree.

ASSOCIATED PLANT SPECIES

In native habitat

Rain tree is found naturally in savannahs, where it is associated with various grasses. It also occurs in deciduous forests and riparian corridors, where it often bears a heavy load of epiphytes on the trunk and branches.

Recent introduction

In places where rain tree has been introduced, it is often planted along roadsides, in parks and pastures, vacant lots, church and schoolyards, and similar spacious, open places. In these locations, it grows in association with an array of cultivated and weedy alien species that characterize disturbed habitats and planned landscapes.

ENVIRONMENTAL PREFERENCES AND TOLERANCES

Climate

Although originating from a part of tropical America that has a pronounced, seasonal dry climate, rain tree is highly adaptable and has proven able to thrive in many tropical and subtropical climate regimes. Today the species is successfully established in a wide range of climates, including both ever-wet (equatorial) and seasonally dry (monsoon) climates that have an annual rainfall of 600–3000 mm (24–120 in) and at elevations ranging from sea level to 300 m (1000 ft) (exceptionally to 1450 m [4750 ft]).

Elevation

In its native range, rain tree grows mostly below 450 m (1470 ft) although the total elevation range is reported to be sea level to 1450 m (4750 ft). In Pacific islands, this species typically is found below 300 m (1000 ft).

Mean annual rainfall

600–3000 mm (24–120 in)

Rainfall pattern

Rain tree can tolerate a wide range of precipitation patterns, including summer, winter, bimodal, and uniform rainfall patterns. In its native range, rain tree often grows along riparian corridors where its roots have access to subsurface moisture, making precipitation less critical.

Dry season duration (consecutive months with <40 mm [1.6 in] rainfall)

Rain tree can survive a dry period of 2–4 months or longer depending on age, size of tree, temperature, relative humidity, and soil.

Mean annual temperature

20–38°C (68–100°F)

Mean maximum temperature of hottest month

24–38°C (75–100°F)

Mean minimum temperature of coldest month

18–20°C (64–68°F)

Minimum temperature tolerated

8°C (46°F)

Soils

Rain tree adapts to a wide range of soil types and pH levels.

Soil texture

Rain tree is indifferent to soil texture; it tolerates a wide range of light, medium, and heavy soils.

Soil drainage

Rain tree thrives in soils that are freely draining, and it tolerates impeded drainage. In some situations, it can tolerate waterlogged soils for short periods. Rain tree is known to grow on slightly elevated land just inland from mangroves (Francis 2004).

Soil acidity

Rain tree thrives in mildly acidic to neutral pH (6.0–7.4), but the literature reports that it tolerates pH as high as 8.5 and as low as 4.7 (such as soils that had been mined for bauxite with highly acidic residues).

Special soil tolerances

Rain tree tolerates shallow soils and soils low in available nutrients.

Tolerances

Drought

Rain tree grows well under climates having a seasonal dry period (2–4 months) as well as under moister conditions where rainfall is distributed evenly year-round. It does not tolerate extended periods of drought.

Full sun

The tree is light-demanding. It is rarely found in dense forest stands; its natural habitat is savannah land, seasonally dry, deciduous forest, and riparian forest corridors.

Shade

Rain tree is intolerant of shade. Seedlings may be grown for 2–4 weeks in partial shade and then gradually shifted to full sun. The seedlings cannot survive below closed stands of other trees. When rain trees are found in mixed stands, they started with or before the other species in the stand. Seedlings are suppressed and killed by dense stands of tall grasses such as Guinea grass (*Panicum maximum*) and elephant grass (*Pennisetum purpureum*) (Francis 2004).

Frost

It cannot tolerate frost or low temperatures.

Waterlogging

Reports vary as to rain tree's ability to tolerate waterlogging. Some observers report that good drainage is essential; others state that rain tree survives impeded drainage and waterlogging.

Salt spray

Wind-blown salt spray may cause tip-burn on the windward side of trees, but this causes only cosmetic damage.

Wind

In Hawai'i, rain tree adapts well to trade winds, although lopsided crowns may develop in exposed situations. Storm winds may uproot and topple rain tree, as it is shallow-rooted. Where sandy or gravely soils allow deep rooting, the species is fairly resistant to hurricane-force winds, suffering limb breakage but not much windthrow (toppling over) or snapping of the trunk. Pavement, foundations, or shallow bedrock restrict root growth and make the species vulnerable to windthrow (Francis 2004).

Abilities

Fix nitrogen

Rain tree fixes nitrogen through an association with strains of rhizobia bacteria (*Bradyrhizobium*). In pasture systems, rain tree enhances growth of grasses below and near the tree canopy through nitrogen enrichment of the soil.

Regenerate rapidly

Rain tree produces seed copiously and natural regeneration is quite dependable. Although predators destroy many seeds, there are so many produced that the next generation is assured. In old fields, or anywhere that sunlight and open ground are available, the tree regenerates spontaneously.

Self-prune

The tree usually has a short bole with heavy side-branching. Even when planted in dense stands, lower branches are often retained.

Coppice

Rain tree has very good coppice ability, although the regrowth rate is moderate, slower than other nitrogen-fixing species such as *Leucaena* spp., *Gliricidia sepium*, etc. In Thailand the tree is cut at 1 m (3.3 ft) height every 6 months for production of fodder.

Pollard

Trees in Hawai'i are often "hat-racked" by tree trimmers, who remove all leafy shoots back to main branches. Trees resprout vigorously and within 12–15 months have a dense, compact crown of new growth.

Other

Medium sized trees can be pruned back severely and moved fairly easily for landscaping purposes.

Growth and Development

Rain tree is a moderately fast-growing tree with typical growth rates of 0.75–1.5 m/yr (2.5–5 ft/yr). Nursery-grown seedlings 3–5 months old are usually 20–30 cm (8–12 in) tall when ready for outplanting. Initial growth is slow but survival is good. Two months after transplanting, seedlings begin to look vigorous and grow rapidly. Two-year-old saplings in mixed plantations attained 2.9 m (9.5 ft) in height and in monospecific plantings at a 3 x 3 m (10 x 10 ft) spacing reached 4.8 m (16 ft) tall and 6.6 cm (2.6 in) dbh. Well tended specimens may attain 15 cm (5.9 in) diameter in 5 years.

Flowering and fruiting

Flowering begins at a young age and has a definite seasonality, beginning at the end of the dry season (March–April in Hawai'i) just after the leaves and mature pods drop. New foliage flushes out and flowering begins more or less simultaneously (April–May in Hawai'i). In its native range flowering occurs January–May, while in Thailand there are two flowering seasons, February–May and September–November, and in Java flowering occurs August–April. Although flowering tends to peak in the spring, trees may have flowers present in almost any month of the year, especially in areas with year-round rainfall.

Yields

Mature trees bear, on average, 200–250 kg (440–550 lb) of pods per tree, per season. Wood yields average annually 25–30 m^3/ha (4290–5140 bf/ac). When grown as a green fodder, it is possible to harvest 550 kg (1210 lb) from a 5-year-old tree.

Rooting habit

The tree has a massive surface root system. The large surface roots common in the species occur most often on clayey and rocky soils but are not as extensive on sandy or gravely soils.

Reaction to competition

Once established, rain tree seedlings grow fast and are tolerant of heavy weed competition. However, survival and

Large trees, as well as seedlings, can be transplanted readily by pruning the roots and branches, and ensuring sufficient irrigation for a few months. PHOTO: C. ELEVITCH

growth rates are improved if vigorous weed control is done until the saplings are taller than the surrounding grasses and herbaceous vegetation.

PROPAGATION

Rain tree is easily propagated by several methods. It may be propagated by seed (the usual method), stem cuttings (using vertical stems), root cuttings, and stump cuttings. In much of the Pacific, however, no special effort is exerted to grow rain tree. If one or a few trees are wanted for home use, seedlings are dug from near a mature tree and transplanted to the garden. Even very large trees can be successfully transplanted with substantial root and top pruning and proper care. Seedlings are also encouraged to grow where they sprout by protecting them and providing some weed control. When larger numbers of trees are required, seed is collected for nursery planting or direct sowing in the field.

Propagation by seed

Seed collection

Pods are collected from the ground beneath trees after they drop; picking pods off the tree is inadvisable because, although the pods take 5.5–8 months to mature, the seeds only fill out and become viable shortly before the pods fall. In some cases the pods are retained on the tree for up to 4 months past maturity.

Seed processing

In Latin America, seeds are manually extracted from the sticky, pitch-like pulp inside the pods. An easier method is to collect seeds from dung of livestock that has eaten the pods; in addition to being less labor intensive, germination is enhanced by passage through the digestive tract of herbivores. In Asia, the pods are placed in a dark place where termites eat the fruit valves and pulp, leaving behind clean seed.

Seed storage

The sweet, sticky fruit pulp (endocarp) promotes an intense insect attack, so careful cleaning of seed is vital before storage. Rain tree seed behavior is orthodox, that is, the seeds retain viability when dried and stored. Seed can be stored for extended time periods at 4°C (39°F) with 6–8% moisture content. Seed stored at 5°C (41°F) or colder retains viability longer than a year.

Pre-planting seed treatments

Fresh seed germination is about 36–50% with no treatment. Germination of untreated seed increases in the course of the first year of storage. Germination is also enhanced by passage of the seeds through the digestive tract of herbivorous animals. Scarification is not essential although it is recommended to ensure fast, uniform, and optimal germination. Manual nicking of the seed coat using a nail clipper or small file works very well, although it is time consuming. Alternatively, immerse the seed for 1–2 minutes in 80°C (176°F) water (water volume 5 times the seed volume). Stir the seeds, then drain and soak them in lukewarm (30–40°C [86–104°F]) water for 24 hours. This method yields 90–100% germination if damaged seeds are removed prior to treatment.

Growing area

Studies indicate that rain tree seedlings are intolerant of shade. Some literature sources recommend partial shade for seedlings in the first 2–4 weeks after emergence and then full sun; other sources state that seedlings should be placed in full sunlight from the beginning.

Germination

Germination occurs 3–5 days after sowing scarified seeds. Pretreatment, although not essential, results in more uniform germination and improves the percentage of seeds that germinate.

Seeds in pod. Note sticky pulp surrounding the seeds. PHOTO: C. ELEVITCH

Media/containers

Seeds may be planted in sand in nursery beds; in nursery mix (3 parts soil: 1 part sand: 1 part compost) in poly bags 10 x 20 cm (4 x 8 in); or direct-seeded in the field.

Time to outplanting

Seedlings are ready for outplanting 3–5 months after germination, by which time they should be 20–30 cm (8–12 in) tall. Seedlings with thick stems, more than 10 mm (0.4 in) in diameter, hold up better to wind and rain.

Approximate size at time of outplanting

Seedlings may be planted out when they have attained a height of 15–30 cm (6–12 in). They may be "stumped" by pruning the roots to a length of 10 cm (4 in), and the stem to a length of 20 cm (8 in). The stem diameter of stumped seedlings should be 5–30 mm (0.2–1.2 in).

Other comments on propagation

Caterpillars can defoliate young seedlings.

Guidelines for Outplanting

Survival and establishment after outplanting improve with vigorous weed control until saplings are taller than the surrounding vegetation and begin to shade it out.

DISADVANTAGES

Rain tree becomes very large, and this limits its utility in some situations, especially in proximity to human activity. The massive branching habit and surface root system can interfere with agricultural activities. For example, the root system may compete too well for moisture and nutrients in agroforestry systems with small trees or shrubs underneath. Due to the shallow root system, the tree is also susceptible to windthrow during storm winds, and in pasture systems this can be dangerous to livestock. Copious seed production and prolific reproduction in the Pacific have helped rain tree naturalize in many places where it has been introduced. The sticky pods and mess of leaf litter are a nuisance when the trees enter the deciduous phase. However, where grazing animals are present, virtually every pod will be consumed.

Potential for invasiveness

Rain tree has naturalized in many places outside its native range and, in the Pacific, is considered a serious pest in Vanuatu and Fiji. Elsewhere in the Pacific it is regarded as innocuous. For example, it is common in Samoa in plantations but does not readily spread to other areas. The precise nature of the threat posed by rain tree has not been articulated; it may simply be a nuisance tree that grows where it is not wanted. The rapid spread and spontaneous appearance of the species in sites distant from seed sources is usually due to dissemination by cattle. Copious seed production and ease of seed dispersal by livestock has the potential to pave the way for rain tree to become a pest in other parts of the Pacific. However, when cattle are present year-round or return at least annually, they consume and kill almost all small rain tree seedlings.

Rain tree has an extensive surface root system, which may interfere with agricultural activities or landscape maintenance especially on clayey or rocky soils. PHOTO: C. ELEVITCH

Susceptibility to pests/pathogens

Lepidopteran caterpillars (*Ascalapha odorata, Melipotis indomita,* and *Polydesma indomita*) defoliate rain trees in many places as they leaf out but without causing serious stress to healthy trees. *Ascalapha odorata, Mocis latipes* (lepidopteran) defoliate seedlings; *Myrmelachista ramulorum* (ant) defoliates and deforms leaves by burrowing in twigs; *Merobruchis columbinus* (bruchid beetle) oviposits in immature fruits and the larvae damage or kill 50–75% of seeds; *Cecidom yidae* (fly) oviposits in immature fruits and causes abortion; *Anypsipyla univitella* (lepidopteran) oviposits in fruit and damages seeds and pods; *Stator limbatus* (beetle) oviposits in seeds in opened pods; *Heteropsylla cubana, Psylla acacia-baileyanae* defoliate trees; *Xystrocera globosa* (borer) attacks sapwood of stressed trees; seedlings are browsed/defoliated by livestock; fruits in the wild are eaten by parrots, tapirs, collared peccaries; flowers are eaten by howler monkeys.

Rain tree is a common ornamental, particularly in public places. PHOTO: C. ELEVITCH

AGROFORESTRY/ENVIRONMENTAL PRACTICES

Today rain tree is grown for nitrogen enrichment of soils in pastures, for shade along streets and roads, in parks, and as a flowering ornamental. It has also long been grown for shade in plantations of coffee, cocoa, and other crops.

Mulch/organic matter

The green foliage and leaf/flower litter that collects beneath the trees makes an excellent nitrogen source for enriching the soil as well as for composting in gardens. It can be periodically pruned for mulch. Because regrowth is relatively slow compared with other nitrogen-fixing trees such as *Gliricidia sepium*, *Calliandra calothyrsus*, and *Leucaena leucocephala,* it is usually not the best choice for this purpose.

Crop shade/overstory

Rain tree is planted for shade in plantations of coffee, cocoa, vanilla, and for young nutmeg and teak.

Alley cropping

Rain tree can be used in alley-cropping if heavily pruned, but it is rarely the most productive species choice for this purpose.

Homegardens

Rain tree can be used in homegardens as a shade tree and for the multiple products it provides, but its immense size limits its use in most urban areas.

Living fences

It can be maintained as a hedge plant with regular heavy lopping.

Windbreaks

Trees provide windbreak in coffee orchards and pastures.

Silvopasture

Rain tree is an excellent choice for pastures not only because its broad canopy provides shelter from the sun, but also because its nitrogen-fixing ability improves the quantity and nutritive quality of forage grasses near and under the trees.

Woodlot

The trunk and branches are used as firewood in places that have no market for the wood for carving or construction. In Central America, cross-sections cut through the trunk were formerly used to make wheels for ox carts.

Native animal/bird food

Wildlife in tropical America eats parts of the tree. The sweet fruit pulp and seeds are eaten by parrots, tapirs, collared peccaries, and rodents; the flowers are eaten by howler monkeys. Insects (moths, bees) visit the flowers as a nectar source.

Rain tree has a characteristic dome-shaped canopy in open environments such as this coffee orchard. PHOTO: C. ELEVITCH

Wildlife habitat

Various reptiles, birds, and small mammals use the tree branches and cavities for nesting and dens.

Host plant trellising

Vanilla is trained up the trunks of rain trees planted for shade.

Bee forage

The flowers, although pollinated in the natural range by nocturnal moths, are an abundant nectar source for bees.

Ornamental

Rain tree is widely planted throughout the tropics as a flowering ornamental shade tree in public places, parking lots, parks, etc.

USES AND PRODUCTS

Rain tree has long been a source of timber and livestock feed (green forage and pods) for local consumption. Minor medicinal and craft uses also are known. The wood is used for carving items for sale to tourists, and the seeds are strung in garlands.

Fruit

The sticky, licorice-flavored fruit pulp is a minor food item for humans, mainly eaten by children. It is known as licorice tree in the English-speaking Caribbean. Although the pods have a nice flavor, they are too astringent to eat more than the pulp from a single pod.

Nut/seed

The seeds, once cleaned from the sticky fruit pulp, are used in making seed necklaces and other craft items in Hawai'i.

Animal fodder

With 13–18% protein, the pods are edible and nutritious for livestock and make an excellent feed supplement (Flores 2002). In Asia, rain tree is grown as a green fodder supplement for goats, sheep, and cattle. A 5-year-old tree can produce as much as 550 kg (1210 lb) of green forage. The pods are ground into a nutritious animal feed in several South American countries.

Beverage/drink/tea

The fruit pulp is used to make a beverage similar to tamarindo (made from tamarind pulp) in Latin America.

Medicinal

There are several folk remedies prepared from various parts of rain tree. The boiled bark is applied as a poultice to cure constipation. In the Philippines, a decoction of the inner bark and fresh leaves is used for diarrhea. In Venezuela, the roots are made into a hot bath for stomach cancer. In the West Indies, the seeds are chewed for sore throat.

Beautiful/fragrant flowers

Rain tree has been introduced to many tropical places for the beautiful masses of pinkish flowers it bears for extended periods.

Timber

The timber is valued for carvings, furniture, paneling, veneers, and is also used for turnery, posts, framing in boat building, plywood, boxes, and crates. The sapwood is narrow and white to light cinnamon. The heartwood is straight or cross grained with a medium to coarse texture. Air-dry specific gravity averages about 0.56. The wood requires careful drying because of shrinkage and moderate to severe warp. It is generally considered a durable wood and resistant to attack by drywood termites (Longwood 1971, Chudnoff 1984).

Fuelwood

In places where there is no demand for rain tree timber for construction or carving, the trunk and branches are used for firewood and charcoal. Although the wood makes good firewood, it burns with a lot of smoke even when very dry.

Craft wood/tools

The famous monkey pod bowls of Hawai'i and other souvenirs are carved from the wood. Rain tree wood was literally the basis for this industry beginning just after World War II ended (ca 1946).

Ornament/decoration

The seeds are used in making seed necklaces, jewelry, and other crafts in Hawai'i.

Canoe/boat/raft making

The wood is popular for large frame members in wooden boats.

Fiber/weaving/clothing

The wood has the right fiber properties for making paper. In the Philippines (Bulacan province), shavings made from the wood are made into hats.

Resin/gum/glue/latex

A low-grade gum exudes from wounded trees. It has no commercial use but may be used locally. In Thailand, rain tree is used as a food source for the lac insect (*Laccifer lacca*), the source of shellac.

Honey

Honey made from rain tree nectar is harvested in several places for local consumption but is not an item of commerce.

URBAN AND COMMUNITY FORESTRY

Rain tree is beloved as a shade tree for avenue planting along streets, in parks, public grounds, and other spacious areas. It is too large for homegardens in urban areas but is suitable for smallholdings in rural areas with adequate space for the trees to develop their impressive crowns. Trees also produce multiple products—edible pods, leaf litter for mulching and composting as well as supplementary livestock feed, nectar for honey bees, wood for crafts and construction—that can be used in rural economies.

Size in an urban environment

Typical specimens of rain tree in Hawai'i attain heights of 15–20 m (50–65 ft) and crown diameters of 25–30 m (80–100 ft). This is too large for homegardens but suitable, and much used, for street tree plantings. Crowns have to be pruned and some surface roots removed periodically to prevent damage to pavement and sidewalks.

Rate of growth in a landscape

It is considered a fast-growing tree, although suboptimal conditions such as poor soil or restricted rooting area in urban areas often result in dwarfing effects on tree growth.

These large rain trees on the edge of a school playing field on Tongatapu island have canopies measuring over 60 m (200 ft) in diameter. PHOTO: C. ELEVITCH

The size of rain tree limits its use in crowded urban lots. However, if enough space is available, the tree makes a wonderful landscaping tree. PHOTO: C. ELEVITCH

Root system

Rain trees have shallow surface roots that thrust up above soil level as they mature, causing damage to pavements and sidewalks as well as building foundations if planted too close.

Products commonly used in a household

In Latin America, the sticky, sweet pulp from the pods is eaten by children and is made into a beverage in the same way as tamarind pulp. Wood from the trees is used for construction, making bowls and other household objects, cart wheels, boats, and furniture. Honeybees visit the trees when they are in bloom, and honey collected from hives is used for local consumption.

Light requirements

Rain tree has high light requirements; it thrives in full sunlight.

Water/soil requirements

Young trees should be irrigated after planting until they are fully established. Where sidewalks or pavement surrounds the tree, supplemental irrigation is beneficial; in open areas without obstruction to rainfall, normal precipitation is adequate for good growth.

Life span

Rain tree is long-lived; 80–100 years is average.

Varieties favored for use in homegardens or public areas

No varieties are known.

Use as living fence, hedge or visual/noise barrier

In the Pacific, rain tree is not used as a hedge or living fence. In Asia, the trees are used as a hedge, with heavy trimming required to maintain a compact growth form. Trimmings are used for livestock feed or green manure.

Birds/wildlife

Nectar from the flowers is utilized by bees and (in Hawai‘i) by nectar feeding birds such as mynahs, cardinals, and bulbuls. The fruit pulp and seeds are eaten by rodents and ungulates—cattle, hogs, goats, sheep, deer—both domesticated and wild.

Maintenance requirements

Rain tree is maintenance-free once established. Occasional pruning to shape the crown and remove dead branches helps maintain an attractive specimen.

Special considerations

High winds will cause dead branches to drop or heavy live branches to break. Branches over structures should be removed. During the deciduous period when leaves and ripe pods fall and shortly thereafter when flowering begins, rain trees are messy. At this time cleanup of leaf litter and pods may be necessary.

Nuisance issues

When ripe pods are on the ground the sticky pulp causes pods and seeds to adhere to shoes and auto tires. This is more of an annoyance than a hazard.

Common pest problems in the landscape

Periodically there are heavy infestations of leaf-eating caterpillars that defoliate trees just after the new leaves emerge. Rain tree is sometimes attacked by coffee twig borer and a variety of other insect pests. These cause only cosmetic damage, and no treatments are required for such pest infestations.

Other comments

Urban community gardeners collect leaf litter from beneath rain trees in urban parks and use it for composting. The high nitrogen content of leaves and flowers adds to soil nitrogen.

COMMERCIAL PRODUCTS

Rain tree provides a number of products that are commercially important in local markets. Throughout its native and introduced range, the timber is prized for carving and turning. It is used in construction, for paneling, and in furniture making. Most timber consumption is local, although the demand for bowls made of the wood in Hawai'i is now supplied from Indonesia and the Philippines.

Spacing

It is seldom planted in single-purpose forestry stands, but it has been demonstrated that a close spacing, 6 x 6 m (20 x 20 ft), produces trees with a longer, straighter bole and fewer branches, although the trunk retains a curved form. Wider spacings can also be used for timber production, even in silvopasture. Wide spacing facilitates rapid growth in trunk diameter. Wood from large branches can also be used.

Management techniques

Rain tree seedlings are intolerant of shade and must be weeded until they are taller than the surrounding grass, which it will then shade out. Seedlings are susceptible to damage from herbicides used for weed control. In areas where animals are free to browse, seedlings should be fenced to protect them. When about 5 years old, a first thinning may be necessary, along with pruning of lower branches to develop clear boles of commercial length.

Design considerations

There is no information recorded about designing commercial plantings of rain tree, other than one report of a failed attempt in Zanzibar that was blamed on too-close spacing (2 x 2 m [6.6 x 6.6 ft]) of seedlings. There is evidence that rain tree can grow too large to be utilized by the technology available in some locations (e.g., mills are too small to saw massive logs, etc.).

Advantages of polycultures

Production of rain tree is said to be better in mixed plantings than in single-species timber plantations.

Estimated yields

Few quantitative data are available. Total wood yields of 10–25 m^3/ha/yr (143–358 ft^3/ac/yr) under a 10–15-year rotation have been reported, although a much lower quantity of milled timber would be realized from small trees. Trees can be grown on short rotations, especially for fuelwood, but in silvopastoral systems rotations may advantageously be much longer, as the trees continue to produce prodigious crops of pods to a great age.

Markets

Two sources report that the crafts made of rain tree wood that are sold in Hawai'i to tourists are now largely imported from the Philippines and Indonesia. There is an indication that there is not enough local production of wood in Hawai'i to meet the demand for tourist curios.

Young rain tree planted for shade in a coffee orchard, Holualoa, Hawai'i.
PHOTO: C. ELEVITCH

INTERPLANTING/SILVOPASTURE

The tree is used in many regions to provide shade for coffee, tea, cacao, nutmeg, patchouli, and vanilla. It is also an important component in silvopastoral systems.

Benefits

Nitrogen fixation at roots improves soil nutrition. Grasses under and near rain trees remain luxuriant and green when nearby grasses in full sun wither and brown. Nutritional value of grasses grown under rain trees is improved. Rain tree is a valuable component of pasture systems for ranching, providing shade from heat and intense sun as well as nutritious pods that are 12–18% protein and 40% digestible. Pods are eagerly eaten by cattle, hogs, and goats; horses eat them if there is nothing else available but reject them if other foods are available. The leaves contain 22–27% crude protein and in some Asian countries are used as a livestock forage supplement for cattle, sheep, and goats.

Potential drawbacks of interplanting

Shallow roots, large branches and dense shade compete with companion crops, requiring heavy pruning to admit light.

PUBLIC ASSISTANCE AND AGROFORESTRY EXTENSION

Extension offices for agroforestry and forestry in the Pacific: http://www.traditionaltree.org/extension.html

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Samanea saman (rain tree)

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Acknowledgments: The authors and publisher thank Dale Evans, John Francis, Jr., J. B. Friday, Eileen Herring, Heidi Johansen, and Art Whistler for their input.

Recommended citation: Staples, G.W., and C.R. Elevitch. 2006. *Samanea saman* (rain tree), ver. 2.1. In: C.R. Elevitch (ed.). Species Profiles for Pacific Island Agroforestry. Permanent Agriculture Resources (PAR), Hōlualoa, Hawai'i. <http://www.traditionaltree.org>.

Sponsors: Publication was made possible by generous support of the United States Department of Agriculture Western Region Sustainable Agriculture Research and Education (USDA-WSARE) Program; SPC/GTZ Pacific-German Regional Forestry Project; USDA Natural Resources Conservation Service (USDA NRCS); Kaulunani, an Urban Forestry Program of the DLNR Division of Forestry and Wildlife and the USDA Forest Service; State of Hawai'i Department of Land & Natural Resources Division of Forestry & Wildlife; USDA Forest Service Forest Lands Enhancement Program; and Muriel and Kent Lighter. This material is based upon work supported by the Cooperative State Research, Education, and Extension Service, U.S. Department of Agriculture, and Agricultural Experiment Station, Utah State University, under Cooperative Agreement 2002-47001-01327.

Series editor: Craig R. Elevitch

Publisher: Permanent Agriculture Resources (PAR), PO Box 428, Hōlualoa, Hawai'i 96725, USA; Tel: 808-324-4427; Fax: 808-324-4129; E-mail: par@agroforestry.net; Web: <http://www.agroforestry.net>. This institution is an equal opportunity provider.

April 2006
ver. 2.1

Santalum austrocaledonicum and *S. yasi* (sandalwood)

Santalaceae (sandalwood family)

***S. austrocaledonicum*: *sandalwud* (Vanuatu: Bislama)**
***S. yasi*: *ahi* (Tonga); *yasi* (Fiji); *asi manogi* (Samoa)**

Lex A. J. Thomson

IN BRIEF

Distribution *S. austrocaledonicum*: New Caledonia and Vanuatu; *S. yasi*: Fiji, Niue, and Tonga.

Size Small shrubs or trees, typically 5–12 m (16–40 ft) at maturity.

Habitat Varies by species, typically subhumid or humid tropics with distinct dry season of 3–5 months.

Vegetation At young stages, dry forest and woodland; possibly closed secondary forest when mature in natural habitats.

Soils Requires light to medium, well drained soils.

Growth rate Slow to moderate, 0.3–0.7 m/yr (12–28 in/yr).

Main agroforestry uses Homegardens, mixed-species forestry.

Main uses Heartwood for crafts, essential oil extraction for cosmetics and perfumery, incense, and religious ceremonies.

Yields Heartwood in 30+ years (greater than 40 kg/tree [88 lb/tree]).

Intercropping Because sandalwood is hemi-parasitic and requires one or more host plants, intercropping is not only possible, but necessary.

Invasive potential Has a capacity for invasiveness in disturbed places, but this is rarely considered a problem.

***Santalum yasi* seedling planted in homegarden, Pangaimotu, Vava'u, Tonga, and protected from damage by stakes.**

INTRODUCTION

Pacific sandalwood species are small trees that occur naturally in open, dry forests and woodland communities. They are typically multi-stemmed and somewhat bushy, attaining a height of 5–12 m (16–40 ft), or up to 15 m (50 ft) for *S. austrocaledonicum* in New Caledonia, at maturity and spreading to about the same width as their height. They are capable of root-suckering: following harvesting, clumps of suckers may regenerate in a circular pattern several meters away from the original stump. They are root-parasitic, which means they have special root extensions that capture nutrients from roots of certain other plants in the soil. Sandalwood cannot persist in moist, dense forest types due to its poor tolerance of high shade levels. Sandalwood species generally have a broad edaphic range, usually with a preference for well drained neutral to slightly alkaline soils. They grow more quickly in fertile soils but are more at risk of being shaded out by taller, faster growing trees on such sites.

Both *S. austrocaledonicum* and *S. yasi* have considerable economic potential, but their populations are depleted, and there is a need to promote greater regeneration and sustainably manage remaining populations. *Santalum austrocaledonicum* is currently being grown in small plantings or managed in natural stands in Vanuatu and New Caledonia in the southwest Pacific. The species grows at moderate rates and can produce substantial quantities of the valued heartwood on a rotation of about 25–40 years. There is a growing interest among villagers, other small-scale entrepreneurs, and government organizations to expand the scale of planting in both countries. Replanting of *S. yasi* is on a small scale, mainly within villages in areas where it naturally occurs. The largest replanting of *S. yasi* has been on the Tongan island of ʻEua, where it has been successfully planted in association with *Pinus caribaea*.

The primary advantages of sandalwoods are their ability to produce a high-value, non-perishable product (heartwood) that can provide cash income to people living in outer islands and more remote communities. They may also be grown in environmentally sensitive areas, such as water catchment and biodiversity conservation areas, where extraction of a few small trees causes minimum disturbance while providing good economic returns.

Sandalwoods are well suited to interplanting, and due to their root-parasitic nature, they need to be grown with other suitable host tree species. They may be interplanted with various other species that can provide additional sources of revenue. In Tonga, sandalwood (*S. yasi*) has been grown with other commercial species including pine, casuarina, citrus, and paper mulberry. Sandalwoods have a good regeneration potential and ability to colonize/invade nearby suitable sites. So long as some mature fruit-bearing trees are retained, birds will spread the fruit. Their invasive potential is seldom considered a drawback due to the exceptionally high value of their heartwood. Furthermore, their small stature and susceptibility to being shaded out means they never become dominant and/or substantially modify or replace existing plant communities.

SANDALWOOD TERMS

Hemi-parasitic Describes a plant which photosynthesizes but which derives water and some nutrients through attaching to roots of other species.

Root-grafting This is where roots of different individual plants grow together, forming functional unions and exchanging materials. Sandalwood roots can root-graft onto many other species, effectively joining whole plant communities through their root systems.

DISTRIBUTION

Native range

S. austrocaledonicum This species is naturally found in the island archipelagos of New Caledonia and Vanuatu in the southwest Pacific.

Var. *austrocaledonicum* is common in the Loyalty Islands and the Isle of Pines but is uncommon on the main island of Grande Terre. It is also present in the Belep islands. In Vanuatu the principal occurrence is around the northwest, west, and southwest portions of Erromango, and on the west coast of Espiritu Santo; it is also found on Tanna, Aniwa, Futuna, Malakula, Efate, and Aneityum.

Var. *pilosulum* is restricted to low elevations on the main island of New Caledonia near Noumea. It also has limited occurrence at high elevation in the Karaka region (northeast slope of Mt. Do between Boulouparis and Thio).

Var. *minutum* is restricted to the northwest side of the main island of New Caledonia.

S. yasi This species occurs in lowland, drier, and more open forest types in Fiji, Niue, and Tonga. The Niuean population may be an ancient or Polynesian introduction. There is one record for Samoa (Savaiʻi), where it appears to be introduced but not naturalized. The range extends from Niue and ʻEua, a southern island in the Tongan group, through

Left: ***Santalum austrocaledonicum*****.** PHOTO: L. THOMSON **Right:** ***Santalum yasi*** **in Tonga.** PHOTO: C. ELEVITCH

Tongatapu, Ha'apai, and Vava'u (Tonga), west and northwards, through the Fiji Islands (Lau group, Kadavu, Nausori Highlands/Viti Levu, Bua/Vanua Levu) to the Udu Peninsula, NE Vanua Levu, North of Fiji.

Current distribution

S. austrocaledonicum Outside of its native range this species has limited planting, mainly for trial purposes in Australia, Fiji, and the Cook Islands.

S. yasi This species has limited planting outside of its natural range, mainly for trial purposes in Australia. Some of its occurrences, e.g., on Niue, may be comprised of naturalized populations following introduction by humans.

BOTANICAL DESCRIPTION

Preferred scientific names

Santalum austrocaledonicum Vieillard
Santalum yasi Seem.

Family

Santalaceae (sandalwood family)

Common names

S. austrocaledonicum *sandalwud* (Vanuatu: Bislama)
S. yasi *ahi* (Tonga); *yasi* (Fiji)*;* asi manogi (Samoa)

Other common names

bois de santal, santal (French)
sándalo (Spanish)
sandalwood (English)

Size

S. austrocaledonicum A shrub or a small tree typically 5–12 m (16–40 ft) tall by 4–8 m (13–26 ft) in crown width. The maximum tree dimension is 15 m (50 ft) tall by 10 m (33 ft) crown width. Maximum bole diameter at breast height is 40–50 cm (16–20 in).

S. yasi Mature trees typically grow to 8–10 m (26–33 ft) tall by 8–12 m (26–40 ft) in crown width, maximally reaching 15 m (50 ft) tall by 13 m (43 ft) in crown width. Maximum bole diameter at breast height is 40–50 cm (16–20 in).

Form

S. austrocaledonicum **and** ***S. yasi*** Shrub to small tree typically with a short, crooked bole and spreading crown in open situations. In forest and sheltered situations, the

Bark of *S. yasi*. PHOTO: L. THOMSON

bole may be straight for more than half the total height. In older specimens the crown is light, straggly, and with drooping branches. The bark is smooth to rough, slightly longitudinally fissured or reticulated, which can be more pronounced with age, (greyish or reddish brown, mottled with patches of lichen).

Flowering

The small flowers are clustered in terminal or axillary panicles about 4.5 cm (1.8 in) long. The bell-shaped flowers open to about 5 mm (0.2 in) across and have parts typically in fours. Buds and newly opened flowers have greenish white to cream-colored perianth segments (or tepals), remaining cream for *S. austrocaledonicum*, but turning light pink, through pink to dark red at maturity for *S. yasi*. Shorter, dark yellow disk lobes alternate with the tepals. The anthers are yellow and red-tinged for *S. yasi*, yellow for *S. austrocaledonicum*, and the style and stigmas are cream/pale yellow.

Under good conditions plants begin fruiting from an early age, typically about 3–4 years, but heavy fruiting may take 7–10 years. There is considerable variation in seasonality of flowering and fruiting. Trees flower and fruit throughout the year, usually with two peaks. The two main flowering periods for *S. yasi* in Fiji are October–November and February. In the southern islands of Tonga (ʻEua and Tongatapu), the main flowering period is (June–) July–August (–September). Further north in the Haʻapai and Vavaʻu groups the peak flowering period is November–December. For *S. austrocaledonicum* in Vanuatu, flowering occurs in January–April, July, and October. In New Caledonia, flowering occurs throughout the year, but there are flowering peaks in February and October, and flowering is rarely observed in June and July.

Leaves

S. austrocaledonicum The foliage shows wide variation. Leaves are opposite, usually in one plane, decussate on erect new growth, simple, entire, glabrous, dark green, and shiny on top and dull light green to glaucous underneath. The shape of the leaf is initially long and thin (5–9 by 0.5 cm [2–3.5 by 0.2 in]) in seedlings and young plants to about 3 years of age, becoming shorter and broader in older plants. Mature leaves are narrowly elliptic, but maybe ovate, lanceolate, or obovate, (3–)4–6(–8) cm by (1–)1.5–2.5(–4.5) cm ([1.2–]1.6–2.4[–3.1] in by [0.4–]0.6–1[–1.8] in) with 6 to 15 pairs of barely visible secondary nerves tapering equally to the base and blunt tip. Var. *minutum* has smaller, more glaucous, bluish-green leaves, about 2 by 0.8 cm (0.8 by 0.3 in).

S. yasi Seedlings have very slender, near-linear, leaves. Leaves are simple, opposite, narrow to broadly lanceolate, shiny, and typically 6–7 by 1.5–2 cm (2.4–2.8 by 0.6–0.8 in). There is considerable variation in foliage size; adjacent plants have been observed to range from 5 by 1 cm (2 by 0.4 in) to 8 x 2.5 cm (3.1 x 1 in). The foliage is light to dark green, but plants growing in the open with few host trees available may have a yellowish-green appearance.

Fruit

S. austrocaledonicum The fruit is a subglobose or ellipsoid, one-seeded drupe (7–20 mm [0.3–0.8 in] long by 10–15 mm [0.4–0.6 in] diameter), green and firm, ripening red, and turning purplish black and thinly fleshy when mature. Fruits have four longitudinal ridges and a square calyx scar at the apex. Fruits from Aniwa (Vanuatu) are much larger (20 x 15 mm [0.8 x 0.6 in]) than those from the Loyalty Islands (15 x 12 mm [0.6 x 0.5 in]). Mature fruits have been reported almost throughout the year, but the main fruiting season is November–January. In New Caledonia, two fruiting seasons are observed, in December–February (main fruiting season) and July–August (light fruiting season).

S. yasi The fruit is a one-seeded, ellipsoid drupe, ca. 12 mm (0.47 in) long by 11 mm (0.43 in) diameter with a small, round calyx scar (about 2 mm [0.08 in] diameter) at the apex, enclosing a rather stout, cone-shaped point. Immature fruits are light green, turning reddish-purple, and finally dark purple or black at full maturity. The main fruiting season corresponds to the wet season, January–March, with light fruiting in the cooler, dry season (June–August).

Fruits of both species mature about 4 months after flowering.




Top left: Flowers of *Santalum austrocaledonicum.* PHOTO: L. THOMSON **Top right: Mature fruit of *Santalum austrocaledonicum.*** PHOTO: L. THOMSON **Bottom right: Mature fruit and flowers of *Santalum yasi.*** PHOTO: L. THOMSON **Bottom left: Flowers of *Santalum yasi.*** PHOTO: C. ELEVITCH

Seeds

The kernels consist of a hard (woody), smooth or slightly rough, light-colored endocarp enclosing a single seed.

S. austrocaledonicum Within var. *austrocaledonicum* the seeds from the Loyalty Islands are much bigger (2400 per kg [1100 seeds/lb]) than those from the Isle of Pines (6000 per kg [2700 seeds/lb]), while those from Vanuatu are intermediate (3300–4500 per kg [1500 seeds/lb]). Var. *pilosulum* has smaller seeds (8400 per kg [3800 seeds/lb]).

S. yasi The seeds are 9–11 mm by 6–7 mm (0.35–0.43 in by 0.24–0.28 in) with approximately 6000–7000 per kg (2700–3200 seeds/lb).

Look-a-like species

Similar species include *S. album* (India, Indonesia, and Australia) and *S. macgregorii* (Papua New Guinea). To date, *S. album* has been little planted in the Pacific islands (Fiji, Tonga, Cook Islands, Samoa, and New Caledonia). The species is in the process of becoming naturalized near old trial plots in northwest Viti Levu, Fiji, and has naturally hybridized with *S. yasi* where the two species have been planted together. *S. album* is the most well known and commercially traded sandalwood species, and its oil provides the international standard for sandalwood oil. The species is deeply ingrained in the philosophical, cultural, and religious ethos of Indian culture, and has been used for more than 2500 years.

How to distinguish from similar species

Fruits are very useful for distinguishing related tropical species. In *S. album* the mature fruits are truncate-globose to ellipsoid; the raised calyx scar is up to about 5 mm across, forming an apical collar and enclosing the flat or slightly depressed disc that ends in a small point. In *S. macgregorii*, the fruit is a green, ovoid drupe (to 8–10 mm [0.3–0.4 in] long), turning purplish or bluish-black at maturity, and contains ellipsoid or sub-spherical seeds 4–6 mm (0.16–



Left: Flowers of *S. album*. PHOTO: C. ELEVITCH **Right: Mature fruit of *Santalum album*.** PHOTO: L. THOMSON

0.24 in) long by (2–)2.5–4.5(–5) mm ([0.08–]0.1–0.18[–0.2] in) wide, with three to four ridges at the pointed end.

GENETICS

Variability of species

All *Santalum* species exhibit considerable morphological variation, and numerous traditional varieties are recognized. There are three formally described varieties of *S. austrocaledonicum* in New Caledonia, as well as two heartwood chemotypes in Vanuatu. One chemotype produces heartwood oils rich in santalols (α-santalol >30–40% and β-santalol >15%) while the other chemotype heartwood oil is rich in Z-nuciferol (7–25%) and/or Z-lanceol (15–41%), with lower concentrations of santalols.

Known varieties

S. austrocaledonicum var. *austrocaledonicum* and var. *pilosulum* have large leaves (about 5 by 2 cm [2 by 0.8 in]) and long petioles (6–16 mm [0.24–0.63 in]) and tepals (1.3 x 0.8 mm [0.05 by 0.03 in]). The flowers and new shoots of var. *austrocaledonicum* are glabrous whereas those of var. *pilosulum* are villous or hairy. Var. *minutum* has much smaller leaves (about 2 by 0.8 cm [0.8 by 0.3 in]) and tepals (1.3 by 0.4 mm [0.05 by 0.02 in]).

ASSOCIATED PLANT SPECIES

S. austrocaledonicum In New Caledonia it mainly occurs in secondary forests and agricultural fallows in the Loyalty Islands. In dry forest (Grande Terre), it is often associated with *Acacia spirorbis*, *Croton insularis*, and *Arytera collina*. It also sometimes occurs with grasses, such as *Panicum maximum*, on plains and with ruderal species (families Fabaceae, Asteraceae, and Convolvulaceae). Var. *minutum* occurs in scrubland, with various shrub species including *Cassinia trifoliata*, *Xanthostemon pubescens*, *Hibbertia deplancheana*. In Vanuatu it frequently occurs with *Acacia spirorbis,* low shrubs, and Cyperaceae. Other associated plant species include coconut, grasses, bamboos, *Cryptocarya turbinata, Hibiscus tiliaceus*, *Dracontomelon vitiensis*, *Garuga floribunda*, *Leucaena leucocephala* (introduced), and *Pterocarpus indicus*.

S. yasi Yasi is mainly found in open forest types (often with a grassy understory), including secondary forests developing in old garden sites. In Tonga, some trees were found in young dense forest on the islands of Vava'u, establishing themselves when the surrounding trees were smaller and the stand had been opened up for cultivation of agriculture crops. It also occurs in low coastal forest associations on small coralline islands. In Fiji associated woody species include *Acacia richii, Casuarina equisetifolia, Calophyllum vitiense, Cocos nucifera, Fagraea gracilipes, Storckiella vitensis, Hibiscus tiliaceus, Thespesia populnea,* and *Dodonea viscosa.* Associated species in Tonga include *Broussonetia papyrifera*, *Citrus* spp., *Diospyros* spp., *Hernandia nymphaeifolia, Inocarpus fagifer, Morinda citrifolia, Pandanus tectorius, Pometia pinnata,* and *Rhus taitensis.*

Species commonly associated in modern introductions

Both species have been successfully interplanted in *Pinus caribaea* plantations on 'Eua, Tonga. They are often planted in Fijian village homegardens with ornamentals and cultural species (e.g., *Pandanus tectorius*, *Polyscias*, *Croton*, *Cordyline,* and *Euodia hortensis*) and fruit trees (e.g., *Artocarpus altilis*, *Citrus* spp., *Musa* spp., and *Pometia pinnata*).

FOLK VARIETIES

In Vanuatu, two folklore varieties of *S. austrocaledonicum* are widely distinguished. These are a "man" variety known variously as *pior laman* (Penour, Valpei; West Santo), *initjinyat atamien* (Anelghowhat, Aneityum), and man *nipigisi* (Port Patrick, Aneityum), and a "woman" variety called *pior akae* (Penour, Valpei), *initjinyat* ataheig (Anelghowhat), and woman *nipigisi* (Port Patrick). The man variety is characterized as a taller tree, with longer bole, longer pointed leaves, producing few or no fruits, while the woman variety has a shorter, fatter bole, smaller branches, a more rounded leaf, and produces many more fruits. The woman variety produces good heartwood early, whereas the male tree needs to be pruned to induce good heartwood.

Several folk varieties of *S. yasi* have been reported in Fiji and Tonga. The varieties reported from Fiji include *yasi dina* (or true sandalwood, i.e., *Santalum*, distinguishing it from other genera that have sweetly fragrant wood), *yasi boi* (fragrant), *yasi buco*, *yasi vula* (white), *yasi damu* (red), and *yasi kula* (red). The latter folk variety has reddish leaves (possibly a micronutrient disorder) and strongly scented heartwood. Varieties reported from Tonga include *fefine* (literally female, with small leaves), *tangata* (with large, long leaves), *kolo* (sweet smelling*), lau lahi*, *uhiuhi,* and *vao*. These varieties mainly refer to particular phenotypes in a population rather than whole populations. In both Tonga and Fiji the identity and morphological traits of these folk varieties may be interpreted somewhat differently by different villagers/villages.

ENVIRONMENTAL PREFERENCES AND TOLERANCES

Climate

S. austrocaledonicum and *S. yasi* prefer warm to hot, lowland, subhumid or wet/dry tropics, with an annual rainfall of 1250–1750 mm (50–70 in) and a distinct dry season of 3–5 months. Tropical cyclones are a feature of the entire distribution, occurring mainly during the hot, wet season (December–April).

Elevation

S. austrocaledonicum 5–800 m (16–2400 ft), usually less than 300 m (1000 ft) in New Caledonia
S. yasi 0–300(–600) m (0–1000[–2000] ft)

Mean annual rainfall

S. austrocaledonicum 800–2500 mm (30–100 in)
S. yasi 1400–2500 mm (55–100 in)

Rainfall pattern

All species prefer climates with summer rains.

Dry season duration (consecutive months with <40 mm [1.6 in] rainfall)

Most localities experience a pronounced dry season of 2–5 months during the cooler months June–October (Southern Hemisphere).

Mean annual temperature

S. austrocaledonicum 23–27°C (73–81°F)
S. yasi 23–29°C (73–84°F)

Mean maximum temperature of hottest month

S. austrocaledonicum 29–33°C (84–91°F)
S. yasi 24–31°C (75–88°F)

Mean minimum temperature of coldest month

S. austrocaledonicum 16–22°C (61–72°F)
S. yasi 18–25°C (64–77°F)

Minimum temperature tolerated

S. austrocaledonicum The absolute minimum temperature is 10–16°C (50–61°F), but possibly as low as 5–7°C (41–45°F) on Mare, Loyalty Islands, New Caledonia.

S. yasi The absolute minimum experienced is around 8–9°C (46–48°F) at the higher elevations sites in western Viti Levu.

For both species the entire distribution is frost-free.

Soils

S. austrocaledonicum The species grows well on pure coralline soil, volcanic ash, schist or sedimentary substrates. The species prefers well drained acidic to alkaline conditions and does not grow well on waterlogged soils and strongly acidic clayey soils.

S. yasi In Fiji the soils are mainly well drained, humic and ferruginous Latisols. In Tonga, its best development is on soils derived from volcanic ash overlying coralline rock.

Soil texture

The trees prefer light and medium, well drained soils (sands, sandy loams, loams, and sandy clay loams).

Soil drainage

Both species require freely draining soils.

Soil acidity

Both species may grow on acid to alkaline soils (pH 4.0–7.4), but prefer neutral soils (pH 6.1–7.4).

Special soil tolerances

Both species can tolerate shallow and infertile soils. In the Poya region of New Caledonia, var. *austrocaledonicum* grows in ferrallitic/ultramafic soils with a limestone substrate. These soils have high levels of exchangeable calcium and potassium and are rich in nickel and chrome. Further north, around Pouembout, it grows in a highly acidic to neutral, magnesium-rich black clay derived from basalt. Var. *minutum* occurs on immature colluvial soil on serpentine peridotite/metamorphic and ultrafmafic gravels. Such soils are infertile with very low levels of phosphorus, potassium, and calcium, but are relatively high in magnesium, nickel, chrome, and manganese.

Tolerances

Drought

They are able to survive a long dry season (up to 5–6 months) when attached hemi-parasitically to suitably drought-tolerant host plants.

Full sun

They grow well in full sun when their roots are attached hemi-parasitically to suitable host species; otherwise, they become yellow (and can die).

Shade

They can survive up to 60–70% shade, but growth will be very slow at higher shade levels. The optimum level of shade is up to about 25%, preferably as "side shade." Side shade is provided by planting adjacent rows of bushy but not spreading plants, which grow up to about the same height as sandalwood but do not overtop and cast overhead shade.

Fire

Both species are sensitive to fire (and grazing from cattle and deer) particularly in the first few years of growth. Plants of some sandalwood species will regrow from coppice following fire; e.g., *S. austrocaledonicum* and younger specimens of *S. album*.

Frost

Both species are frost-sensitive.

Waterlogging

They prefer good drainage and will die or die back following any prolonged period (greater than 2 weeks) of waterlogging.

Salt spray

Plants growing in near-coastal situations may suffer severe scorching by salt-laden winds and total defoliation following cyclonic storms, but usually they totally recover.

Wind

Mature plants are typically of low stature and are generally fairly resistant to strong winds associated with cyclonic storms, except in open areas. Younger plants in open areas, especially if they have grown quickly and have a heavy canopy, may be blown over or suffer breakage of stems and branches. Older trees growing among established forests can also suffer from limb damage during cyclone events. The most susceptible trees are those with forked trunks, which can easily split.

GROWTH AND DEVELOPMENT

Growth rate

S. austrocaledonicum In New Caledonia in young plantations (up to 5 years) individuals show mainly an increase in height with a mean annual growth increment in trunk diameter of about 6 mm. The average diameter growth rate in older plants is 3.8–4.8 mm per year. In Vanuatu young plants (up to 3 years old) can grow at moderately fast rates, e.g., 1 m height per annum and 1 cm diameter increment (measured at 20 cm above ground level) per annum. Diameter growth averaged 6–10 mm per year at 18–26 years, and 6–7 mm per year after 28–33 years. Trees can grow at moderate rate over the projected rotation period of about 25–40 years.

S. yasi Early height growth is slow to moderate, e.g., 0.5–0.7 m per year, but is variable depending upon environmental conditions and host species. Under suitable growing conditions it may attain harvestable size in about 25 years; e.g., 20–25 cm diameter near ground level, with substantial heartwood development.

Rooting habit

Sandalwoods have a widely spreading surface root system capable of grafting onto many other plant species and tapping water and mineral nutrients.

Reaction to competition

Sandalwoods, especially as young plants, react poorly to competition from monocotyledons (including grasses and palms such as coconut). Being hemi-parasitic, they are best grown in close proximity to suitable host species.

Diseases and Pests

S. austrocaledonicum In New Caledonia plants are sometimes attacked by insects (*Ceroplastes* and *Coccus*), but damage is rather minor. Fungal damage has been observed on leaves of nursery seedlings. Plants are susceptible to brown root rot (*Phellinus noxius*).

S. yasi Yasi is susceptible to *Phellinus noxius*, and mature specimens may quickly succumb to it. This disease is potentially serious, as it can spread rapidly to adjacent trees through root grafting. In cool, wet, cloudy weather, seedlings can be attacked by a fungus (anthracnose type) that can cause severe leaf spotting (hypersensitive reaction) followed by defoliation. Seedlings are susceptible to root rot-fungi in poorly draining and unsterilized media. Yasi is also susceptible to sandal spike disease, caused by a mycoplasma-like organism; this pathogen causes considerable damage to *S. album* in India (but is absent from the South Pacific region).

ABILITIES

Regeneration

Regeneration of wild sandalwood stands typically occurs very slowly following harvesting due to the removal of most of the larger fruiting specimens, and in at least some cases the removal of other species upon whose roots the sandalwood plants parasitize.

Self-prune

Self pruning is variable; in open situations, sandalwood plants often retain branches to near ground level. In shadier situations, especially where the shade is cast from overhead, the plants exhibit reasonably good self-pruning characteristics. For *S. yasi* suitable shade regimes to keep plants growing straight and to avoid a bushy habit include strong lateral shade with no overhead shade or a high canopy producing intermediate shade.

Coppice

Plants frequently resprout from basal coppices or by root suckering off lateral roots (following removal of the stump and major roots). Many species are capable of root suckering as long as not too much of the root system is removed during harvest. However, such coppice regrowth is likely to die out in more heavily shaded situations.

Pollard

Plants can be pollarded, but this is not an appropriate regime for sandalwood where the economic value is concentrated in the heartwood in the lower bole and large woody roots.

PROPAGATION

All *Santalum* species are readily propagated by seed in the nursery. They may also be propagated through encouraging seedling development underneath selected heavy-bearing plants; such wildlings can be transplanted to a new location. Vegetative cuttings may be struck under mist from seedling material. Cuttings from young plants initiate and develop adventitious roots much more readily than cuttings from more mature plants. Grafting and root segment cuttings from mature specimens can be used to conserve selected individuals or bring them into breeding programs.

Propagation by seed

Seed collection

It is recommended that mature fruits be collected while still attached to the tree, although recently fallen fruits may also be acceptable if not exposed to the sun. Fruits that have attained maturity are full size and usually have begun to show slight color change, commonly a reddish tinge, the fruit becoming entirely red to dark purplish black.

S. austrocaledonicum The main fruit collection period is from November to January.

S. yasi The main fruit collection period is from January to March.

Seed processing

The fleshy mesocarp needs to be removed from the fruits without delay. Fruits that are hard to depulp by hand may be soaked in water for 1–2 days to soften the pulp prior to its removal. The depulped, cleaned seeds are then disinfected (e.g., with sodium hypochlorite or diluted bleach) before being rinsed and air dried in a well ventilated room

When picked green, fruits are rarely viable. A reddish or purplish tinge is a first indication that seeds are mature. Pictured: *S. album*. PHOTO: L. THOMSON at a temperature below 25°C (77°F) out of direct sun for up to 2–3 weeks. Seeds usually have a high purity, but number of viable seeds per kg varies considerably between species, provenances, and individual seed lots.

Depending on the seed source, there are 2400–8400 seeds per kg (1100–3800 seeds/lb):

S. austrocaledonicum Loyalty Islands: 2400 per kg (1100 seeds/lb); Isle of Pines: 6000 per kg (2700 seeds/lb); Vanuatu: 3300–4500 per kg (1500–2000 seeds/lb)

S. austrocaledonicum* var. *pilosulum 8400 per kg (3800 seeds/lb)

S. yasi 6000–7000 seeds per kg (2700–3200 seeds/lb)

For newly collected seed, viability is high for *S. yasi* and *S. album*, often 80–90% after 2–3 months, for naked seed (embryo extracted). Germination is lower for nicked seed, e.g., 60–70% after 3 months, and lower and much slower for untreated seeds.

Seed storage

Many *Santalum* species show intermediate storage behavior, with seeds rapidly losing viability during storage. Seed storage behavior varies between species, and may even vary among different seed sources for *S. austrocaledonicum*. For example, seeds from the Isle of Pines may be safely stored for several years, whereas those from the Loyalty Islands lose viability within a few months. Seed storage behavior for *S. yasi* is unknown, but seeds stored for longer periods (>6–12 months) will have very low viability. *S. album* has an orthodox seed storage behavior, but viability generally declines after several years in storage.

Seed for storage should be placed in airtight containers in the refrigerator (2–4°C [36–39°F]) as soon as possible following surface drying. In general, ultra-dry storage (e.g., down to about 2% moisture content) is recommended for seeds of high oil content that are normally short-lived in storage.

It is usually preferable to sow sandalwood seed as soon as possible after collection to reduce the risk of the seeds losing viability during storage.

Pre-planting treatments

For *S. austrocaledonicum*, pretreatment of seed promotes rapid and uniform germination. The recommended seed pretreatment method is as follows:

1. Nick the seed coat at the pointed end of seed using a sharp knife.
2. Soak seeds overnight in a solution of gibberellic acid (GA3) at rate of 0.1 to 0.25 g/l.
3. Drench the seeds in a fungicidal solution, e.g., benlate,

Top: *Santalum* seeds sprouting in pure vermiculite. PHOTO: C. ELEVITCH
Bottom: *S. yasi* in containers with host plants *Calliandra calothrysus* (foreground), *Casuarina equisetifolia* (middle), and *Alternanthera* sp. (background). PHOTO: L. THOMSON

for a few minutes before sowing (optional).

Treatment of freshly collected seed with gibberellic acid (GA) gives quick and homogeneous germination but is not recommended for routine nursery production of seedlings due to high cost. GA treatment might best be used for smaller, more precious research samples, etc.

The following treatment has been shown to produce quick germination of the Hawaiian species *S. ellipticum* and *S. freycinetianum.* Before treatment, seeds should be removed from the ripe fruit, cleaned by hand, and air-dried for about a week. Then a small part of the seedcoat at the apex of the seed should be removed so that the embryo becomes visible but not damaged. This can be done using large nail clippers, forceps, or medium sandpaper. Subsequently, the seed can be soaked in small amounts (0.05%) of the plant hormone gibberellic acid for 5 days, changing the solution daily. Then the seed is removed from the growth hormone solution and dusted with a 1:1 mixture of powdered sulfur and captan to prevent fungus infection. Seeds should be placed in a covered tray on new, wet vermiculite to allow germination to occur.

Growing area

Seeds are generally germinated under cover in a glasshouse (or other covered nursery structure) in a freely draining medium, e.g., 1:1 sterilized river sand, peat moss mixture, or 2:1 sand:compost. The mixture should be kept slightly moistened (but not wet, in order to avoid rotting of seeds and damping off). The optimum temperature for germination is 28–31°C (82–88°F). Germination trays should be protected from rats, birds, and other predators that will eat seeds or young germinants.

As seedlings age they are moved to progressively higher light levels, e.g., 50% shade in the early months, then 25% shade and several months of hardening under full sun prior to field planting.

Germination

S. austrocaledonicum Nicked seed commences germination after 2 weeks and is completed by 8 weeks; most germination occurs between 30 and 40 days. Whole seed is much slower to germinate, commencing after about 40 days. Germination rates of greater than 50% are expected for fresh seed that has been collected from mature fruits still on the tree and appropriately handled and cleaned.

S. yasi Germination of nicked seed occurs rather slowly over a long period, e.g., from 40 to 120 days after sowing. As they appear, germinants are transplanted into pots, preferably before the seed coat falls from the germinating shoot.

Seedlings are pricked out at the two- or four-leaf stage into polypots (16 x 6.5 cm [6.3 x 2.6 in]). At this time a host plant is usually planted together with the seedling (see “Recommended hosts” sidebar).

RECOMMENDED HOSTS

Acacia species, *Calliandra calothyrsus*, and *Casuarina* spp. may be used as pot hosts, but *Calliandra* needs frequent cutting back to prevent it from overtopping the sandalwood.

S. austrocaledonicum *Acacia spirorbis* makes a good long-term host plant under both natural conditions and in plantations. For ultramafic soils, other good nitrogen-fixing host species are *Casuarina collina* and *Gymnostoma deplancheana*.

S. yasi Good long-term hosts include *Citrus* spp., *Acacia richii*, *Calliandra calothyrsus,* and *Casuarina equisetifolia*.

S. album Good intermediate and long-term hosts include *Acacia trachycarpa*, *Casuarina junghuhniana* (long-lived), *Cathormium umbellatum* (long-lived), *Crotalaria juncea*, *Desmanthus virgatus*, and *Sesbania formosa*.

Media

The potting mixture should be well drained with reasonable water-holding capacity. A typical growing medium for *S. yasi* in Fiji is a moderately fertile, forest loam (67%), and river sand (33%) plus 2 kg NPK fertilizer per cubic meter (2 oz/ft^3).

Time to outplanting

Seedlings are ready for planting when the height is about 20–25 cm (8–10 in), usually taking approximately 5–6 months.

Guidelines for outplanting

Sandalwoods need to be either planted out among established long-term host plants, or else together with intermediate hosts (relatively short-lived woody perennials) while longer term hosts are established.

Survival rates are high (often above 80%) for larger, healthy seedlings planted at the onset of the rainy season and kept well weeded in the first 2 years. Survival and growth will be low for plants

- established in more shady forest situations
- in grassy, sunny situations
- in polycultures underneath coconut plantations.

S. yasi seedling ready for outplanting. PHOTO: L. THOMSON

Propagation using wildlings

The following technique is useful for promoting germination of wildlings, which can then be transplanted and grown in the nursery before field planting in a suitable location:

- Select sandalwood trees that are fruiting or are otherwise known to fruit heavily.
- Clean all undergrowth from beneath the canopy of the selected sandalwood trees.
- Loosen the soil in the cleared area by shallow digging or cultivating only the top 5 cm (2 in) of soil.
- Wildlings begin to germinate in the cultivated area about 1–2 months after soil disturbance.
- If possible water the cultivated area during dry periods or after some germinants are observed.
- Keep the cultivated area free from regrowth of weeds.

Propagation by vegetative cuttings

Rooting of cuttings varies considerably between species and half-sibling families, and rooting success declines rapidly with stock plant age. Successful root initiation and development to a level of greater than 40%, can only be obtained using shoot material collected from seedlings and struck under intermittent misting in suitable media (e.g., 1:1 sand/peat or 1:1 sand/coconut coir). The order of ease of rooting is *S. yasi* > *S. austrocaledonicum* > *S. macgregorii* > *S. album*. There is a need for further work to identify appropriate stock plant treatments and environmental conditions to optimize rooting success for each species.

Propagation by root cuttings

Root segments (about 5–10 cm [2–4 in] long and greater than 1 cm [0.4 in] in diameter) may be collected from larger specimens of *S. album* (and probably other sandalwood species) and used to strike cuttings. The cuttings are treated with rooting powder (e.g., Seradix B_2) and placed horizontally at a depth of 1 cm [0.4 in] in a freely-draining medium (e.g., 50:50 coarse washed river sand and peat moss) which is kept moist (but not saturated) in a glasshouse (or alike). The time for sprouting is from about 1 to 3 months. The percentage of root segments forming shoots and roots is typically low (e.g., 10–50%) and dependent on

Freshly dug up *S. austrocaledonicum* seedlings for immediate transplant to other areas on the island of Aniwa, Vanuatu. PHOTO: T. PAGE

Young *S. austrocaledonicum* seedling with artificial shelter, Efate, Vanuatu. PHOTO: L. THOMSON

seasonal factors.

DISADVANTAGES

The main drawbacks of sandalwood cultivation are:

- lack of seed and planting materials
- lack of varieties or cultivars with known oil qualities and yields
- relatively complex silviculture and need to be grown with suitable host plant species
- susceptibility to root and butt rot fungi and rapid death of plants when grown in higher rainfall zones
- risk of theft of trees when nearing maturity.

Potential for invasiveness

Pacific island sandalwoods have not become naturalized outside of their native range. Sandalwood species generally have a capacity for invasiveness in disturbed, open plant communities, but this is not considered a problem because of their very high value and because they do not dominate or appear to modify such communities in any substantial way. There is a risk that some planted host species, especially exotic leguminous trees, might become invasive. Accordingly, it is recommended that local plant species are screened first for suitability as hosts and used preferentially as hosts, especially in and around areas of high biodiversity conservation value.

Sandalwood species are root parasites, with the potential to root-graft and link almost whole plant communities. They are therefore at particular risk of pathogenic fungi that can also spread from tree to tree through root grafts, such as *Phellinus noxius*.

Host to crop pests/pathogens

Sandalwood species are not known to be an important host of any crop pests or diseases.

Other disadvantages or design considerations

These trees need to be planted in well protected areas in which opportunities for theft are minimized, such as in homegardens, smaller remote islands, and well fenced and closely guarded locations. Fencing is also necessary in areas with wild steers because of their feeding preference toward developing sandalwood saplings.

AGROFORESTRY/INTERPLANTING PRACTICES

Alley cropping

Sandalwoods are suitable for inclusion in alley cropping systems, especially where the other alley species include good hosts, e.g., *Calliandra* spp.

Homegardens

They are very suitable for planting in homegardens, which have the advantages of mixture of host species, intermediate/variable light levels, and high security.

Improved fallows

They could be included in improved fallows of nitrogen-fixing trees, with a fallow rotation of 20 or more years to ensure that sandalwoods attain commercial maturity.

Windbreaks

Sandalwoods are suitable for inclusion in windbreaks, especially where the main windbreak species include good hosts, e.g., *Casuarina* spp.

Woodlot

Sandalwoods are suitable for inclusion in woodlots, especially when planted along sun-exposed edges of the woodlot and in combination with compatible species, e.g., with *Pinus caribaea*, as has been done in Tonga.

Native animal/bird food

The fruits of sandalwood are consumed by various bird species, including pigeons. For soft-beaked species the seeds may pass through the digestive system intact and be widely disseminated.

Host plant trellising

There is minor potential to trellis slower-growing vines that would not interfere with full sun reaching the canopy,

Left: *S. yasi* grown on fence line between two house lots in Tonga. Right: *Alyxia stellata*, a traditional vine used in garlands, climbing on yasi in a homegarden in Tonga. PHOTOS: C. ELEVITCH

such as maile (*Alyxia stellata*).

Ornamental

Sandalwoods are quite attractive, especially when in flower, and are especially suitable for home and village gardens.

USES AND PRODUCTS

Wood from sandalwood was traditionally used in the South Pacific for carvings, cultural uses, medicine, and burnt as an insect repellent. However, it is rarely used nowadays because of its scarcity and cash value. The grated wood was traditionally used to a limited extent to scent coconut oil (for application to the hair and body) and cultural artifacts such as tapa cloth.

Both *Santalum austrocaledonicum* and *S. yasi* produce highly prized sandalwoods, often similar in quality to the well known *S. album* from India and Indonesia. The heartwood of *S. yasi* was a major export during the early 1800s, and the sandalwood trade was one of the first attractions drawing Europeans into the South Pacific. Sandalwood from *S. yasi* is still exported to a limited extent from Fiji and Tonga, experiencing short-lived boom periods associated with a buildup of sandalwood stocks, the most recent in Fiji being in the mid–late 1980s when a ban on commercial exploitation was lifted. *S. austrocaledonicum* was heavily exploited over about three decades in the middle of the 1800s in New Caledonia and Vanuatu, and it has been utilized periodically since. Carvings, sandalwood oil, and incense production, listed in order of highest to lowest value, are the three major present-day wood uses of *S. austrocaledonicum.*

Medicinal

Sandalwood has various and generally not well documented medicinal uses. In Samoa, a decoction of sandalwood and *Homolanthus* leaves is taken to treat elephantiasis or lymphatic filariasis.

Craft wood/tools

The highest-value sandalwood is used for carving (religious statues and objects, handicrafts, art, and decorative furniture). Larger basal pieces and roots are preferred for carving.

Cosmetic/soap/perfume

The oil from the heartwood, extracted by steam distillation or by solvent, is used for cosmetics, scenting of soaps, perfumery, aromatherapy, and medicinal purposes. The oil content of heartwood varies considerably among species, individual trees, and location within the tree, but is typically in the range of 3–7% for basal stem/large root sections. Oil is currently distilled from *S. austrocaledonicum* and *S. album*, but not *S. yasi* (due to lack of supply).

Ceremonial/religious importance

Heartwood from sandalwood trees yields an aromatic oil that is widely valued and has been the basis of a lucrative and exploitative trade for hundreds of years. In Tonga, the oil is used to scent tapa cloth and anoint corpses in royal funerals. *S. yasi* is also featured in Tongan legends and songs. Heartwood and sapwood are powdered together to produce incense or joss sticks used in Asian religious ceremonies. Sawdust, wood shavings from carving or wood residue after oil distillation may be used.

Sandalwood sculptures Bangalore, India. PHOTO: M. MERLIN

COMMERCIAL PRODUCTS

The primary commercial products from sandalwood are the heartwood and the essential oil distilled from the heartwood. The international standard for the oil of *S. album* (ISO/DFIS 3518) includes four compounds in the chromatographic profile (α-santalol, trans-α-bergamotol, epi-β-santalol, and Z-β-santalol), but only two, Z-α-santalol (41–55%) and Z-β-santalol (16–24%), are assessed in the standard. The total santalol content of *S. yasi* oil (the component most associated with sandalwood's essence) is 60–70% and similar to that of *S. album* (the industry standard and most sought-after oil). The composition of heartwood oil from *S. austrocaledonicum* from New Caledonia (Maré Island and Isle of Pines) resembles *S. album*, with very similar levels of the major fragrant constituents, 48–49% α-santalol and 20–22% β-santalol. In Vanuatu there are two chemotypes of *S. austrocaledonicum*, one chemotype being rich in santalols (>30–40% α-santalol and >15% β-santalol) while the second chemotype contains Z-nuciferol (7–25%) and/or Z-lanceol (15–41%) and lower proportions of santalols.

The heartwood from Pacific sandalwood species is mainly exported to Asia. Most *S. yasi* from Tonga gets exported to East Asian countries, particularly China (via Hong Kong), Taiwan, and Japan, but some is also supplied to the United States. The main markets for sandalwood oil are Europe and the United States.

Spacing for commercial production

Spacing for commercial production varies considerably depending on the type of planting. The final crop is likely to be around 100 mature sandalwood trees per hectare (10 x 10 m [33 x 33 ft]) due to need to include host tree/shrub species (at a rate of 2–4 per sandalwood depending on host species). Due to the high value and demand for even a single mature tree, there is effectively no minimum area or number of trees required for commercial production. The plantation area required to provide raw material for a small/medium scale oil distillation operation of *S. austrocaledonicum*, e.g., producing 800 liters per annum (845 qt/yr) from 20–40 mt (22–44 t) of heartwood, is estimated to be about 60–120 ha (150–300 ac), based on a 30-year rotation.

Management objectives

The main management objective should be to establish and manage a good mixture of host plant species that provide a suitable light/shelter regime.

Host tree species may need to be pruned or progressively thinned to maintain good levels of sunlight to maturing sandalwood plants.

For *S. yasi* careful pruning of side branches, removing no more than 25% of canopy at any one time, has been advocated to encourage development of a main bole. Regular removal of competing leaders (breaking by hand) in younger specimens may be a more satisfactory approach.

For soils of lower fertility, periodic fertilizing with 100 g (3 oz) NPK fertilizer per tree will promote more rapid growth.

Weed growth, especially of long, flammable grasses, needs to be well controlled in the early years. Weeds should be manually removed to avoid the risk of herbicide drift and/or translocation through weeds to sandalwood plants via root system connections.

This brush-like regrowth with stunted leaves is indicative of herbicide poisoning, in this case translocated from weeds that were poisoned near this *S. album* tree. PHOTO: C. ELEVITCH

Design considerations

Greater accessibility of sandalwood plantations increases the risk of theft.

Advantages and disadvantages of growing in polycultures

A diverse mixture of host species is preferred so as to:

- enable sandalwood trees to optimally obtain their mineral nutrition/water needs, and,
- reduce pest and disease risks associated with reliance on just one or two main hosts.

Estimated yields

S. austrocaledonicum A rough estimate of heartwood production is 50–100 kg (110–220 lb) per tree after 30 years.

S. yasi With good silviculture, it is estimated that trees can produce about 1–2 kg (2.2–4.4 lb) of heartwood each year from age 10 years. Therefore a 20–25-year-old tree, growing under good conditions, can produce 15–30 kg (33–66 lb) of heartwood (including from roots).

S. album It is estimated that trees can produce about 20–40 kg (44–88 lb) of heartwood on a 20 year rotation, under South Pacific conditions and given appropriate silviculture.

On-farm processing

Whole trees including major roots are harvested. The main on-farm processing is careful removal of the sapwood, using a large, sharp knife. Sandalwood wood pieces that are kept in dry conditions for several months may exhibit small increases in oil content and improvement in quality (but this is offset by a lower weight and hence return to the grower).

Markets

The world production/consumption of sandalwood oil is in the order of several hundreds of metric tons. India is the major producer (90% of world production) and user of sandalwood oil. Exports from India of *S. album* oil during the 6 year period 1987/88–1992/93 averaged 40.5 mt (45 t) with the main importers of this oil being France and the United States. Indonesian exports of *S. album* oil during 1987 to 1992 averaged 15 mt/yr (17 t/yr) and went mainly to the U.S., which is the single largest market outside India. International demand for *S. album* oil is not being met, and prices continue to rise. Markets for *S. austrocaledonicum* oil, up to about 15–20 mt (17–22 t) per year, include France, Germany, and the United States.

Annual global sandalwood heartwood production is estimated to be approximately 5100 mt (5600 t), however, production has declined markedly over the past 20–30 years. China, Taiwan, Singapore, Korea, and Japan, with no natural resources of sandalwood, are the main markets, together with India, which has its own production capability. Production of sandalwood heartwood from the South Pacific is highly variable, experiencing periods of boom and bust since exploitation commenced in the early 1800s.

INTERPLANTING/FARM APPLICATIONS

Example system 1

Location

South Efate, Vanuatu

Description

This is a recently developed system (since 1997) of growing sandalwood (*S. austrocaledonicum*) in planted lines as part of a mixed farming enterprise following recommendations provided by the South Pacific Regional Initiative on Forest Genetic Resources (SPRIG) Project. Sandalwood plants are established either using seedlings or direct-seeding.

Yields

Plants are healthy, bushy, and have shown good growth, e.g., about 1 m (3.3 ft) height growth per year. The previous system had been to plant sandalwood seedlings underneath residual remnant forest, which resulted in very slow growth due to insufficient light.

Crop/tree interactions

The lines of sandalwood are interplanted with lines of *Casuarina* (every third line) that act as a permanent host and windbreak. Intermediate hosts included vegetable crops such as *Capsicum*.

Spacing

The spacing is about 3 m (10 ft) between and within double rows of sandalwood trees with every third row comprising *Casuarina.*

Example system 2

Location

Tanna, Vanuatu

Description

This is a recently developed system (since about 1996) in which sandalwood (*S. austrocaledonicum*) wildlings are transplanted around the perimeter of new village garden areas established within bush and secondary forest.

Yields/Benefits

Plants are healthy and have shown good stem form and early growth, e.g., about 1 m (3.3 ft) height growth per year. Sandalwood grows very well along forest edges/verges, due to the good balance of light and hosts, and this system takes advantage of this.

Crop/tree interactions

On the bush/forest side of the plot, the sandalwood plants gain access to root systems of diverse permanent hosts and receive some side and overhead shade, which encourages better stem form. On the garden side, sandalwood plants have the advantage of good weed control plus high levels of sunlight. The main crop was ginger, but this system would work well with almost any vegetable or root crop.

Spacing

The sandalwood trees are planted in a line along the boundary perimeter of the garden area. Spacing is variable, about 3–4 m (10–13 ft) between trees.

Example system 3

Location

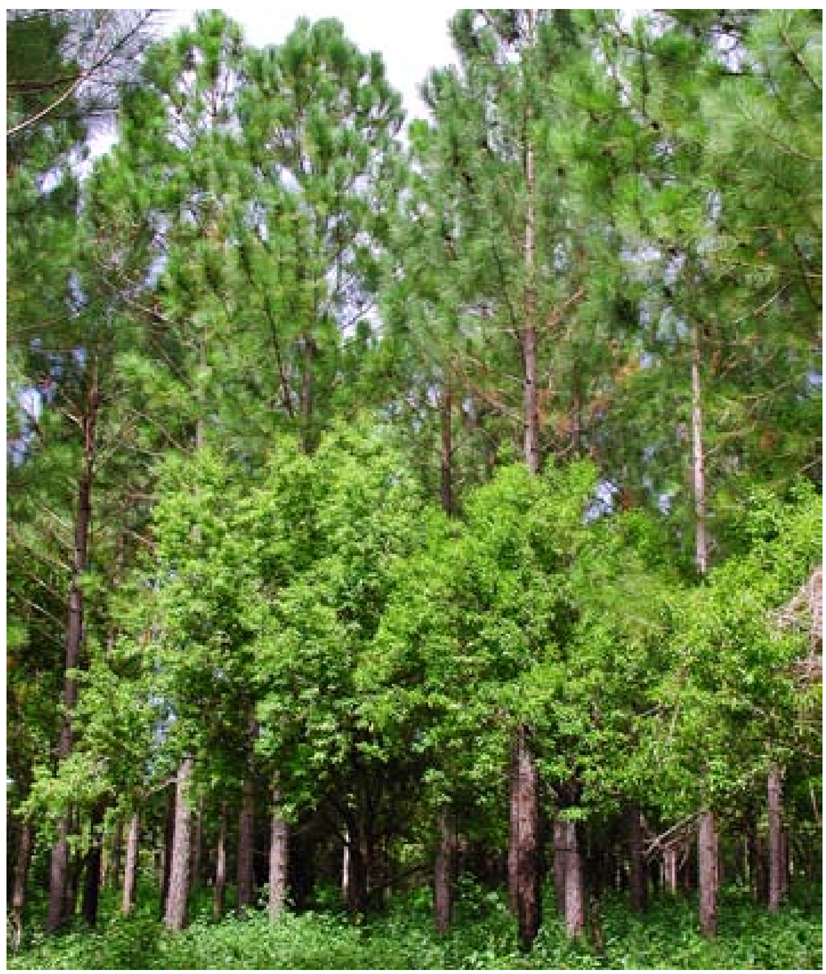
'Eua, Tonga

Description

This is a recent system dating from the early 1990s involving interplanting of *S. yasi* in a *Pinus caribaea* plantation.

Yields

Sandalwood trees in pine plantations appear to reach 8–12 m (26–40 ft) in height and 15 cm (6 in) in diameter, with about 40% heartwood in the basal stem section, after about 15–20 years. With improved silviculture, including



***S. yasi* grown on the edge of a *Pinus caribaea* woodlot.** PHOTO: L. THOMSON more light through early thinning of pines and inclusion of some better host species, the growth rates would be enhanced. It is estimated that trees produce about 1-2 kg (2.2-4.4 lb) of heartwood each year from age 10 years. Therefore, a conservative estimate would be that a 20–25-year-old yasi tree, growing under good conditions, can produce 15–30 kg (33–66 lb) of heartwood (including from roots).

Crop/tree interactions

The pine provides a good physical environment for the sandalwood, i.e., good shelter and intermediate light levels that encourage good stem form.

Spacing

Pines are planted at 4 x 3 m (13 x 10 ft), or 833 stems per hectare (340 stems/ac). The sandalwood is interplanted with pine, preferably when the pines are 3 years old (although this could be done when the pines are between 2–4 years) Sandalwood could be planted between every second row and at a spacing of 8 x 6 m (26 x 20 ft), or about 208 stems per ha (84 stems/ac). Ideally, the pine rows would run north-south to allow maximum sunlight to fall on the smaller sandalwoods. The pines should be thinned (at least once) and heavily pruned to produce better quality and bigger sawlogs, and to provide a more open stand that is favorable to growth of sandalwood. Smaller nitrogen-fixing trees, such as *Calliandra*, *Casuarina*, *Sesbania*, *Gliricidia*, *Cajanus*, and *Citrus* ought to be included in this system.

PUBLIC ASSISTANCE AND AGROFORESTRY EXTENSION

Extension offices for agroforestry and forestry in the Pacific: http://www.traditionaltree.org/extension.html

Organizations that have special sandalwood extension programs include Department of Forests, Vanuatu, Department of Forestry, Fiji, and Conservation and Forestry Division, Tonga.

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Traditional Tree Initiative—Species Profiles for Pacific Island Agroforestry (www.traditionaltree.org)

Santalum austrocaledonicum and *S. yasi* (sandalwood)

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Acknowledgments: The author and publisher thank Dale Evans, Tony Page, Jacques Tassin, and Art Whistler for their input. Photo contributions from Mark Merlin and Tony Page are greatly appreciated.

Recommended citation: Thomson, L.A.J. 2006. *Santalum austrocaledonicum* and *S. yasi* (sandalwood), ver. 2.1. In: Elevitch, C.R. (ed.). Species Profiles for Pacific Island Agroforestry. Permanent Agriculture Resources (PAR), Hōlualoa, Hawai‘i. <http://www.traditionaltree.org>.

Sponsors: Publication was made possible by generous support of the United States Department of Agriculture Western Region Sustainable Agriculture Research and Education (USDA-WSARE) Program; SPC/GTZ Pacific-German Regional Forestry Project; USDA Natural Resources Conservation Service (USDA NRCS); State of Hawai‘i Department of Land & Natural Resources Division of Forestry & Wildlife; and the USDA Forest Service Forest Lands Enhancement Program. This material is based upon work supported by the Cooperative State Research, Education, and Extension Service, U.S. Department of Agriculture, and Agricultural Experiment Station, Utah State University, under Cooperative Agreement 2002-47001-01327.

Series editor: Craig R. Elevitch

Publisher: Permanent Agriculture Resources (PAR), PO Box 428, Hōlualoa, Hawai‘i 96725, USA; Tel: 808-324-4427; Fax: 808-324-4129; E-mail: par@agroforestry.net; Web: <http://www.agroforestry.net>. This institution is an equal opportunity provider.

Species Profiles for Pacific Island Agroforestry
www.traditionaltree.org

April 2006
ver. 4.1

Santalum ellipticum, *S. freycinetianum*, *S. haleakalae*, and *S. paniculatum* (Hawaiian sandalwood)

Santalaceae (sandalwood family)

ʻ*iliahialoʻe* (*S. ellipticum*)
ʻ*iliahi*, *ʻaʻahi*, *ʻaoa*, *lāʻau ʻala*, *wahie ʻala* (*S. freycinetianum*, *S. haleakalae*, and *S. paniculatum*)

Mark D. Merlin, Lex A.J. Thomson, and Craig R. Elevitch

IN BRIEF

Distribution Hawaiian Islands, varies by species.

Size Small shrubs or trees, typically 5–10 m (16–33 ft) or larger at maturity.

Habitat Varies by species; typically xeric, subhumid, or humid tropics with a distinct dry season of 3–5 months.

Vegetation Open, drier forests and woodlands.

Soils All species require light to medium, well drained soils.

Growth rate Slow to moderate, 0.3–0.7 m/yr (1–2.3 ft/yr).

Main agroforestry uses Homegardens, mixed-species forestry.

Main uses Heartwood for crafts, essential oil extraction.

Yields Heartwood in 30+ years.

Intercropping Because sandalwood is parasitic and requires one or more host plants, intercropping is not only possible but necessary.

Invasive potential Sandalwood has a capacity for invasiveness in disturbed areas, but this is rarely considered a problem.

Santalum freycinetianum **var. *lanaiense*, rare, nearly extinct. Photo taken near summit of Lānaʻihale, Lānaʻi in 1978.**

INTRODUCTION

Hawaiian sandalwood species are small trees that occur naturally in open, drier forest and woodland communities. They are typically multi-stemmed and somewhat bushy, attaining a height of 5–10 m (16–33 ft) or larger at maturity, and spreading to about the same width. Sandalwoods generally do not persist in moister, denser forest types due to their poor tolerance of high shade levels. The trees generally tolerate a broad range of soil conditions but show a preference for well drained neutral to slightly alkaline soils. They grow more quickly in fertile soils but are then at risk of being shaded out or overtopped by taller, faster growing trees on such sites.

In Hawai'i, there was a general belief in the early part of the 20th century that sandalwood had become extinct (St. John 1948). In fact, all four of the presently recognized species still exist. Three of these are not yet threatened with extinction or extirpation from any island where they are endemic. The fourth species, *S. haleakalae,* currently is a geographically and ecologically very restricted species. Its seeds and seedlings are quickly consumed by rats in its limited subalpine habitat on the upper slopes of East Maui's Haleakalā volcano. In addition, *S. freycinetianum* var. *lanaiense* on Lana'i Island is presently threatened by alien ungulate browsing and may become extinct in the near future if complete removal of the introduced hoofed animals is not sanctioned and carried out quickly. Although Hawaiian sandalwood species are still rare in most of their former ranges, natural, or perhaps artificial, regeneration could conceivably provide a very valuable natural resource that could be harvested on a sustainable basis.

Sandalwood trees are root-parasitic, which means they have special root extensions that capture water and nutrients from roots of certain other plants. The plants that donate nutrients to sandalwood are called hosts, and sandalwood does not grow well without them. Sandalwoods are also capable of root-suckering; this is most apparent after a tree is cut down, when clumps of suckers may regenerate in a circular pattern several meters away from the original stump.

Sandalwoods are well suited to interplanting, and due to their root-parasitic nature they need to be grown with other suitable host tree species. They may be interplanted with various other species, which could provide additional sources of revenue. Sandalwoods have a good regeneration potential and ability to colonize/invade nearby suitable sites. As long as some mature fruit-bearing trees are retained, birds will spread the fruit. Their invasive potential is seldom considered a drawback due to the exceptionally high value of their heartwood coupled with their small stature and susceptibility to being shaded out.

SANDALWOOD TERMS

Hemi-parasitic Describes a plant that photosynthesizes but derives water and some nutrients through attaching to roots of other species. Sandalwood is hemiparasitic. In this text, the term "parasitic" is used in place of "hemi-parasitic."

Root-grafting This is where roots, usually of the same or related species, grow together, form functional unions, and exchange materials. Sandalwood roots can "graft" onto many different species, effectively joining whole plant communities through their root systems.

DISTRIBUTION

Native range

S. ellipticum

Endemic to Hawaiian islands, this species can be found as a sprawling to bushy shrub near the ocean shore. It is also occasionally found as a somewhat larger shrub to small tree in dry gulches, on slopes or ridges, and frequently in 'a'ā lava or rocky habitats. The species also grows in arid shrub land and forest, often persisting in areas invaded by non-native species up to elevations up to 560 m (1840 ft), and sometimes as high as 950 m (3120 ft) elevation on all of the main islands. It is now extinct on Kaho'olawe and Laysan, rare on Kaua'i, and on Hawai'i it is only known to exist in scattered areas, such as in the Kohala Mountains, Pu'uwa'awa'a in the North Kona District, and Pu'upāpapa and several other of the nearby cinder cones in the South Kohala District. It may also be found very rarely in the lower subalpine area between Mauna Kea and Mauna Loa (Wagner et al. 1999).

S. freycinetianum

Endemic to Hawaiian islands, this species can be found occasionally to commonly in moderately wet to very humid forests but also in dry forest on Lāna'i; it frequently occurs on slopes or ridges from as low as 250 m (820 ft) to as much as 950 m (3120 ft) on Kaua'i, O'ahu, Moloka'i, Lāna'i, and Maui (Wagner et al. 1999).

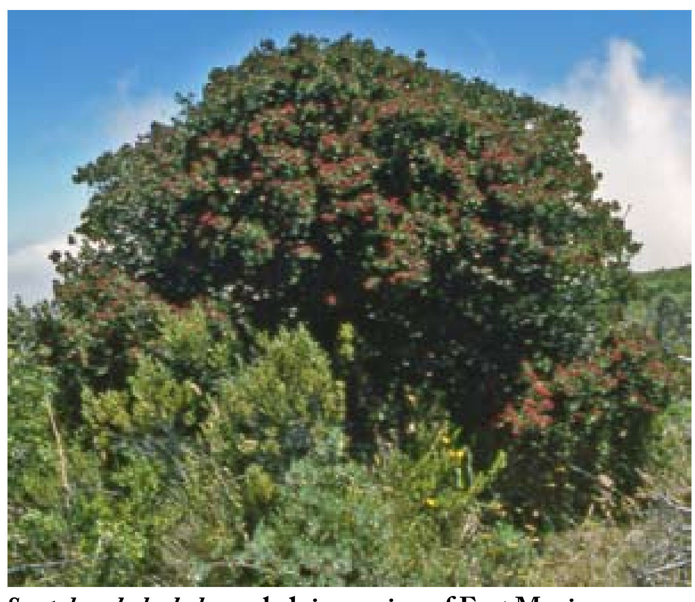
S. haleakalae

Endemic to Maui only, this species is restricted to scattered areas in the subalpine shrub land on dry slopes, especially in foggy areas at 1900–2700 m (6230–8860 ft) on Haleakalā (Wagner et al. 1999).

Santalum ellipticum **along Wai'anae coast, O'ahu.** PHOTO: M. MERLIN

Santalum freycinetianum**, southern Wai'anae mountains, O'ahu.** PHOTO: M. MERLIN

Santalum paniculatum**, Pu'uhuluhulu, island of Hawai'i.** PHOTO: M. MERLIN



Santalum haleakalae**, subalpine region of East Maui.** PHOTO: M. MERLIN

S. paniculatum

Endemic to Hawai'i island only, this species is found in dry forest areas on lava substrates or on cinder cones up to higher elevations in more humid forest, or in secondary *Metrosideros* forest from about 450 m to 2550 m (1480–8360 ft) in elevation (Wagner et al. 1999).

Current distribution

Hawaiian species have primarily been planted inside of their natural range for economic or preservation purposes.

BOTANICAL DESCRIPTION

Preferred scientific names

Santalum ellipticum Gaud.
Santalum freycinetianum Gaud.
Santalum haleakalae Hillebr.
Santalum paniculatum Hook. & Arnott

Family

Santalaceae (sandalwood family)

Common names

Hawai'i

S. ellipticum: *'iliahialo'e*
S. freycinetianum, S. haleakalae, S. paniculatum: *'iliahi*, *'a'ahi, 'aoa, lā'au 'ala, wahie 'ala*

Other generic common names

sandalwood (English)
sándalo (Spanish)
bois de santal (French)

Size

S. ellipticum

A sprawling shrub to small tree, typically 1–5 m (3.3–16 ft) tall and 1–3 m (3.3–10 ft) in canopy diameter, maximally reaching 12 m (39 ft) tall and 5 m (16 ft) in canopy diameter, and bole diameter at breast height (dbh) of 30 cm (12 in). This species is extremely variable in vegetative and floral characters (Wagner et al. 1999, Little and Skolmen 1989).

S. freycinetianum

A small shrub to tree typically 1–9 m (3.3–30 ft) tall and 3–7 m (10–23 ft) in canopy diameter. The maximum tree dimension is 13 m (43 ft) tall and 10 m (33 ft) in canopy diameter, and bole diameter at breast height is 80 cm (31.5 in) (Wagner et al. 1999, Little and Skolmen 1989).

S. haleakalae

A small tree typically 2–4 m (6.6–13 ft) tall and 2–4 m (6.6–13.2 ft) canopy diameter. The maximum tree dimension is 4 m (13.2 ft) in height and canopy diameter. Maximum bole dbh is 20 cm (8 in) (Wagner et al. 1999, Little and Skolmen 1989).

S. paniculatum

A shrub or tree 3–10 m (10–33 ft) tall and 3–7 m (10–23 ft) canopy diameter. In some relatively protected situations, *S. paniculatum* will grow to heights of 15–20 m (49–66 ft). The maximum canopy diameter is 10 m (33 ft) with a bole diameter at breast height of 1 m (3.3 ft) (Wagner et al. 1999, Little and Skolmen 1989).

Flowering (Wagner et al. 1999)

Under good conditions plants begin flowering from an early age, typically about 3–4 years, but heavy flowering and fruiting may take 7–10 years. There is considerable variation in seasonality of flowering and fruiting. Trees flower and fruit throughout the year, usually with two peaks. Most species have a fruiting season throughout spring, summer, and fall.

S. ellipticum

The inflorescence is greenish in bud; after opening, the corolla remains greenish but is tinged with brown, orange, or salmon. Flowers are about as long as wide, produced in terminal, and more or less axillary, compound cymes. Pedicels are 0–1 mm (0–0.04 in) long, the floral tube is campanulate to conical, 4–7 mm (0.16–0.28 in) long, and the ovary is inferior. Flowers produce a sweet fragrance.

S. freycinetianum

Flowers are longer than wide, red to yellow in bud, and produced in terminal, more or less axillary, relatively open, compound cymes. Pedicels are normally 1–4 mm (0.04–0.16 in) long, with bracts that are rapidly deciduous. The floral tube is yellowish white to white but turns red as it ages; it is campanulate to cylindrical. The inner surface of the corolla, normally 8–17 mm (0.32–0.67 in) long, is pink to dark red. The ovary is partly inferior. Flowers produce a weak fragrance.

S. haleakalae

Flowers are longer than wide, reddish to cream-colored in bud, and produced in congested, terminal, compound cymes, very occasionally with a few extra axillary flower clusters. The pedicels are 2–4 mm (0.08–0.16 in) long. The bracts persist until flowering, and the campanulate to cylindrical floral tube is white, turning dark red as it ages. The

***Santalum ellipticum*.** PHOTOS: M. MERLIN

***Santalum haleakalae*.** PHOTO: M. MERLIN, INSET: J. B. FRIDAY

***Santalum freycinetianum* var. *lanaiense*.** PHOTOS: J. B. FRIDAY

***Santalum paniculatum*.** PHOTOS: C. ELEVITCH

corolla is 8–17 mm (0.32–0.67 in) long; its outer surface is dark red and glaucous externally, turning to the same color on the inner surface after opening. The ovary is partly inferior. Flowers produce a weak fragrance.

S. paniculatum

Flowers are approximately as long as wide, greenish in bud, and produced in terminal and more or less axillary, compound cymes. The pedicels are about 1 mm long. The floral tube is campanulate to conical. The corolla is 4–8 mm (0.16–0.32 in) long and greenish but tinged with brown, orange, or salmon after opening. The ovary is inferior. Flowers produce a sweet fragrance.

Leaves (Wagner et al. 1999)

S. ellipticum

Leaves are 2.5–6.1 cm (1–2.4 in) long and 1.7–4 cm (0.67–1.6 in) wide, with petioles up to 15 mm (0.6 in) long. They are elliptic to orbicular, ovate, or obovate in shape and leathery to succulent. They have dull, grayish green, frequently glaucous upper and lower surfaces.

S. freycinetianum

Leaves are 4–9 cm (1.6–3.5 in) or occasionally longer and 1.3–7.5 cm (0.5–3 in) wide, with an acute to rounded apex. Petioles are 5–25 mm (0.2–1 in) long. The leaves are green,

Santalum ellipticum**.** PHOTO: J. B. FRIDAY

Santalum haleakalae**.** PHOTO: M. MERLIN

Santalum freycinetianum* var. *lanaiense**.** PHOTO: J. B. FRIDAY

Santalum paniculatum**.** PHOTO: C. ELEVITCH

occasionally a bit glaucous, more or less wilted in appearance, and tinged with purple when immature.

S. haleakalae

Leaves are 2.5-7.5 cm (1–3 in) long and 2–6 cm (0.8–2.4 in) wide with 2–7 mm (0.08–0.3 in) long petioles. Leaf shape is ovate, obovate, or orbicular, and the stiff to coriaceous surfaces are olive green, frequently tinged purple, and normally glaucous.

S. paniculatum

Leaves are 2.5–8 cm (1–3.1 in) long and 2–4.5 cm (0.8–1.8 in) wide with 2–15 mm (0.08–0.6 in) long petioles. Leaf shape is ovate, elliptic, or obovate, and the surfaces have glossy upper sides and dull, sometimes pale, lower sides. Both surfaces are often glaucous, and usually of different colors, occasionally yellowish orange to bluish or olive green.

Fruit (Wagner et al. 1999)

S. ellipticum

Mature fruits are purple to black drupes, often glaucous, 9–12 mm (0.4–0.5 in) long, with a distinctive apical receptacular ring.

S. freycinetianum

Mature fruits are reddish purple to almost black drupes at maturity, 8–24 mm (0.3–1 in) long, with a distinctive sub-apical receptacular ring.

S. haleakalae

Mature fruits are black or purplish black drupes 10–15 mm (0.4–0.6 in) long, with a distinctive sub-apical receptacular ring.

S. paniculatum

Mature fruits are purple to black drupes 10–12 mm (0.4–0.5 in) long, with a distinctive apical receptacular ring.

Seeds

The kernels consist of a hard, woody, smooth or slightly rough, light-colored endocarp enclosing a single seed. Data is lacking for seed size for the Hawaiian species.

Birds are the principal means of seed dispersal. However, in many habitats the fruits and seeds are attacked by rats (*Rattus exulans*, which were introduced by Polynesians before 1778, and more recently, *R. rattus*). In fact, rats have all but eliminated reproduction of the endangered Lana'i variety of *S. freycinetianum* in the wild by eating the fruits before they fall (Ziegler 2003).

Rooting habit

Sandalwoods have a widely spreading surface root system capable of grafting onto many other plant species and tapping water and mineral nutrients.

Look-a-like species

Look-a-likes include *S. album* (from India, Indonesia, and Australia), but it has been little planted in Hawai'i.

How to distinguish from similar species/look-a-likes

Fruits are very useful for distinguishing related tropical species. In *S. album,* the mature fruits are truncate-globular to ellipsoidal, have a raised calyx scar to about 5 mm (0.2 in) across forming an apical collar, and enclose a flat or slightly depressed disc with a small point.

GENETICS

Variability of species

All species exhibit considerable morphological variation, and numerous traditional varieties are recognized. In the past, taxonomists have divided the extremely variable

***Santalum album* fruit.** PHOTO: L. THOMSON

species of *Santalum ellipticum* and *S. freycinetianum*. This resulted in the classification of as many as nine different native Hawaiian *Santalum* species. The four presently accepted Hawaiian species may be derived from two separate colonizing events. These are represented by two sections of the genus *Santalum*. *S. freycinetianum* and *S. haleakalae* are related to *S. album* and are all lumped into the section *Santalum*, characterized by red or red-tinged petals with flowers longer than wide that produce much nectar. *Santalum ellipticum* and *S. paniculatum* are the lone members of the endemic section *Hawaiiensia* Skottsb. They are typified by green petals that become yellowish brown, orange, or occasionally salmon, and the flowers are approximately as wide as long but produce little or no nectar. *Santalum ellipticum* and *S. paniculatum* probably evolved from other Polynesian species of *Santalum*. (Wagner et al. 1999).

Known varieties (Wagner et al. 1999)

S. ellipticum

This species is highly variable, both in vegetative and floral characters. As many as six taxa have been proposed for individuals belonging to *S. ellipticum*. However, there is no single or group of characters that provide a sound basis for an enhanced subdivision of this species. Research by Stemmermann (1980), based on leaf succulence, glaucous fruit, and shrubby habit, recognized a coastal type as var. *littorale*. However, all of the characters used to differentiate the variety can also be found in inland plants in *S. ellipticum*. Furthermore, the coastal form represents an extreme of the variation pattern. Essentially, this form represents an ecotype and probably does not warrant formal recognition.

S. freycinetianum

Three varieties with overlapping phenotypic forms have been recognized for this widespread species. These are *S. freycinetianum* var. *lanaiense* and var. *pyrularium*. These varieties are differentiated on the basis of leaf and floral tube form.

S. haleakalae

This geographically and ecologically restricted species appears quite closely related to *Santalum freycinetianum* var. *lanaiense* and is thus in need of additional research. Such investigation may show that the specific rank for *S. haleakalae* is unwarranted and it is best included under *S. freycinetianum*.

S. paniculatum

Although Fosberg (1962) included this species as a variety of *S. ellipticum*, more recent taxonomic research by Stemmermann (1980) indicates that, based on differences in leaf form and color, and shrub or tree habit, there are two significantly intergrading varieties of *S. paniculatum*; these are var. *paniculatum* and var. *pilgeri*.

ASSOCIATED PLANT SPECIES

S. ellipticum

This species has successfully developed into relatively large individuals when growing with endemic species such as *Wikstroemia sandwicensis* (ʻākia) and the Nihoa Island fan palm *Pritchardia remota* (loulu) in windward, lowland areas among other native species. In more xeric environments *S. ellipticum* has developed successfully in association with the endemic shrub *Chenopodium oahuense* (ʻāheahea), an introduced euphorb (*Chamaesyce hypericifolia*), and introduced grass species. Apparently *S. ellipticum*, if it does need a host plant, is flexible in the species it can parasitize for needed nutrients (Culliney and Koebele 1999).

S. freycinetianum

This species obtains some vital nutrients from other woody species such as koa (*Acacia koa*), an endemic forest tree which, when available, is reportedly the main host (Culliney and Koebele 1999).

S. haleakalae

Not identified, but most likely needs native species adapted to the subalpine habitat as hosts for its partial parasitism.

S. paniculatum

Not identified, but most likely needs to parasitize any of a number of native or exotic species that are adapted to the relatively wide range of habitats in which this species can grow.

ENVIRONMENTAL PREFERENCES AND TOLERANCES

Climate

Hawaiian species are variously adapted to a variety of ecological ranges (from sea level to the subalpine zone), at least as represented by the existing populations.

S. ellipticum

Adapted to arid habitats with typical summer drought in leeward lowland locations.

S. freycinetianum

Adapted to moderately wet to wet habitats.

S. haleakalae

Adapted to cool to cold, moderately wet to arid subalpine habitat of Haleakalā.

S. paniculatum

Adapted to moderate dry to wet habitats on Hawaiʻi only.

Elevation

S. ellipticum 0–560 (–950) m (0–1840 [–3120] ft)
S. freycinetianum (250–) 400–650 (–950) m ([820–] 1310–2130 [–3120] ft)
S. haleakalae (1800–) 1900–2700 m ([5900–] 6230–8860 ft)
S. paniculatum 450–2000 (–2550) m (1480–6560 [–8360] ft)

Mean annual rainfall

Direct rainfall data for Hawaiian species is lacking. General information on moisture regime is:

S. ellipticum Xeric lands.
S. freycinetianum Mesic to wet forest.
S. haleakalae Xeric subalpine.
S. paniculatum Xeric to wet forests.

Rainfall pattern

All species are found in climates with summer rains.

Dry season duration (consecutive months with <40 mm [1.6 in] rainfall)

Most localities experience a pronounced dry season of 2–5 months during the cooler months from January to May.

Mean annual temperature

Direct temperature data correlated to species is lacking.

Minimum temperature tolerated

For all species, the entire distribution is frost-free, with the exception of *S. haleakalae*.

Soils

S. ellipticum thrives in sandy soils, including those derived from raised limestone, but also does well in clay soils. Additional soil data for this and the other Hawaiian sandalwood species are lacking.

Soil texture

They prefer light and medium, well drained soils (sands, sandy loams, loams, and sandy clay loams).

Soil drainage

All species require freely draining soils.

Soil acidity

Acid to neutral soils (pH 4.0–7.4) are acceptable. They prefer neutral soils (pH 6.1–7.4).

Special soil tolerances

The species tolerate shallow and infertile soils.

Tolerances

Drought

They are able to survive a long dry season (up to 5–6 months) when attached parasitically to suitably drought-tolerant host plants.

Full sun

The plants can grow well in full sun when roots are attached parasitically to suitable host species; otherwise, plants growing in full sun can become yellow and even die.

Top: *Santalum ellipticum* is unique in its adaptation to coastal conditions, here in Makapu'u, O'ahu. PHOTO: M. MERLIN **Bottom: *Santalum ellipticum* growing in an upland area in Pu'uwa'awa'a, Hawai'i.** PHOTO: J. B. FRIDAY

Shade

They can survive with up to 60–70% shade, but growth will be very slow at higher shade levels. The optimum level of shade is up to about 25%, preferably as side shade. Side shade is provided by adjacent bushy, but not spreading plants that grow up to about the same height as sandalwood without overtopping them and casting overhead shade.

Fire

All species are sensitive to fire (and grazing) particularly in the first few years of growth.

Frost

All of the tropical sandalwood species are likely or known to be frost-sensitive, except perhaps *S. haleakalae*, which is adapted to the subalpine zone of Haleakalā.

Waterlogging

Prefer good drainage and will die or die back following any prolonged period (longer than 2 weeks) of waterlogging.

Salt spray

Plants growing in near-coastal situations may suffer severe scorching by salt-laden winds followed by total defoliation after cyclonic storms, but they usually recover fully. A coastal ecotype of *S. ellipticum* is an exception; it is adapted to growing near or along the coast, usually as a sprawling or small shrub.

Wind

Mature plants are typically of low stature and fairly resistant to strong winds associated with cyclonic storms. Younger specimens in open areas, especially if they have grown quickly and have a heavy canopy, may be blown over by strong winds or suffer breakage of stems and branches.

GROWTH AND DEVELOPMENT

Growth rate

After exhausting energy stored in the seed, seedlings may stop growing for a number of weeks during what may be termed a "waiting period." When necessary root contacts are established with other species, a rapid increase in growth of the plant begins. Frequently, the new growth in *S. ellipticum* and *S. paniculatum* manifests a distinct alteration of leaf color from an initial red or pink to a bluish green. Rapid addition of new foliage is a strong indication that the plant has established good water and nutrient uptake by its own roots in the soil and through its unions with roots of other plants. Development regimes and longevity records for Hawaiian sandalwood species are lacking.

Reaction to competition

Sandalwoods, especially as young plants, react poorly to competition from monocotyledons (such as grasses and coconuts). Being parasitic, they are best grown in close proximity to suitable host species.

Diseases and pests

Hawaiian sandalwood species generally appear to resist most insect attack, although weak infestations of whitefly or scale insects sometimes do occur. Insecticidal soap may be used to treat such pest infestations. Infrequently, a small gray weevil feeds on the young leaves, but usually not to a significantly damaging degree. Some insects such as cockroaches, sow bugs, crickets, and a variety of cutworms may nibble at ground-level stem parts. Slugs and snails may also feed on newly sprouted plants. To avoid lethal girdling of a seedling, a protective barrier such as a plastic container should be used to protect each newly planted seedling. This is laborious for new plantings of many seedlings but may preclude large losses (Culliney and Koebele 1999).

Abilities

Regenerate rapidly

Regeneration of wild sandalwood stands typically occurs very slowly following harvesting. This is due to the removal of most of the fruiting, larger specimens and, in at least some cases, the removal of other species whose roots the sandalwood plants parasitize.

Self-prune

In open situations, sandalwood plants often retain branches to near ground level. In shadier situations, especially where the shade is cast from overhead, plants exhibit reasonably strong self-pruning characteristics. Suitable shade regimes to keep plants growing straight and to avoid a bushy habit include either strong lateral shade with no overhead shade or a high canopy of intermediate shade.

Coppice

Plants frequently resprout from basal coppice, or by root suckering off lateral roots following removal of the stump and major roots. However, such coppice regrowth is likely to die out in heavily shaded situations.

Pollard

Plants can be pollarded, but this is not an appropriate regime for sandalwood because of the slow regrowth.

Other

Many species are capable of root suckering as long as not too much of the root system is removed during harvest.

Root shoots of *S. paniculatum* growing from exposed root. PHOTO: C. ELEVITCH

PROPAGATION

All species are readily propagated by seed in the nursery. Seedlings can also be collected from underneath selected heavy-fruit-bearing specimens and then transplanted to a new location. Vegetative cuttings taken from seedling material may be struck under mist. Cuttings from young plants strike much more readily than cuttings from old plants. Grafting and root-segment cuttings from mature specimens can be used to conserve selected individuals or bring them into breeding programs.

Since Hawaiian sandalwood plants rarely develop beyond the seedling stage in containers, they should be outplanted when they are youthful seedlings, before 6 months of age (Culliney and Koebele 1999).

Propagation by seed

Seed collection

It is recommended that mature fruits be collected while still attached to the tree, although recently fallen fruits may also be acceptable. Fruits that have attained maturity are full size and usually have begun to show slight color change, commonly a reddish tinge. For most species, flowering may occur year-round, with peak flowering in the late summer and fall. For all species, fruits mature about 4 months after flowering. Ripe fruits are reddish-purple to black. Seeds may be collected from the tree by hand, or collected from the ground, often with the pulp decayed or removed by birds.

Seed processing

The fleshy mesocarp needs to be removed from the fruits as soon as possible. Fruit that is hard to depulp by hand may be soaked for 1–2 days to soften the pulp prior to its removal. The depulped, cleaned seeds may then be disinfected (e.g., with diluted bleach) before being rinsed and air-dried in a well ventilated room, at a temperature below 25°C (77°F), out of direct sun, for up to 2–3 weeks. The number of viable seeds per unit weight varies considerably among species, provenances, and individual seedlots.

Seed storage

Many sandalwood species show intermediate storage behavior, with seed rapidly losing viability during storage. Seed storage behavior varies among species, and may even vary among seed sources. Seeds with high oil content, such as those of *Santalum*, are normally short-lived in storage.

It is usually preferable to sow sandalwood seeds as soon as possible after collection to reduce the risk of their losing viability during storage. If seeds must be stored, they should be placed in airtight containers in the refrigerator (2–4°C [36–39°F]) as soon as possible following surface drying. In general, ultra-dry storage (e.g., down to about 2% moisture) is recommended for this type of seed. Seeds of *S. freycinetianum* air-dried to 8% moisture have retained good viability for several years when stored at 5°C (41°F).

Germination rates vary from 10% to 50%, depending on seed lot and germination method. Germination of up to 90% can be achieved with fresh and healthy seed and proper germination technique.

Pre-planting treatments

Scarification treatment has been shown to produce quick germination of viable seeds of *S. ellipticum* and *S. freycinetianum.* Before treating, seeds should be removed from the ripe fruit, cleaned by hand, and air-dried for about a week. After this, a small part of the seed coat at the apex of the seed should be removed so that the embryo becomes visible but is not damaged. This can be done using nail clippers, forceps, or medium sandpaper. Soaking the seeds in a growth hormone solution can greatly improve results. One recommended method is to soak the seeds in diluted (0.05%) gibberellic acid (a plant hormone) for 5 days, changing the solution daily. After 5 days, the seeds are removed from the growth hormone solution and dusted with a 1:1 mixture of powdered sulfur and captan to prevent fungus infection.

Growing area

Seeds are germinated under cover in a greenhouse or other protective structure. The germination area should be protected from rats, birds, and other predators that will eat seeds or young seedlings. As seedlings grow, they are moved to progressively higher light levels, e.g., 50% shade in the early months, then 25% shade. Two months of hardening under full sun is recommended prior to field planting.

Germination

Seeds are germinated in trays of vermiculite, preferably with a translucent cover to keep humidity high and protect from pests such as rats and birds. The mixture should be kept slightly moist but not wet in order to avoid rotting of seeds and damping off. The optimum temperature for germination is between 28°C and 31°C (82–88°F). When pretreated as described above, *S. ellipticum* and *S. paniculatum* begin to germinate after approximately a week and continue germinating over a 2–3 week period. Without the hormone and scarification pretreatments, germination takes much longer (Culliney and Koebele 1999). The seed's thick wall will develop a crack as the root emerges. The seedlings can then be placed in individual containers in a mixture consisting of equal parts of fine cinder (not black sand) and vermiculite. The success rate of germination following the above treatment can be greater than 90%, even for seeds more than 6 months old (Culliney and Koebele 1999).

At the two- or four-leaf stage a host plant can be planted together with the seedling (see host table).

S. paniculatum **germinants sprouting in pure vermiculite.** PHOTO: C. ELEVITCH

Media

The potting mixture used should be well drained with reasonable water-holding capacity, such as equal parts of fine cinder (not black sand) and vermiculite.

Time to outplanting

Seedlings are ready for outplanting after about 6 months when height is about 20–25 cm (8–10 in).

Guidelines for outplanting

Sandalwoods need to be either planted out among established long-term host plants, or else together with intermediate hosts (relatively short-lived woody perennials) while longer term hosts are established (see Suitable Hosts box).

Survival rates are high (>80%) for large, healthy seedlings planted at the onset of the rainy season and kept well weeded in the first 2 years. Survival and growth will be low for plants established in shady forest situations or grassy, sunny situations.

Santalum ellipticum and *Santalum freycinetianum* should be placed in the ground within 2–6 months of germinating, because they will hardly ever grow beyond this stage in pots. The seedlings can be planted directly into the ground from their vermiculite sprouting trays after establishment in a 1:1 fine cinder:vermiculite mixture. The planting hole should have enough space so as to not cramp the root structure of the seedling (Culliney and Koebele 1999).

SUITABLE HOSTS

Koa (*Acacia koa*), koaiʻa (*Acacia koaia*), aʻaliʻi (*Dodonea viscosa*), koʻokoʻolau (*Bidens* spp.) are thought to be good native Hawaiian host plants. Exotics such as amaranth (*Amaranthus* sp.), strawberry (*Fragaria* sp.) and beggar's tick (non-native *Bidens* spp.) are reputed to be good short-term hosts. Other exotics that are used outside Hawaiʻi as long term hosts (but not recommended in Hawaiʻi unless already present on site) include *Calliandra* spp., *Casuarina* spp., and *Pinus caribaea*.

Propagation using wildlings

The following technique is useful for promoting germination of wildlings, which can then be transplanted and grown on in the nursery before field planting in a suitable location.

- Select sandalwood trees that are fruiting or are known to fruit heavily.
- Clean undergrowth from beneath the canopy of the selected sandalwood trees.
- Loosen the soil in the cleared area by shallow digging or cultivating only the top 5 cm (2 in) of the soil.
- Wildlings begin to germinate in the cultivated area about 1–2 months after soil disturbance.
- If possible, water the cultivated area during dry periods or after some seedlings are observed.
- Keep the cultivated area weeded.

DISADVANTAGES

The main drawbacks of planting sandalwood are

- lack of seed and planting materials
- relatively complex silviculture and need to be grown with suitable host plant species
- susceptibility to root and butt rot fungi and rapid death of plants when grown in higher rainfall zones
- risk of theft of trees when nearing maturity.

Potential for invasiveness

Sandalwood species generally have a capacity for invasiveness in disturbed, more open plant communities. This is not considered a problem because of their very high value, their small stature, and the fact that they do not appear to modify such communities in any substantial way. Due to being classified as a parasitic plant, importation of viable *Santalum* seed into the U.S. (including Hawai'i) is prohibited by federal law.

Host to crop pests/pathogens

Not known to be an important host to any crop pests and diseases.

Other disadvantages or design considerations

Security is an issue with sandalwood. Trees should be planted in well protected areas in which opportunities for theft are minimized, such as in homegardens, isolated areas, and well fenced, closely guarded locations.

Sandalwoods are root parasites, with the potential to "root graft" and link whole plant communities. They are therefore at particular risk of infection from pathogenic fungi, such as *Phellinus noxius,* that can also spread from tree to tree through root grafts. For this same reason, herbicide sprayed on healthy plants can be transferred to sandalwood through root grafts.

Threats to survival

A wide range of contemporary dangers threaten the survival of native sandalwood species in Hawai'i.

- In addition to the rapacious early historic harvesting, recent logging on Hawai'i has occurred within perhaps the only remaining groves of large and numerous sandalwood trees.
- Fires, fueled by alien underbrush such as fountain grass (*Pennisetum setaceum*), also threaten remaining sandalwood trees.
- Conversion of forests lands to agricultural crops has been a major threat to sandalwood at lower elevations since humans arrived. This threat continues to this day as population pressure leads to clearing additional land for agricultural uses.
- Cattle, goats, and deer all readily eat sandalwood foliage. Cattle and horses trample the shallow root systems. The impact of these mammalian herbivores must be curtailed to safeguard remaining trees and protect new plantings.
- Rats and mice voraciously consume sandalwood seeds. On Lāna'i and at Haleakalā, these rodents have virtually eliminated natural reproduction.
- Aggressive alien vines such as banana poka (*Passiflora mollissima*) and German ivy (*Delairea odorata*) climb over native vegetation and shut out sunlight. Because sandalwood is a light-demanding species, these aliens pose a threat to it.
- Off-road vehicles impact native Hawaiian coastal plants. Such activity has severely damaged native plants at Ka'ena Point, O'ahu, including *S. ellipticum*.

AGROFORESTRY/ ENVIRONMENTAL/ INTERPLANTING PRACTICES

Alley cropping

Sandalwoods are suitable for inclusion in alley cropping systems, especially where the other alley species include good hosts, e.g., *Calliandra* spp.

Homegardens

The trees are very suitable for planting in homegardens, which have the advantages of mixture of host species, intermediate/variable light levels, and high security.

Improved fallows

Could be included in improved fallows of nitrogen-fixing trees, with a fallow rotation of 20 or more years to ensure that sandalwoods attain commercial maturity.

Windbreaks

Sandalwoods are suitable for inclusion in windbreaks, especially where the main windbreak species include good hosts, e.g., *Casuarina* spp.

Woodlot

Sandalwoods are suitable for inclusion in woodlots, especially when planted along sun-exposed edges and in combination with compatible species, e.g., *Acacia koa*.

Native animal/bird food

The fruits of sandalwood are consumed by various bird species.

Host plant trellising

There is minor potential to trellis slow-growing vines that would not interfere with full sun reaching the canopy, such as *maile* (*Alyxia oliviformis*).

Bee forage

When in flower, the trees are attended my many pollinators, including honeybees.

Coastal protection

S. ellipticum provides a small amount of coastal protection, as it can grow near (within a few meters) the sea.

A BRIEF HISTORY OF HAWAIIAN SANDALWOOD EXPLOITATION

During the latter part of the 18th century and early part of the 19th century, a series of events occurred in the Hawaiian islands that had profound effects on both the natural environment and human social conditions. The third Pacific expedition of Captain James Cook arrived in Hawaiʻi in 1778, ushering in the historic period for the archipelago. Alien species, new materials, and novel ideas entered the remote islands and precipitated significant changes in many realms of activity, including politics and human ecology. Kamehameha the Great rose to power and progressively consolidated his rule over the islands. By 1810 he had successfully unified all the main islands, a feat never previously accomplished. During this period, the commercial value of Hawaiian sandalwood as an export item became known to various foreign traders and native chiefs.

Before the introduction of Hawaiian sandalwood onto the Canton market, most of the wood sold in China was "white sandalwood" (*Santalum album*), which was imported from India and the East Indies. Around the end of the 18th century, the supply of this Asian white sandalwood was becoming insufficient to meet market demands in China. This shortage resulted in an increasing market value of acceptable sandalwood from a variety of source areas, including Hawaiʻi. As the islands emerged as a major source of raw material, the remote archipelago soon became known in China as "Tahn Heung Sahn" or "the Sandalwood Mountains" (Kepler 1983).

In the very early years of the sandalwood trade, the American entrepreneurs dealt with the chiefs as well as Kamehameha the Great himself; however, Kamehameha eventually provided himself with an exclusive monopoly over the sandalwood trade. The sudden wealth and availability of many new material goods seem to have overwhelmed the paramount authority of Hawaiʻi in these frenetic years of Hawaiian sandalwood exploitation. Kamehameha accumulated large amounts of luxury goods.

The great burden of harvesting the sandalwood necessary to pay for the debts Kamehameha I had incurred was principally laid upon the common Hawaiian people. The King "...ordered men to go out in the mountains to cut sandalwood," and then to transport this heavy harvest "... to the landings" (Kuykendall 1938). Judd (1926) tells us that because of the lack of roads and vehicles the wood "...was carried down in the form of logs, 3 to 6 feet long, and from 2 to 18 inches in diameter, after the bark and sap[wood] had been chipped off with adzes."

Large numbers of people were involved in the harvesting and handling of the sandalwood. Frequent transport of heavy loads of sandalwood often produced callused areas *(leho)* on the shoulders of male bearers. Men with these marks were called *kua-leho* or "callous backs" (Lydgate 1916).

Sandalwood harvesters were often gone for several days, sometimes for weeks, in the mountains collecting sandalwood. Many died of exposure and other misfortunes in the cold, often damp uplands. Kepler (1983) provides a graphic description of the obligate harvester: "It has been said that every piece of sandalwood cut during those boom years was stained with blood. Some villagers died in harness [carrying the ti leaf bound wood on their backs], crumbling motionless on the trails; others, less fortunate, turned into living skeletons, weak from the corroding effects of exhaustion, disease, malnutrition, and exposure to the chilly mountain winds without adequate clothing. To aggravate matters, much cutting was done at night with the aid of sandalwood torches."

For many years it was widely assumed that the sandalwood trees had become extinct due to the exploitative harvesting that had occurred for more than 50 years (e.g., Kuykendall and Gregory 1926, Mesick 1934, Cartwright 1935, Smith 1956). However, it has long been known by some botanists, foresters, and other naturalists—and more recently by the general public—that sandalwood species can still be found in Hawaiʻi. Nevertheless, except for some higher mountain areas, such as uplands in the Kona District of Hawaiʻi, the quantity of trees is generally much smaller than it was before the foreign trade.

The ecological impacts of removing the great majority of the sandalwood plants from the Hawaiian forests are not at all clear. According to Judd (1926), the "...damage to the forest consequent to the trade...was insignificant in comparison with the damage to the native forest wrought by cattle." As noted above, under natural conditions, the sandalwood species of Hawaiʻi are found in a mixed association with a number of other species, primarily in the drier forest regions; and, while the selective removal of *Santalum* trees did not remove the forests themselves, the exploitative harvesting processes may very well have opened the way for an unknown number of alien species to become established. Certainly the impacts of human harvesting and the unprecedented grazing and trampling by newly introduced ungulates (e.g., goats and cattle), as well as the possible negative consequences of the introduced seed predators (rats and mice), did not provide ecological conditions conducive to the regeneration of the native vegetation.

Source: Merlin and VanRavenswaay 1990

***Alyxia stellata*, a traditional vine used in leis, climbing on *Santalum yasi* in a homegarden in Tonga.** PHOTO: C. ELEVITCH

Ornamental

All species are quite attractive, especially when in flower, and suitable for homegardens.

USES AND PRODUCTS

Wood from sandalwood was traditionally used in the Pacific islands for carvings, cultural uses, medicine, and burnt as an insect repellent; it is rarely used nowadays because of its scarcity and cash value. Heartwood from sandalwood trees yields an aromatic oil. The oil was traditionally used to a limited extent to scent coconut oil (for application to the hair and body) and cultural artifacts such as tapa. Today, the oil is widely valued and has been the basis of a lucrative and exploitative trade for hundreds of years.

In the Hawaiian Islands, during the late 18th and early 19th centuries, the aromatic lower trunks and rootstock of native *Santalum* species were harvested in great quantity and shipped to China, where they were used to make incense, fine furniture, and other desirable products. The extensive and often exploitative sandalwood trade in Hawai'i was an early economic activity that adversely affected both the natural environment and the human population. Indeed, this activity represented an early shift from subsistence to commercial economy in Hawai'i that was to have far-reaching and long-lasting effects in the islands.

Fruit/Nut

The seed kernels are said to be edible (and some say tasty), although the scarcity of seeds and their high value for propagation makes their use as food somewhat inappropriate.

Medicinal

Traditionally, the fragrant heartwood (*'la'au 'ala*) of sandalwood trees (collectively known as *'iliahi*), was used in medicines. A shampoo made from a leaf infusion was used for curing dandruff and eliminating head lice. A drink made from finely ground powdered heartwood, mixed with other plants, followed by laxative was used in curing diseases of both male and female sex organs (Krauss 1993).

Fuelwood

In Hawai'i, *Santalum* spp. were sometimes used for firewood (Wagner 1986); however, as sandalwood, at least *S. freycinetianum*, did not make useful charcoal, residents in Hawai'i during the early 20th century cut and burned it as a mosquito repellent (St. John 1947).

Craft wood/tools

The highest value sandalwood is used for carving religious statues and objects, handicrafts, art, and decorative furniture. Larger basal pieces and roots are preferred for carving. In Hawai'i, sandalwood was sometimes used to make musical instruments such as the musical bow (*'ūkēkē*) (Buck 1964, Krauss 1993).

Canoe/boat/raft making

Sandalwood trees in Hawai'i were used in some parts of traditional canoe construction. For example, *hoe* (paddles) were fashioned from sandalwood.

Cosmetic/soap/perfume

The oil from the heartwood, extracted by steam distillation or by solvent, is used for cosmetics, scenting of soaps, perfumery, aromatherapy, and medicinal purposes. In Hawai'i, the heartwood was pounded into a fine powder, and this, or fine chips, was pounded into new tapa (paper mulberry) cloth. The heartwood powder was also used to scent coconut oil and used to make a waterproof, perfumed tapa (Krauss 1993, Kepler 1985).

Ceremonial/religious importance

A mixture of heartwood and sapwood is powdered and made into incense or joss sticks which are used in eastern religious ceremonies. Sawdust, wood shavings from carv-

Sandalwood sculptures Bangalore, India. PHOTO: M. MERLIN

ing, or wood residue after oil distillation may be used.

URBAN AND COMMUNITY FORESTRY

This much-revered native plant can have a place in many urban environments, but it requires proper care and protection. Being a parasite, sandalwood must be grown in the company of other plants. This makes Hawaiian sandalwood a perfect component in a group planting of native Hawaiian plants, although it will form root associations with many exotic species as well. Cultivating sandalwood is relatively new, and there is quite a bit that is not yet known about horticultural practices. It does require special care (no herbicide, no nearby foot or vehicle traffic, etc.), which may mean significant alterations in regular landscaping practices. Even the best and most experienced tree growers often have trouble establishing sandalwood trees. However, once established, sandalwood trees tend to be tough, tenacious plants. Sandalwood is a "must-have" species for native plant landscapes.

Before planting sandalwood, a plan should be made sure it has the company of other plants that will act as hosts throughout its lifetime. When planting short-lived hosts such as aʻaliʻi, a long-term host such as koa should also be planted nearby well before the short-term host dies. It is best to think of sandalwood as a member of a plant community, rather than a lone specimen.

Size in an urban environment

Some Hawaiian sandalwoods can reach 5–10 m (16–33 ft) at maturity, but it typically takes trees many decades to reach their mature size. The canopy diameter is approximately half the height of the tree. Because of the slow rate of growth and relatively small size of the tree, growing too large is often not an issue.

Size for each species:

S. ellipticum A sprawling shrub to small tree, typically 1–5 m (3.3–16 ft) tall.
S. freycinetianum A small shrub to tree, typically 1–9 m (3.3–30 ft) tall.
S. haleakalae A small tree, typically 2–4 m (6.6–13.2 ft) tall.
S. paniculatum A shrub or tree 3–10 m (10–33 ft) tall.

Rate of growth in a landscape

Under optimum conditions, the growth rate can be 0.7 m/yr (2.5 ft/yr) in height, although it is usually slower. As with most trees, the rate of growth decreases as the tree gets older.

Root system

Sandalwood's extensive network of roots links with roots of other species that serve as a source of moisture and nutrients. Because sandalwood roots are intimately linked with the surrounding plant community, the health of sandalwood trees is tied to the health of neighboring plants. The trees also have an extensive surface root system and can produce suckers where the roots are damaged or when the main stem is cut down, injured, or stressed.

Products commonly used in a Pacific island household

The wood was traditionally used by Hawaiians in crafts, for its scent, and in medicine. The seed kernels are edible (and some say tasty), a food that can be taken advantage of when seeds are abundant. The flower clusters and young leaves of some species are used in leis (McDonald and Weissich 2003). Perhaps the greatest value of growing sandalwood in the landscape is an intangible one: the satisfaction of nurturing this esteemed cultural tree.

Light requirements

As young seedlings, or trees that have not yet formed strong root associations with host plants, moderate shade may be beneficial until strong root associations are formed with other plants. Healthy sandalwood plants that have formed root associations with other plants grow best in full sun. Trees can grow with moderate side shade or moderately filtered light.

Water/soil requirements

Specific soil requirements are unknown for Hawaiian sandalwoods. Most other *Santalum* species require well drained soils but tolerate shallow or infertile soils. Some Hawaiian sandalwoods grow in ʻaʻā lava together with species such as lama, aʻaʻliʻi, māmaki, ʻōhiʻa, māmane, ʻūlei, and ʻalaheʻe.

Life span

Longevity data for sandalwood are lacking. Given ideal conditions, it is expected to grow for many decades.

Varieties favored for use in homegardens or public areas

There are no varieties specifically selected for urban environments. It is strongly recommended that seed be used whose natural origin is as close as possible to the planting area and environment. See "Native range" above for information about the natural distribution of the various species.

Seasonality of leaf flush, flowering, fruiting

Growth of leaves, flowers, and fruits varies between species, individual plants, and environments. Plants typically grow throughout the year. Usually there are two peaks of flowering and fruiting, although in some areas flowering and fruiting is strongly seasonal, and in others they are nearly continuous.

Exceptional ornamental values

The flowers and berries are attractive, and the flowers are mildly scented. The newly flushing leaves of *S. freycinetianum* and *S. haleakalae* are tinged with purple before turning green.

Use as living fence, hedge or visual/noise barrier

Sandalwood trees are too slow growing and sensitive to environmental factors to be practical for these uses.

Bees and other pollinators frequent the abundant flowers. *S. paniculatum*, Kealakekua, Hawaiʻi. PHOTO: C. ELEVITCH

Maintenance requirements

Because sandalwood trees rely on root connections with nearby plants, herbicide used to control weeds is easily transferred through the root systems to the sandalwood trees. Therefore, weeds within a radius of the tree equal to about twice its height should be cut by hand or machine. As with most native Hawaiian plants, avoid any herbicide drift from nearby applications that can adhere to the tree leaves even in minute quantities.

Surrounding host species may require pruning, especially if they grow much faster than sandalwood (e.g., aʻaʻliʻi, māmaki, etc.) in order to allow adequate light to penetrate.

For low-fertility soils, fertilizing with a handful (up to 100 g [4 oz]) of slow-release NPK fertilizer per tree may help when trees show signs of yellowing or slow growth. Use of rapidly available, soluble commercial fertilizers is not well studied for sandalwood. Another option is to spread a 3 cm (1.2 in) layer of weed-seed-free compost around the tree, and cover it with 5–10 cm (2–4 in) of weed-free woody mulch such as chipped tree limbs. This mulch slowly adds nutrients and organic matter to the soil, protects the tree's surface roots, and helps conserve soil moisture. Be sure to keep the mulch 10 cm (4 in) away from the trunk of the tree to avoid rotting the bark and girdling the tree.

Special considerations regarding leaf, branch, and fruit drop

None.

Nuisance issues

None.

Hazards

None.

Common pest problems

As with all plants, supporting plant health is the best way to prevent pest and disease problems. The Hawaiian sandalwoods are tough trees once established and are little affected by insects. Whitefly or scale can be treated with insecticidal soap. Certain insects such as cockroaches, sowbugs, crickets, and cutworms may nibble at ground-level stem parts. Slugs and snails may also feed on newly sprouted plants. To avoid lethal girdling of a seedling, a protective barrier such as a plastic container can be used to protect newly planted seedlings (Culliney and Koebele 1999).

COMMERCIAL PRODUCTS

The primary commercial products from sandalwood are the heartwood and the essential oil distilled from the heartwood.

The heartwood from Pacific sandalwood species is mainly exported to Asia. For example, most *S. yasi* from Tonga is exported to East Asian countries, particularly China via Hong Kong, Taiwan, and Japan, but some is also supplied to the U.S. The main markets for sandalwood oil are Europe and the U.S. In the latter part of the 20th century *Santalum paniculatum* wood was also exported from western Hualālai (Kona District, Hawai'i) to Asia.

One of the advantages of growing sandalwoods is their ability to produce a high-value, non-perishable product (heartwood) that can provide cash income even when grown on a small scale. They may also be grown in environmentally sensitive areas, such as water catchment and biodiversity conservation areas, where extraction of a few small trees can cause minimum disturbance while providing good economic returns.

Spacing for commercial production

The spacing for commercial production varies considerably depending on type of planting. The final crop is likely to be around 100 mature sandalwood trees per hectare (40 trees/ac) due to need to include host tree/shrub species (at a rate of 2–4 per sandalwood trees depending on host species). Due to the high value and demand for even a single mature tree, there is effectively no minimum area or number of trees required for commercial production.

Management objectives

The main management objective should be to establish and manage a good mixture of host plant species which are necessary for sandalwood and provide suitable light and shelter. Host tree species may need to be pruned or progressively thinned to maintain good levels of sunlight to maturing sandalwood plants. For soils of lower fertility, periodic fertilizing with 100 g (4 oz) NPK fertilizer per tree, when tree growth slows, will promote more rapid growth. Weed growth, especially of long, flammable grasses, needs to be well controlled in early years. Weeds should be manually removed to avoid the risk of herbicide drift and/or translocation through weeds to sandalwood plants.

Design considerations

Greater accessibility of sandalwood plantations increases the risk of theft.

Advantages and disadvantages of growing in polycultures

A diverse mixture of host species is preferred so as to

- enable sandalwood trees to optimally obtain their mineral nutrition and water needs
- reduce pest and disease risks associated with reliance on just one or two main hosts.

Estimated yields

No data available.

On-farm processing

Whole trees including major roots are harvested. The main on-farm processing is careful removal of the sapwood, using a sharp knife. Wood pieces that are kept in dry conditions for several months may exhibit small increases in oil content and improvement in quality, but this is off-set by a lower weight and hence a lower return to the grower.

Markets

The world production and consumption of sandalwood oil is on the order of several hundred tons per year. India, with 90% of the world's production, is the major sandalwood producer. It is also the largest user of sandalwood oil. Exports from India of *S. album* oil during a 6 year period 1987/88–1992/93 averaged 40.5 metric tons (mt) (44.6 t), with the main importers of this oil being France and the U.S. Indonesian exports of *S. album* oil during 1987 to 1992 averaged 15 mt/yr (16.5 t/yr) and went mainly to the U.S., which is the single largest market outside India. International demand for *S. album* oil exceeds supply, and prices continue to rise. Annual global sandalwood heartwood production is estimated to be approximately 5100 mt (5610 t); however, production has declined markedly over the past 20–30 years. Apart from India, with its own production capability, China, Taiwan, Singapore, Korea, and Japan, with no natural resources of sandalwood, are the main markets.

PUBLIC ASSISTANCE AND AGROFORESTRY EXTENSION

Extension offices for agroforestry and forestry in the Pacific: http://www.traditionaltree.org/extension.html

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Santalum ellipticum, *S. freycinetianum*, *S. haleakalae*, and *S. paniculatum* (Hawaiian sandalwood)

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Acknowledgments: The author and publisher thank John Culliney, Dale Evans, Danica Harbaugh, Eileen Herring, Heidi Johansen, and Brian Kiyabu for their input. Contributions of photographs by J. B. Friday are greatly appreciated.

Recommended citation: Merlin, M.D., L.A.J. Thomson, and C.R. Elevitch 2006. *Santalum ellipticum*, *S. freycinetianum*, *S. haleakalae*, and *S. paniculatum* (Hawaiian sandalwood), ver. 4.1. In: Elevitch, C.R. (ed.). Species Profiles for Pacific Island Agroforestry. Permanent Agriculture Resources (PAR), Hōlualoa, Hawai‘i. <http://www.traditionaltree.org>.

Sponsors: Publication was made possible by generous support of the United States Department of Agriculture Western Region Sustainable Agriculture Research and Education (USDA-WSARE) Program; SPC/GTZ Pacific-German Regional Forestry Project; USDA Natural Resources Conservation Service (USDA NRCS); Kaulunani, an Urban Forestry Program of the DLNR Division of Forestry and Wildlife and the USDA Forest Service; State of Hawai‘i Department of Land & Natural Resources Division of Forestry & Wildlife; USDA Forest Service Forest Lands Enhancement Program; and Muriel and Kent Lighter. This material is based upon work supported by the Cooperative State Research, Education, and Extension Service, U.S. Department of Agriculture, and Agricultural Experiment Station, Utah State University, under Cooperative Agreement 2002-47001-01327.

Series editor: Craig R. Elevitch

Publisher: Permanent Agriculture Resources (PAR), PO Box 428, Hōlualoa, Hawai‘i 96725, USA; Tel: 808-324-4427; Fax: 808-324-4129; E-mail: par@agroforestry.net; Web: <http://www.agroforestry.net>. This institution is an equal opportunity provider.

April 2006
ver. 2.1

Syzygium malaccense (Malay apple)

Myrtaceae (myrtle family)

acpuhl **(Kosrae);** ***ʻahiʻa*** **(Societies);** ***apel*** **(Pohnpei);** ***arfatlh*****,** ***harafath*****,** ***faliap*****,** ***faliyap*** **(Yap);** ***faariyap*****,** ***fasniyaap*****,** ***feniyap*** **(Chuuk);** ***fekakai*** **(Niue);** ***fekika kai*** **(Tonga);** ***jambosier rouge*** **(French);** ***kaʻika*** **(Cooks);** ***kafika*** **(ʻUvea, Futuna);** ***kavika*** **(Fiji);** ***keʻika*** **(Mangareva);** ***kehiʻa*** **(Southern Marquesas);** ***kehika*****,** ***kehika inana*** **(Northern Marquesas);** ***kidel*** **(Palau);** ***makupa*** **(Guam); Malay apple, mountain apple (English);** ***nonu fiʻafiʻa*** **(Samoa);** ***ʻohiʻa ʻai*****,** ***ʻohiʻa*** **(Hawaiʻi)**

W. Arthur Whistler and Craig R. Elevitch

IN BRIEF

Distribution Throughout the tropics, but especially in Indo-Malaya, Southeast Asia, Melanesia, Polynesia, and Micronesia.

Size Medium tree typically 5–12 m (16–40 ft) in cultivation.

Habitat Humid and subhumid tropics, usually found sea level to 600 m (1970 ft).

Vegetation Associated with a wide range of species worldwide.

Soils Wide range of types from sand to heavy clay (not on atolls).

Growth rate Moderate, 0.6–1 m/yr (2–3 ft/yr) for the first few years.

Main agroforestry uses Homegardens.

Main products Fruit, medicinal, ornamental.

Yields 21–85 kg (48–188 lb) fruit per tree, for eating fresh.

Intercropping Compatible with many species and does well mixed with many other species in homegardens.

Invasive potential Although it is not considered invasive, it has naturalized in localized areas where it was introduced.

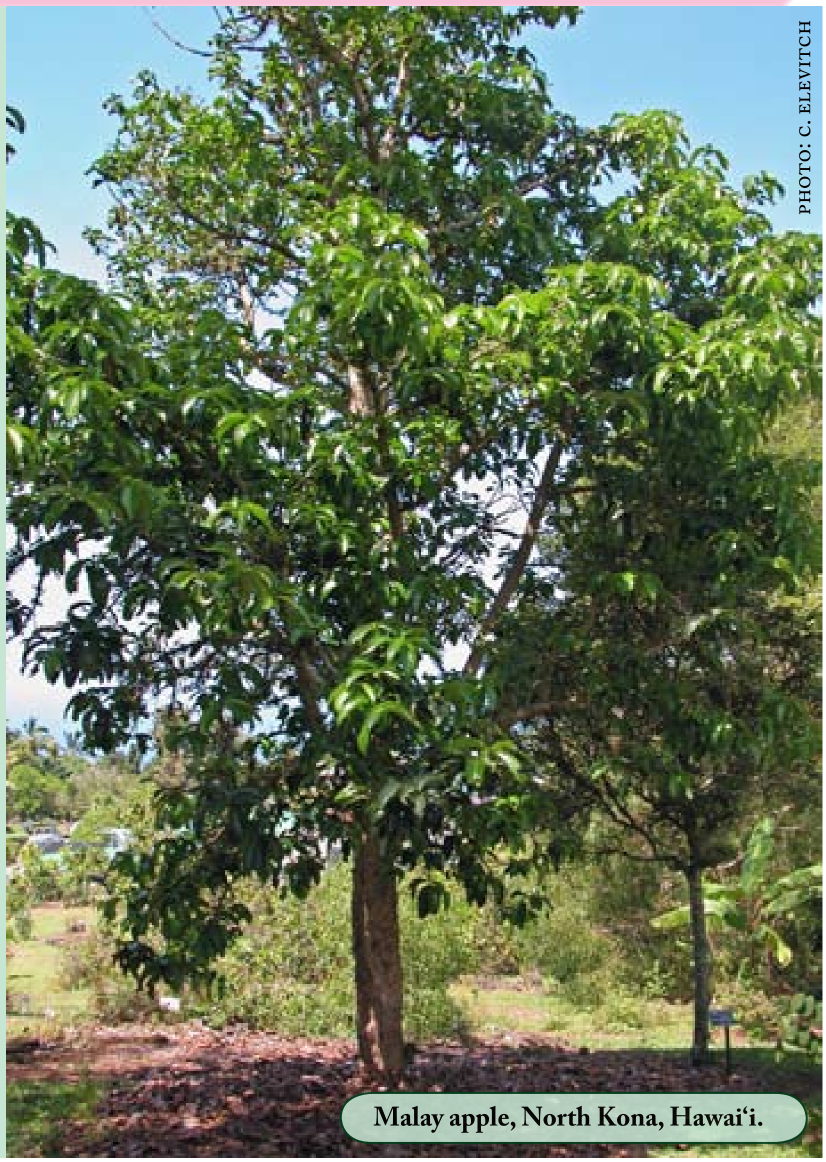

PHOTO: C. ELEVITCH

Malay apple, North Kona, Hawaiʻi.

INTRODUCTION

The Malay apple is a medium-size tree that has been cultivated for a long time in the tropics. Its native range is thought to lie somewhere between Melanesia and Southeast Asia, but exactly where is not known. It was originally found in lowland to montane rainforest. Today, over most of its range it is found in homegardens and plantations, although rarely in montane forest. In a few places where it was introduced (e.g., Hawai'i), it is found in native forest as relictual stands from which it does not spread (no local birds can disperse the fruit). Because of its large fruit and seed, it is rarely invasive but may persist in groves that were formerly planted in native forest. The tree is valued for its large edible fruits that are eaten fresh. Because of its fruits seasonality and short shelf life, it has not been grown in large plantations for export and is thus mostly locally consumed rather than exported. It can be a significant cash crop, however, when sold in local markets. Thus it is ideal for homegardens and casual intercrop plantings. It thrives in areas with sufficient year-round rainfall and can be irrigated in areas with a dry season. The tree is also widely used in traditional medicines. The wood is of average quality but is little used because of the availability of better timber species.

DISTRIBUTION

Native range

It has been cultivated for so long that its origin is uncertain. However, it is native to somewhere in the Indo-Malayan region or Southeast Asia, probably originally in lowland rainforest.

Current distribution

It is now cultivated throughout the tropics, especially in Indo-Malaysia, Southeast Asia, Melanesia, Polynesia (where it was an ancient introduction as far east as Hawai'i), and Micronesia (where it is apparently a modern introduction in the eastern part of its range, Pohnpei and Kosrae). In some places, such as in Melanesia (e.g., Vanuatu and Fiji), it appears to be naturalized. In Hawai'i, it is common in forest groves that are probably remnants of former cultivation, but the tree does not readily spread from these.

BOTANICAL DESCRIPTION

Preferred scientific name

Syzygium malaccense (L.) Merr. & Perry

Family

Myrtaceae (myrtle Family)

Non-preferred scientific names

Eugenia malaccense L.
Jambosa malaccensis (L.) DC.

Common names

Pacific islands:

acpuhl (Kosrae)
'ahi'a (Societies)
apel (Pohnpei)
arfatlh, *harafath*, *faliap*, *faliyap* (Yap)
faariyap, *fasniyaap*, *feniyap* (Chuuk)
fekakai (Niue)
fekika kai (Tonga)
jambosier rouge, poire de Malaque, pomme Malac, *pomme de Malaisie, pomme de Tahiti* (French)
ka'ika (Cooks)
kafika ('Uvea, Futuna)
kavika (Fiji)
ke'ika (Mangareva)
kehi'a (Southern Marquesas)
kehika, *kehika inana* (Northern Marquesas)
kidel (Palau)
makupa (Guam)
Malay apple, mountain apple (English)
nonu fi'afi'a (Samoa)
'ohi'a 'ai, *'ohi'a*, *'ohi'a 'ai ke'oke'o*, *'ohi'a hakea*, *'ohi'a kea*, *'ohi'a leo*, *'ohi'a 'ula* (Hawai'i)

Size

It grows up to 16 m (53 ft) or more in height but is often only 5–12 m (16–40 ft) when grown in cultivation.

Form

The crown is oblong, pyramidal, or cylindrical, sometimes sub-tiered, with many small horizontal to ascending branches. The bole is short and often fluted.

Flowers

An inflorescence of short, few-flowered cymes up to 6 cm (2.4 in) long is borne on the trunk or older branches. Calyx turbinate, 1.2–1.8 cm (0.5–0.7 in) long, notched to form 4 pale yellow, rounded lobes 4–6 mm (0.2–0.3 in) long. Corolla with 4, red or pink (rarely white), suborbicular petals 7–11 mm (0.3–0.4 in) long, early caducous. Ovary inferior, style long, with a simple style up to 2.5 cm (1 in) long. Stamens many (ca. 200), free, red, 1–2 cm (0.4–0.8 in.) long.

Flowering is usually seasonal, from 1–2 months in duration, but it varies widely from place to place and even from year to year. In some areas, Malay apple flowers two or three times per year. It occurs mostly in the spring (August–November) in the South Pacific, but from May–February in Fiji, in February and from June–October in Vanuatu, and from May–June on Java. In Hawai'i, lying north of the equator, it flowers from March–April, and in Pohnpei flowering apparently occurs twice a year, in November–December, and again in April–May. Trees begin flowering at an age of 7–8 years.

Leaves

Leaves are opposite, simple, blade ovate to oblong, mostly 10–30 cm (4–12 in) long, often affected by insect galls, acute to rounded at the base, acute to acuminate at the tip; leaf surfaces are glabrous, glossy green with entire margins and a thick, red petiole 2–10 mm (0.1–0.4 in) long.

Fruit

Fruit a large, fleshy, ovoid berry 3–7 cm (1.2–2.8 in) long, glossy red or sometimes white or white with red streaks. Like flowering, fruiting is variable. In the South Pacific, it usually occurs in late spring to summer (November–February), but from September–May in Vanuatu, and from August–September in Java. In India, the main crop occurs from May–July and there is often a second crop in November and December. In Hawai'i, fruiting occurs in June to November or even December, and in Pohnpei in January–February and June–December. Latitude and local climate may be the major determinants of flowering time. Fruits mature in 60 days from the full opening of the flowers and fall quickly once fully ripe. Ripened fruit deteriorate rapidly. The trees can produce fruit within 5 years after planting.

Seeds

Each fruit contains a single large, subglobose seed or a pair of subglobose to hemispherical seeds 1.6–2 cm (0.6–0.8 in) in diameter, light-brown externally, green internally, and somewhat meaty in texture. The fruits of some trees are entirely seedless. In its native range, the seeds are probably dispersed by birds (particularly pigeons), who eat the fruit, and also by

Flower buds, flowers, and ripening fruit. PHOTOS: C. ELEVITCH fruit bats. Where suitable dispersers are absent, the tree disperses poorly, probably not spreading far from the parent tree (and hence is not naturalized in these areas).

Rooting habit

No information available.

Similar species/look-a-likes

It is similar to *Syzygium aqueum* (bell or water apple), a tree cultivated in the Pacific for its edible fruits. The fruits of this species, however, are smaller and bell-shaped (widest toward the free end), and the flowers are white rather than red. It is also similar to *Syzygium samarangense*, a tree sometimes cultivated in the Pacific and becoming naturalized in native forests. The flowers of this tree are white and the leaves are subsessile (i.e., having the petioles less than 7 mm [0.25 in] long). All three species are used interchangeably where they occur together. *Syzygium malaccense* also differs from the other two by typically having the inflorescences borne on the branches and occasionally on the trunk rather than at or near the ends of the stems.

GENETICS

Known varieties

Two color forms exist over most of its range, the common one with red fruits and flowers, and a less common one with white fruits and flowers. These have not been given taxonomic rank, but in Polynesia and Melanesia they are recognized in the local languages (usually with a color qualifier added to the native name). Some commercial companies recognize many selected clones. Trees of selected varieties are available from local tropical fruit nurseries, especially in south Florida.

Culturally important related species in the genus

Many native trees belonging to the genus *Syzygium* are found on the high islands of the tropical Pacific, some of them important timber species. Two other species are cultivated in western Polynesia (and native to Fiji), *Syzygium corynocarpum* and *Syzygium neurocalyx*. The seasonal fruits of these two species were once commonly used for personal adornment (i.e., for making fragrant leis) and sometimes for scenting coconut oil.

ASSOCIATED PLANT SPECIES

Malay apple does not have any specific associates, as it occurs over such a wide geographical area, each with its own flora. However, it is typically grown in mixed plantings in and around villages together with other cultivated species, such as coconut, banana, breadfruit, etc.

Associated species commonly found in native habitats

Not usually found in native forest, but when it is, it occurs with numerous species.

Species commonly associated as aboriginal introductions in Pacific islands

Several other fruit trees were aboriginal introductions into the Pacific islands (Polynesia at least). These include Tahitian chestnut (*Inocarpus fagifer*), breadfruit (*Artocarpus altilis*), and Polynesian plum (*Spondias dulcis*).

ENVIRONMENTAL PREFERENCES AND TOLERANCES

Climate

The tree thrives in cultivation in volcanic soil with sufficient year-round rain in the humid and subhumid tropics. It does not do well on atolls, either because of the calcareous soil or insufficient rainfall. The tree is restricted to the tropics, being intolerant of any frost. Hence, it is found only in tropical regions. It does well at cool elevations, as at higher elevations in Hawai‘i, either planted around houses, where it can be watered during dry periods, or in mountain forests where there is sufficient natural rainfall.

Elevation range

The tree can grow from near sea level to 1200 m (4000 ft) but is usually found below 600 m (2000 ft).

Mean annual rainfall

The lower rainfall range is 1500 mm (60 in), and there is no upper limit.

Rainfall pattern

It prefers year-round rain but can tolerate seasonal rain as long as there is no extended dry period. Trees grown in areas with a seasonal dry period need to be irrigated during the drought.

Mean annual temperature

24°–27°C (75–81°F) (estimate)

Minimum temperature tolerated

It is intolerant of frost.

Soils

The tree grows vigorously on a range of soil types from sand to heavy clay. It tolerates moderately acid soil but in high pH soil it develops nutritional deficiencies that can be overcome with the occasional use of micronutrient sprays. It does not do well in highly alkaline situations. In India, the tree reportedly grows best on the banks of ponds, lakes, and streams where there is good drainage.

Soil texture

It tolerates medium to heavy texture soils (loams, sandy clay loams, sandy clays, clay loams, and clays).

Soil drainage

It grows in soils with free drainage.

Soil acidity

pH 6.1–7.4

Special soil tolerances

None known.

Tolerances

Drought

It does not do well in areas with a seasonal drought, unless it is irrigated during the dry season or grows near a water body. Established trees can tolerate more extensive periods of drought, up to 6 months. Significant leaf fall occasionally occurs, although the tree will not totally defoliate.

Full sun

The tree grows well in full sun if given enough water.

Shade

Partial shade is tolerated.

Fire

It is probably not adapted to fire, as it is native to wet tropical rainforest, which is not subject to fire.

Frost

The tree is intolerant of frost.

Waterlogging

The tree does not tolerate waterlogging. Where it is grown in wet places (such as the banks of irrigation canals), it is usually put in mounds or other slight elevations to keep the roots from being in waterlogged soil for prolonged periods of time.

Salt spray

It is not known to be tolerant of salt spray.

Wind

It does not do well in strong wind because of its fragile wood, according to some sources, but others note that the "trees are quite wind resistant." The tree has been used in windbreaks.

GROWTH AND DEVELOPMENT

When grown from seed, germination occurs in 4–6 weeks. The trees grow fast when weeded and mulched during the first year or two. After 5 years, faster growing individuals can start producing fruit.

Growth rate

There is no data available, but growth rate is moderate even in early years, likely less than 75 cm (30 in) per year.

Reaction to competition

The tree is tolerant of competition, as it thrives in old forest but does best when periodically weeded when young.

PROPAGATION

The seeds germinate well, and many can usually be found sprouting under their parent tree. While seed propagation is common, air-layering has been successfully used, and cuttings have been rooted in sand in Hawai'i. These vegetative methods of reproduction are used especially on high yielding individuals. Some people prefer to graft superior varieties onto seedling stocks.

Propagation from seed

(after Wilkinson and Elevitch 2003)

Seed collection

Seeds are best collected during the fruiting season, which varies from place to place. They have short viability, so they should be taken from the fruit and planted right away. The most readily available supply of seeds is found under cultivated trees. Seeds should be collected from individual trees with the most desirable fruits.

Seed preparation

No special preparation is needed for the seeds. It is best to remove most of the flesh in order to minimize fungal attacks. This can be easily done by lightly rubbing the seeds together in water. No pretreatment is needed prior to sowing.

Ripe fruit cut in half to show fleshy seed inside. PHOTO: C. ELEVITCH

Seed storage

The seeds are fleshy and do not retain viability when stored or dried. Because of their short viability, they should be planted straight out of the fruit. If necessary, seeds can be stored 2–3 weeks wrapped in a lightly moistened medium such as paper towel and kept in a cool, dark place.

Media

When growing seedlings in containers, use a well drained potting medium such as 50% coarse peat moss, 25% perlite, and 25% vermiculite amended with a little compost, dolomite lime, gypsum, micronutrients, and slow release 14-14-14 fertilizer. Also, natural soils mixed with sand, volcanic cinders, or composted organic matter can be used for seedling production, although these may contain live weed seeds that increase maintenance in the nursery.

Growing area

Full sun or light shade are recommended. As seeds readily germinate under fruiting trees, seedlings can also be grown in deep shade, although growth will be slower. Seeds can be grown in containers in the nursery or sown directly in the field.

Germination

Seeds are planted no more than 4 cm (1.5 in) deep in nurseries or directly in the field. The seeds will germinate in 4–6 weeks. The germination rate is high for fresh seed (and, indeed, prolific under trees in the wild).

Time to outplanting

If seedlings are grown in containers rather than directly in the field, the seedlings are typically transplanted to their final destination when 8 months old.

Size at outplanting

The size at outplanting is ideally 35 cm (1 ft) or larger.

Vegetative propagation

While seed propagation is common, superior types are multiplied vegetatively. Air-layering and cuttings are both successful methods. Air-layering is best carried out on young branches 1–2 years old. A branch diameter of 1–2 cm (0.4–0.8 in) and length of 30–45 cm (12–18 in) are ideal. Pick branches that are easy to access, and preferably with stems that are shaded by other branches. Air-layering works well any time of year, but the mother plant should be in good health and have adequate water and nutrition available. Cuttings have been successfully rooted in sand in Hawai‘i. Cuttings are ready for transplanting 6 weeks after rooting.

Seedling ready for outplanting. PHOTO: C. ELEVITCH

DISADVANTAGES

The fruit is only slightly sweet, although it makes a refreshing snack when picked and eaten out-of-hand. The fruit is crisp, delicate, and rather watery, with a very short shelf life, and is therefore difficult to market commercially. It is rarely grown in commercial plantations, but mostly as a tree or two in homegardens or plantations. The fruit does not make very good jams, because most of the taste is lost during preservation.

Potential for invasiveness

In most places where it has been introduced it is unable to spread. It is not considered invasive, although it has naturalized in isolated areas where it was introduced.

Diseases and pests

The tree is fairly resistant to pests. The trees are frequently attacked by termites in India. It is reported that sap-feeders, defoliators, miners, and borers have been found on the foliage and on dead stems. Native fruit flies attack the tree in Vanuatu, but otherwise very little is known about this, because the tree has not been a major commercial crop. In Hawaiʻi, rose beetles often attack the foliage of young trees, which can suppress early growth. Rose beetle attacks usually diminish in older trees.

Host to crop pests/pathogens

Not known as a host for pests.

AGROFORESTRY/ENVIRONMENTAL PRACTICES

Crop shade/overstory

Not reported to be used for this, however it is frequently found in and among numerous crops in homegardens.

Homegardens

It is commonly used in homegardens, being planted around houses and in plantations.

Windbreaks

Malay apple has been used in windbreaks.

Native animal/bird food

The tree has fruit that is edible by birds. It is also a food source for fruit bats during its fruiting times.

Ornamental

The tree is quite attractive and highly ornamental, especially when in bloom, and it makes a nice shade tree.

Fruit of white-fruited type. PHOTO: C. ELEVITCH

USES AND PRODUCTS

The Malay apple was brought to the Pacific islands by early inhabitants and was one of the few fruit trees available to them. It was once an important supplemental (and seasonal) fruit crop. Today, because other more prolifically fruiting and better tasting fruits are available (e.g., mango and papaya), cultivation of Malay apple has decreased. However, it is still a useful crop and is easily cared for in a homegarden. The wood is average but little utilized since other better woods were and are available.

Fruit

The ripe fruit is eaten raw. The skin is thin and the flesh is crisp and white. The slightly sweet taste is refreshing and can be a crunchy addition to a mixed fruit salad. Although not suited for jams or jellies, the half-ripened fruit can be pickled. Pickled or preserved slices and sauces, very heavily spiced, are found in southeast Asia. Wine is made from the fruit in Puerto Rico.

Medicinal

In Samoa an infusion of the crushed leaves or scraped bark is very commonly taken as a potion, the leaves are chewed and the juice swallowed, or the leaf juice is dripped into the mouth of an infant to treat mouth infections. In Tonga an extract of bark scrapings is commonly administered to treat throat infections and stomachache, and is an ingredient in various remedies for a complex of abdominal ailments known as kahi. An infusion of the bark is used to treat coughs in Futuna and Niue. In the Cook Islands a solution of the crushed leaves, or to a lesser extent the grated bark, is widely used to treat thrush, and a solution of the grated bark is sometimes administered as an emetic. Various uses, some of them as a purgative, are reported in Tahiti, few if any of them dealing with children's mouth infections. In the Marquesas coconut oil in which fragments of the bark have been soaked is taken as a purgative. In Hawai'i the bark was crushed and its juices taken for sore throat, juice extracted from the bark was mixed with salt and applied to cuts, and the leaves were crushed and ingested for bronchitis. The use of the plant for treating mouth infections such as thrush is reported from as far away as Indonesia and is likely to be an ancient Polynesian practice. In Malaysia the powder from the dried leaves is reportedly used on a cracked tongue, a preparation of the root is a remedy for itching, and a preparation of the root is given to alleviate swelling. The root bark is used to treat dysentery and serves as an emmenagogue (promoting menstrual function) and abortifacient. Cambodians reportedly take a decoction of the fruit, leaves, or seeds as a febrifuge (against fever). In Brazil various parts of the plant are used as remedies for constipation, diabetes, coughs, pulmonary catarrh, headache, and other ailments. Numerous other uses are reported over the range of the species.

Beautiful/fragrant flowers

The flowers are very attractive but fragile and not easily used. After picking, they soon shed numerous red stamens. Early sources in Fiji noted "the natives gathering handfuls of them [the showy red stamens] to strew on their heads." In Hawai'i both blossoms and fruit were used to make leis.

Timber

The reddish, soft to hard, tough and heavy timber is difficult to work, as it is inclined to warp. However, it is sometimes employed for construction as house posts, fence posts, rafters, railway ties, and for carving bowls. In Chuuk it has been used to make outrigger booms.

Nutritional Analysis (after Morton 1987)

	Per 100 g of Edible Portion
Moisture	90.3–91.6 g
Protein	0.5–0.7 g
Fat	0.1–0.2 g
Fiber	0.6–0.8 g
Ash	0.26–0.39 g
Calcium	5.6–5.9 mg
Phosphorus	11.6–17.9 mg
Iron	0.2–0.82 mg
Carotene	0.003–0.008 mg
Vitamin A	3–10 I.U.
Thiamine	15–39 mcg
Riboflavin	20–39 mcg
Niacin	0.21–0.40 mg
Ascorbic Acid	6.5–17.0 mg

Craftwood

In Hawai'i the wood was considered sacred and carved into religious images.

Fuelwood

Occasionally used for firewood, the tree is not usually so utilized, especially if the tree still is producing fruits.

Canoe/boat/raft making

The wood is used to make outrigger booms in Chuuk.

URBAN AND COMMUNITY FORESTRY

Because of its beauty, low demand for care, and abundant, refreshing fruit, Malay apple is well suited for urban environments. The tree was widely introduced into Pacific islands by native people and integrated into their homegardens, medicine, and spiritual beliefs. Planting and preserving this tree in urban environments forms a living connection to aboriginal cultures.

Size in an urban environment

Malay apple typically reaches 5–12 m (16–40 ft). Pruning can control the tree's size, although heavy pruning can kill the tree.

Rate of growth in a landscape

The rate of growth is moderate, about 75 cm (30 in) per year in height. In the most favored environments, such as low elevation and moist valleys, it may grow faster.

Root system

There is no information available, but it is unlikely the tree would cause problems with pavement.

Products commonly used in a Pacific island household

The fruit is best to eat freshly picked from the tree, which makes the tree ideal for homegardens. It is also used for a multitude of home remedies.

Light requirements

The tree prefers full sun but it can grow well with light shade, especially if the shade is from the side rather than overhead.

Water/soil requirements

It grows in a wide range of soils but requires free drainage. It grows best in moist valleys, along waterways, and in other situations where soil moisture is high. In urban environments, areas with roof or gray-water run-off may be preferred.

Life span

The longevity is unknown, although several decades is expected.

Varieties favored for use in homegardens or public areas

There are two color forms, red and white, both of which are grown in homegardens. Trees with large and especially sweet fruit are sometimes cloned by cutting or air-layering.

Exceptional ornamental values

The tree flowers abundantly as many as three times per year, filling the trunk and inner part of large branches with bright red or white, mildly fragrant flowers, which can be seen through openings in the canopy. Each flowering period lasts about 2 weeks, leaving the ground under the tree temporarily carpeted in red or white.

Use as living fence, hedge or visual/noise barrier

Because of its irregular canopy and slow regrowth after pruning, Malay apple is rarely used for these purposes. It is, however, used in multi-row, multi-species windbreaks that take up more space than usually available in urban environments.

Birds/wildlife

Many birds enjoy eating the ripe fruit, both on the tree

The brief flowering period is followed by a colorful carpet of flower stamens under the tree. PHOTOS: C. ELEVITCH and after falling to the ground. Pigs most certainly will eat fallen fruit.

Maintenance requirements

Once established, the tree rarely requires any special care. Mulching with organic materials, such as grass clippings or other plant foliage (shredded or not), will help conserve soil moisture while slowly releasing nutrients into the soil.

Nuisance issues

Fruits drop quickly after ripening and attract rats and fruit flies. If the juicy fruits are allowed to ripen and fall to the ground, the tree could be considered "messy." The fruit decomposes rapidly, and usually there are no offensive associated smells or other problems.

Hazards

None.

Common pest problems

Serious pest problems are rare. In Hawai'i, rose beetles commonly feed on young trees, defoliating them periodically. Without leaves, the tree's growth is slowed. Once trees reach 5–7 years, problems with rose beetles usually disappear. Keeping young trees healthy by mulching and ensuring continual soil moisture will help them recover from rose beetle attacks.

COMMERCIAL PRODUCTS

The tree is primarily important as a supplemental fruit crop. The fruit is mostly consumed raw and locally rather than being exported. For marketing, the ripe fruits must be hand-picked to avoid damage and to have a longer shelf-life. However, because the fruit is seasonal and somewhat insipid, it is best eaten immediately after harvest and does not have much commercial value other than being sold in local marketplaces during the fruiting season. The wood is of some value but is not used commercially.

Spacing for commercial production

In India, commercial trees are spaced 6–10 m (20–33 ft) apart in fields prepared and enriched as for any other crop, and thereafter they require little care except for elimination of weeds, periodic fertilization, and plentiful irrigation in very dry weather. However, the Malay apple is usually grown in homegardens mixed with other species.

Management

Weeding needs to be done only during the early stages of growth. The tree can be pruned to ensure that fruit is borne low for ease of picking. However, the tree regrows only weakly from pruning, and heavy pruning can kill the tree.

Advantages and disadvantages of polycultures

It does well mixed with other species and is not usually grown in monocultures.

Estimated yields

Yields of 21–85 kg (48–188 lb) per tree have been reported.

On-farm processing methods required to access market

Because of its short shelf life and fragile skin, the fruit is not very suitable for markets, except at the local level. The sooner the fruit is chilled, the longer the shelf life; chilled soon after harvest, the shelf life may be extended from 2 days to a week.

On-farm processing methods

In ancient Hawai'i the fruit was partially dried for palatability and storage.

Markets

It is rarely exported, except to cities near where the trees are grown (e.g., in Singapore).

INTERPLANTING/FARM APPLICATIONS

Malay apple is often planted in and among other trees such as citrus, coffee, macadamia nuts, etc. It is a good fruit for eating while working in the field. By planting at various elevations on a farm, the season fruits are available can be extended by several weeks.

PUBLIC ASSISTANCE AND AGROFORESTRY EXTENSION

Extension offices for agroforestry and forestry in the Pacific: http://www.traditionaltree.org/extension.html

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Malay apple grows well in mixed plantings, here surrounded by breadfruit, ti, coffee, and coconut. PHOTO: C. ELEVITCH

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Traditional Tree Initiative—Species Profiles for Pacific Island Agroforestry (www.traditionaltree.org)

Syzygium malaccense (Malay apple)

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Acknowledgments: The authors and publisher thank Dale Evans, Heidi Johansen, Ken Love, and Peter van Dyke for their input.

Recommended citation: Whistler, W.A., and C.R. Elevitch. 2006. *Syzygium malaccense* (Malay apple), ver. 2.1. In: Elevitch, C.R. (ed.). Species Profiles for Pacific Island Agroforestry. Permanent Agriculture Resources (PAR), Hōlualoa, Hawai'i. <http://www.traditionaltree.org>.

Sponsors: Publication was made possible by generous support of the United States Department of Agriculture Western Region Sustainable Agriculture Research and Education (USDA-WSARE) Program; SPC/GTZ Pacific-German Regional Forestry Project; USDA Natural Resources Conservation Service (USDA NRCS); Kaulunani, an Urban Forestry Program of the DLNR Division of Forestry and Wildlife and the USDA Forest Service; State of Hawai'i Department of Land & Natural Resources Division of Forestry & Wildlife; USDA Forest Service Forest Lands Enhancement Program; and Muriel and Kent Lighter. This material is based upon work supported by the Cooperative State Research, Education, and Extension Service, U.S. Department of Agriculture, and Agricultural Experiment Station, Utah State University, under Cooperative Agreement 2002-47001-01327.

Series editor: Craig R. Elevitch

Publisher: Permanent Agriculture Resources (PAR), PO Box 428, Hōlualoa, Hawai'i 96725, USA; Tel: 808-324-4427; Fax: 808-324-4129; E-mail: par@agroforestry.net; Web: <http://www.agroforestry.net>. This institution is an equal opportunity provider.

Terminalia catappa (tropical almond)

Combretaceae (combretum family)

alite **(Solomon Islands pidgin);** ***'autara'a, 'aua, 'auari'i, 'auari'iroa*** **(Societies);** ***kamani haole, kamani 'ula,*** **false** ***kamani*** **(Hawai'i);** ***kauariki, kaukauariki, taraire*** **(Cooks: Mangaia);** ***ma'i'i, koa'i'i, koua'i'i, ta'ie*** **(Marquesas);** ***natapoa*** **(Vanuatu: Bislama); tropical, beach, or Indian almond (English);** ***talie*** **(Samoa);** ***talise*** **(Papua New Guinea: Tok Pisin);** ***tavola, tivi*** **(Fiji);** ***telie*** **(Tonga, 'Uvea, Futuna, Tokelau, Tuvalu)**

Lex A. J. Thomson and Barry Evans

IN BRIEF

Distribution Naturally widespread in subtropical and tropical zones of Indian and Pacific Oceans and planted extensively throughout the tropics.

Size Large tree 25–40 m (82–130 ft) tall.

Habitat Subtropical and tropical maritime climates with annual rainfall generally 1000–3500 mm (40–140 in); elevations below 300–400 m (1000–1300 ft).

Vegetation Associated with coastal vegetation, especially strandline communities and beach forests including rocky shores and edges of mangrove swamps.

Soils Adapted to a wide range of lighter textured soil types.

Growth rate Fast in early years, about 2 m/yr (6.6 ft/yr).

Main agroforestry uses Soil stabilization, coastal protection.

Main products Nuts, timber.

Yields Kernel yield is estimated to be about 5 kg (11 lb) per tree per year; timber yields can reach 15–20 m^3/ha/yr (215–286 ft^3/ac/yr) (estimate).

Intercropping Short term crops can be interplanted during the first 2–3 years after establishment.

Invasive potential Has moderate potential for invasiveness into disturbed seaside habitats.

PHOTO: C. ELEVITCH

Large tree near shoreline, Apia, Samoa.

INTRODUCTION

Tropical almond (*Terminalia catappa*) is a large, spreading tree now distributed throughout the tropics in coastal environments. The tree is tolerant of strong winds, salt spray, and moderately high salinity in the root zone. It grows principally in freely drained, well aerated, sandy soils.

The species has traditionally been very important for coastal communities, providing a wide range of non-wood products and services. It has a spreading, fibrous root system and plays a vital role in coastline stabilization. It is widely planted throughout the tropics, especially along sandy seashores, for shade, ornamental purposes, and edible nuts. The timber makes a useful and decorative general-purpose hardwood and is well suited for conversion into furniture and interior building timbers. Fruits are produced from about 3 years of age, and the nutritious, tasty seed kernels may be eaten immediately after extraction.

Tropical almond is easily propagated from seed, and is fast growing and flourishes with minimal maintenance in suitable environments. Selected cultivars of the species warrant wider commercial planting for joint production of timber and nuts. The tree has a demonstrated potential to naturalize in coastal plant communities, but not to adversely dominate such communities.

The productivity and marketing of cultivars with large and/or soft-shelled nuts needs to be assessed. There is also a need for experimental work to develop vegetative propagation techniques and more efficient techniques for processing fully mature fruits including drying, storage, and cracking of nuts.

DISTRIBUTION

Native range

Tropical almond has a vast natural distribution in near-coastal areas of the Indian Ocean, through tropical Asia, and into the Pacific Ocean. The extent to which its range has been increased through movement and dispersal by humans is difficult to determine. It extends from the Seychelles through India, the Andamans and adjacent islands, and throughout Southeast Asia (Myanmar, Thailand, the Malay Peninsula, Vietnam, the Philippines, Indonesia) to Papua New Guinea and northern Australia as far south as the Tropic of Capricorn. The species is found throughout the South Pacific region, including the Solomon Islands, Vanuatu, and Fiji. It is present on nearly all the high archipelagos of Polynesia and Micronesia but may be an aboriginal introduction to the eastern parts of its current range (including all of eastern Polynesia).

Current distribution

Tropical almond has been introduced, and frequently naturalized, in many tropical parts of the world including Brazil, the Caribbean, and East Africa. It is naturalized in Florida and Puerto Rico. In Hawai'i, the species was introduced very early, probably before 1800, and is now naturalized at low altitudes, mainly near beach shores.

BOTANICAL DESCRIPTION

Preferred scientific name

Terminalia catappa L.

Family

Combretaceae (combretum family)

Non-preferred scientific names

Phytolacca javanica Osbeck
Terminalia mauritiana Blanco
Terminalia moluccana Lamk.
Terminalia procera Roxb.

Common names

alite (Solomon Islands pidgin)
'autara'a, *'aua*, *'auari'i*, *'auari'iroa* (Societies)
kamani haole, *kamani 'ula*, false *kamani* (Hawai'i)
kauariki, *kaukauariki*, *taraire* (Cooks: Mangaia)
ma'i'i, *koa'i'i*, *koua'i'i*, *ta'ie* (Marquesas)
natapoa (Vanuatu: Bislama)
tropical, beach, or Indian almond (English)
talie (Samoa)
talise (Papua New Guinea: Tok Pisin)
tavola, *tivi* (Fiji)
telie (Tonga, 'Uvea, Futuna, Tokelau, Tuvalu)

Size

Tropical almond is a medium to large tree to 25–40 m (82–130 ft) in height and with a similar crown spread in open situations. At maturity the trunk attains a diameter at breast height (dbh) of 50–150 cm (20–60 in).

Typical form

Younger trees display a characteristic pagoda form, with a single bole and monopodial horizontal branching in regular false whorls of 4–5 branches. Along each lateral, new branches are formed in a characteristic, bifurcating pattern. The tiered crown becomes flatter with widespread branches in older specimens. The bole is usually straight and reasonably cylindrical, but in exposed coastal situations it may be

Top left: Close-up of flowers and buds. PHOTO: L. THOMSON **Right: Fruits on tree.** PHOTO: C. ELEVITCH **Bottom left: Horizontal branching of young trees.** PHOTO: C. ELEVITCH

crooked and/or leaning. Buttresses, when present, are up to 3 m (10 ft) in height, variable, straight to curved, thick to thin, sometimes branching. Large trees may develop big, occasionally branching buttresses and often have twisted, leaning trunks.

Flowers

The flowers are small (4–6 mm [0.16–0.24 in] across), white or cream-colored, five-lobed, arranged on long (8–25 cm (3.2–10 in) axillary spikes, with a mildly unpleasant smell. Within a spike the majority of the flowers are male, with only a few bisexual flowers positioned toward the base. Plants usually commence flowering and fruiting from a young age, e.g., within 2–3 years of outplanting, but this varies with site and genotype. On highly fertile sites mature fruits have been collected from 18-month-old plants. Trees may refoliate and flower very soon (e.g., within 6 weeks) after being completely defoliated by cyclonic winds.

In Hawai'i, Fiji, Vanuatu, and Tonga flowering and fruiting occur sporadically throughout much of the year. Flowering and fruiting of cultivated trees appears to be more synchronous in Vanuatu, where flowering peaks around October to January and is followed by fruiting around March to June.

Leaves

The leaves are arranged in close spirals, often crowded toward the ends of the upturned branchlets. The leaf blade is simple, broadly obovate, 8–25(–38) x 5–14(–19) cm (3–10[–15] x 2–6[–7] in), with (5–)8–12 pairs of secondary veins. The leaf tip is rounded and blunt, gradually tapering to a narrowly subcordate base (the latter being a useful diagnostic feature). New leaves have a covering of soft, appressed, brown hairs. Mature leaves are mostly glabrous (shiny), leathery, and dark green, turning bright yellow then vivid to dark red before falling. The trees are briefly deciduous during the dry season, or in some environments they may lose their leaves twice in a year.

Fruit

Typically one to five fruits develop on the basal part of the flower spike. The fruit is a sessile, laterally compressed, ovoid to ovate, smooth-skinned drupe. During maturation, it changes color from green through yellow to bright red or dark purplish-red at full maturity. Fruit size varies considerably, e.g., 3.5–7 x 2–5.5 cm (1.4–2.8 x 0.8–2.2 in), with extremes in length from 2.5 to 10 cm (1–4 in). The kernel consists of two delicate and intricately entwined cotyledons enclosed in an inconspicuous cream-colored, rarely red, testa.

In the South Pacific tropical almond growing at lower latitudes may produce fruit sporadically throughout the year, with heavier crops toward the end of the year on trees growing at higher latitudes. In New Guinea the productive period is between November and March, especially December–February. In Vanuatu the main crop is around the middle of the year (May–June), with a smaller crop around December. In Samoa fruiting occurs in June–July and February–March. In Tonga the reported fruiting season varies between island groups, e.g., September–December in the south (Tongatapu and ʻEua) and February–May further north (Haʻapai and Vavaʻu).

Seeds

In the Pacific islands trees exhibit large variations in the size and shape of fruits, nuts, and kernels, but it is difficult to classify this variation. For example, in Vanuatu, the nuts can be 3.9–5.1 long by 2.6–3.8 cm across (1.5–2 x 1–1.5 in) and weigh 7–14 g (0.25–0.5 oz). Kernels are in the size range of 2.2–4.4 x 8–1.4 cm (0.9–1.7 x 0.3–0.6 in) and weigh 0.1–0.9 g (0.04–0.32 oz). The percentage kernel content varies from 1% to 10%.

The rind of the fruit is a light, pithy, or corky tissue that enables the fruit to float and be dispersed by sea currents. Trees are also found away from coasts due to fruits being carried inland and dropped by frugivorous birds and bats, and as a result of deliberate planting by humans.

Bark

The bark is gray to dark gray-brown and shallowly fissured. Continuous vertical fissuring and discontinuous horizontal cracks produce a grid appearance; the somewhat flaky bark peels off in curved or straight scales along these lines.

Rooting habit

The trees usually have a spreading, fibrous, near-surface

Top: Buttress of large tree, Hilo, Hawaiʻi. PHOTO: J. B. FRIDAY
Bottom: The extensive surface root system is exposed on this sandy, coastal slope. PHOTO: C. ELEVITCH

lateral root system, although the species is normally deep rooted in sand (Francis 1989). Shallow lateral root systems can develop in response to high water tables, making such trees susceptible to windthrow (Wood 1970).

Similar or look-a-like species

The genus *Terminalia* comprises about 150–250 tropical tree species. Closely related species in the South Pacific include *T. glabrata* Forst. f. and *T. littoralis* Seem.

How to distinguish from similar species/look-a-likes

Tropical almond is distinguished from most *Terminalia* spp. by its subcordate (heart-shaped) leaf base. *T. catappa* has larger, glossy, dark green leaves, thicker branchlets, longer flower spikes, and larger fruits than *T. littoralis* (typically >3.5–5 cm [>1.4–2 in] compared with ≤ 2.5 cm [1 in] long). *T. catappa* is distinguished from the eastern Polynesian *T. glabrata* by its shorter, thicker leaf petioles typically ≤1.5 cm (0.6 in) compared with 1.5–2.5 cm (0.6–1 in) long; heart-shaped leaf base compared with cuneate to acute; and winged, typically larger fruits >3.5–5 cm (>1.4–2 in) compared with 2.5–5 cm (1–2 in) long and more strongly angled fruits. Some authors consider *T. glabrata* to be a "wild" form of *T. catappa*, and more taxonomic studies, including using molecular markers, may be needed to determine the classification status of *T. glabrata*.

Top: Comparison of flowering twigs of *T. littoralis* (left) and *T. catappa* (right). PHOTO: L. THOMSON **Bottom: *T. littoralis*, 'Upolu, Samoa.** PHOTO: C. ELEVITCH

GENETICS

Variability of species

Major variation exists in a range of economically important nut characteristics, mainly as a result of traditional selection for trees with desirable traits and their propagation by peoples in various parts of its range in Melanesia. Selection has occurred for large fruits and/or kernels and ease of cracking. In Vanuatu the variability in the species is high; variations occur mainly in fruit size, color, and shape (Walter and Sam 1993). There is little variation within the species in most parts of the Solomon Islands, except for the Santa Cruz Islands (Temotu Province) where selection has produced some large-fruited forms. Two fruit types have been reported from the Mussau Islands, Bismarck Archipelago, Papua New Guinea (Lepofsky 1992). One type has a soft endocarp that can easily be broken with the teeth, while the other has a hard endocarp that must be hit with a stone or cut with a knife to extract the nut; it is uncertain whether the soft-shelled trees breed true to type. The island of Iwa, in the Marshall Bennett Group (PNG), is also renowned for its soft-shelled nuts. In Tonga two forms are distinguished: those with red fruits (*telie kula*) found along beaches and those with light green fruits (*telie hina*) found inland. In a Rapid Rural Appraisal study, four folklore varieties were identified for Ha'apai (Tonga), i.e., *'amanu*, *lau lalahi*, *lalike,* and *kai* (Tupoulahi-Fusimalohi 1999). In Samoa there is modern introduction of *T. catappa* with larger edible fruits.

In India several forms differing in leaf shape and fruit characteristics have been recognized. One type has an edible, sweet flesh (mesocarp) and is cultivated in gardens. Variation has also been reported in kernel taste and size from planted trees in the Caribbean and the southern United States.

Known varieties

While many variants are reported (see above), the species is invariably propagated from seed, which gives rise to variation in the offspring. Accordingly there is continuous variation with intermediate forms for various characters.

The species should be highly amenable to improvement through a breeding program given

- the high level of variation in nut characteristics
- short intergeneration times, i.e., the young age, about 3–4 years, at which plants flower and fruit, and
- ready access to flowers in low lateral branches for controlled pollination (although the flowers are small and crowded).

ASSOCIATED PLANT SPECIES

Tropical almond is a characteristic species of tropical beach forests, especially raised sandy beaches above high tide. It is also found along rocky shores, and sometimes on the edges of mangrove swamps. It may also grow as a pioneer on denuded or disturbed lands up to 300 m (1000 ft) elevation. In Vanuatu occasional seemingly wild trees in the forest are likely to be remnants of former settlements or gardens. In French Polynesia, it appears to have partly replaced the indigenous *T. glabrata.*

Kernels from three selected nut morphotypes of tropical almond (left) compared with wild type (right) in Vanuatu.
PHOTO: K. AKEN

TERMINALIA TERMS

- **Fruit**—the outer skin (exocarp) and flesh (mesocarp), the shell (endocarp), and kernel.
- **Nut**—the shell (endocarp) and the kernel.
- **Kernel**—the edible kernel or seed and testa (skin surrounding testa).

Associated species commonly found in native habitats

Associated species include *Acacia simplex*, beach heliotrope (*Tournefortia argentea*), *Barringtonia asiatica*, *Calophyllum inophyllum,* beach she-oak (*Casuarina equisetifolia*), coconut (*Cocos nucifera*), *Cordia subcordata*, *Excoecaria agallocha*, *Hernandia nymphaeifolia*, beach hibiscus (*Hibiscus tiliaceus*), *Intsia bijuga,* noni (*Morinda citrifolia*), *Scaevola taccada*, *Schleinitzia insularum, Terminalia littoralis*, *Thespesia populnea*, and *Vitex trifoliata.*

ENVIRONMENTAL PREFERENCES AND TOLERANCES

Climate

Tropical almond is well adapted to maritime subtropical and tropical climates where rainfall is usually in the range of 1000–3500 mm (40–140 in) per annum, distributed rather uniformly throughout the year or with a summer maximum. It is invariably found near the coast, at elevations of less than 300–400 m (1000–1300 ft), where there is little seasonal and diurnal variation in temperatures. The entire range is frost-free.

Elevation range

1–400 m (3–1310 ft).

Mean annual rainfall

1000–3500 (–4500) mm (40–140 [–180] in).

Rainfall pattern

The tree prefers climates with summer or uniform rainfall patterns.

Dry season duration (consecutive months with <40

mm [1.6 in] rainfall)

Up to 4–6 months.

Mean annual temperature

23–28°C (73–82°F)

Mean maximum temperature of hottest month

25–32°C (77–90°F)

Mean minimum temperature of coldest month

17–24°C (63–75°F)

Minimum temperature tolerated

5–7°C (41–45°F) (estimated)

Soils

Tropical almond naturally occurs on various coastal soils, especially raised sandy and rocky beaches. It is adapted to a wide range of lighter-textured soil types, including brackish/saline and alkaline sands over limestone, but requires good drainage when grown on heavier, clayey soils.

Soil texture

It prefers light to medium soils (sands, sandy loams, loams, and sandy clay loams).

Soil drainage

It requires freely draining soils.

Soil acidity

Acid to neutral/mildly alkaline soils (pH 4.0–8.5).

Special soil tolerances

Tropical almond tolerates shallow soils and slightly saline soils.

Tolerances

Drought

It is likely to be tolerant of droughts of less than 4–6 months duration and may shed leaves/canopy to withstand long dry spells.

Full sun

The tree grows most rapidly in full sun and regenerates mainly in open, well lit situations.

Shade

Tropical almond tolerates 0–25% shade. Seedlings and saplings tolerate moderate shade levels but require high light levels to grow satisfactorily, and mature trees prefer full sunlight.

Fire

It is resistant to low- to medium-intensity fires, with trees observed to regrow after burning during clearing operations.

Frost

The entire natural range is frost free. The tree is likely to be damaged at low temperatures (e.g., less than 5–7°C [41–45°F]).

Waterlogging

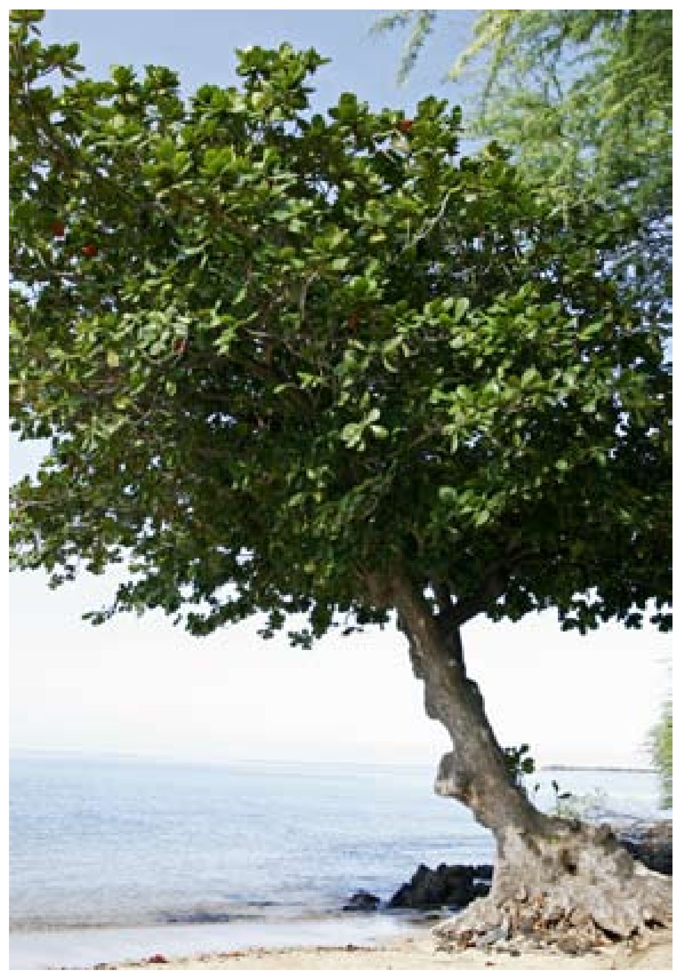
The species is not well adapted to waterlogged conditions.

Salt spray

The species typically grows within a short distance (<100–200 m [330–660 ft]) from the ocean and is adapted to exposure to strong, often salt-laden winds.

Wind

Tropical almond is adapted to strong, steady coastal winds, as well as rather frequent (every 2–5 years) exposure to



Tropical almond can withstand coastal winds and salt spray.
PHOTO: C. ELEVITCH

tropical cyclones over large parts of its range. While the species has overall good wind-firmness, some individuals suffer stem breakage and/or uprooting during tropical cyclones. Tropical almond may be partially defoliated by very strong winds, and this may aid its wind-firmness during cyclones.

Abilities

Regenerate rapidly

The species regenerates abundantly on its preferred littoral sites, notably in beds of washed–up debris and sand in strandline communities.

Self-prune

Tropical almond produce tiers of four or five branches; as new tiers are produced by the leader apex, some of the lower branch tiers die back. The extent of self-pruning is variable, depending on genotype, density of surrounding vegetation, and light levels.

Coppice

Seedlings and saplings coppice strongly, although the extent of regrowth after severe pruning or damage is unknown in mature trees. The main leader may be cut out of the top, sometimes more than once, to create a very wide-spreading shade or specimen tree. Excessive pruning by wind or man may cause weakening or death of mature trees.

GROWTH AND DEVELOPMENT

Growth rate

Under favorable conditions tropical almond is moderately fast to fast growing, with height growth in early years averaging around 1.5–2 m (5–7 ft) per year. Very fast early height growth of 3–5 m (10–16 ft) per year has been observed on fertile sites on Santo, Vanuatu. Diameter growth is about 1 cm/yr (0.4 in/yr) over the life of the tree, up to 2 cm/yr (0.8 in/yr) for widely spaced trees growing in fertile sites.

Reaction to competition

On favorable sites the tree is able to quickly gain site control and shade out most weeds. It may be necessary to prune the lower one or two tiers of branches to reduce access for climbing weeds. This will also improve amenity as a shade tree.

PROPAGATION

The species is readily propagated from seed. Mass vegetative propagation by rooted cuttings is also feasible.

Propagation by seed

Seed collection

The timing of fruit maturation varies among regions and may be sporadic or occur more than once per year (see above under “Fruit”). Fruits are ready for collection when they are full size (which varies among trees) and have begun to show some color change (i.e., become red-purple or yellow, or brownish in the case of green-fruited forms). Mature fruits are harvested from the tree by hand and/or with the aid of long-handled pole pruners. Recently fallen fruits may be collected from the ground.

Seed processing

There are about 15–60 fresh fruits/kg (7–27 fruits/lb). The fleshy outer covering should be removed from the seed/nut as soon as possible after collection (within 1–2 days), e.g., by careful hammering between two flat stones. After removal of the fleshy outer covering, there are about 70–150 nuts (nut-in-shell) per kg (32–68 nuts/lb).

Seed storage

The seed storage behavior is unknown, but seeds appear to lose viability fairly rapidly under storage. Until effective medium-term seed storage procedures are developed it is recommended that seeds be sown within 4–6 weeks of collection.

Pre-planting treatments

Seeds may be sown without any pretreatment.

Growing area

Seeds are germinated in a freely draining potting mix in germination trays in a protected, rat-free area under cover, such as a shade house. Seedlings should be transplanted into containers as soon as is practicable after germination and emergence. Plants grow rapidly and require larger containers than many forest tree species: suitable containers include 15 cm (6 in) polybags or tapering, rigid plastic tubes (e.g., 15 cm [6 in] deep by 6.5 cm [2.6 in] square at top).

Seedlings are progressively moved to higher light levels, e.g., 30–50% shade for 1–2 weeks after transplanting, then 25% shade for 1 month, then full sun for 2 months prior to outplanting.

Germination

Germination typically commences in 3–8 weeks, with a germination rate of greater than 50% for freshly harvested fully mature fruit.

Media

Seedlings should be grown in a standard potting mixture or fertile, freely draining sandy loam or loam, preferably with good levels of organic matter. Incorporation of a controlled-release, complete fertilizer into the potting mixture will ensure rapid, healthy seedling growth.

Time to outplanting

The time from germination to outplanting is about 4 months.

Approximate size

Plants should be about 25 cm (10 in) (max. 30 cm [12 in]) tall at outplanting. Smaller seedlings about 20–25 cm (8–10 in) high may also be used.

Propagation of seedlings of better nut morphotypes for distribution to farmers, Santo, Vanuatu. PHOTO: K. AKEN

Guidelines for outplanting

Seedlings should be outplanted at the onset of the wet season, typically early December in the South Pacific. A typical sequence for seedling production in Vanuatu would be June, seed collection; July–August, germination; September–November, nursery phase; December–January, field planting.

Propagation by cutting

For vegetative propagation for selected nut types, seedling hedges of better nut types can be planted. These trees can be regularly cut back to a height of about 20–30 cm (8–12 in) or, preferably, by laying seedlings flat, pinning, and cutting back new shoots. Multinode, semi-hardwood cuttings should be treated with rooting hormone (0.4% IBA powder), set in washed river sand, and rooted under mist.

DISADVANTAGES

The species has no major drawbacks. The tree is already naturally very widespread in the Asia-Pacific region and has multiple uses, including providing important environmental services such as coastal protection. The nuts are often not utilized or highly regarded as food because of the small size of the kernels and the difficulty of extracting them, but use of selected genetic material can greatly improve the utility of tropical almond nuts as human food.

Potential for invasiveness

The species naturalizes readily in suitable littoral habitats, and may be regarded as a potential weed threat to native plant communities. However, the tree is usually not considered a weed problem.

Diseases and pests

Plants are susceptible to termite attack, and damage may occur in some parts of its range. The leaves may be attacked and eaten by various insects and larvae, including rose beetles, but the plant generally recovers well from insect damage and defoliation. The Secretariat of Pacific Community Plant Protection Service has developed a list of pests and diseases that have been reported on tropical almond in different countries, including 85 insects, 13 fungi, 8 nematodes, and 3 mites (J. Wright pers. comm. 2004). Pink disease (*Corticium salmonicolor*), a fungal stem canker, was recorded on tropical almond in India.

Host to crop pests/pathogens

The fruits are hosts for 21 fruit fly species including Caribbean fruit fly (*Anastrepha suspensa*) in Florida, and of the Mediterranean fruit fly (*Ceratitis capitata*) in Costa Rica, as well as a fruit piercing moth (*Ophiusa coronata*)

AGROFORESTRY/ENVIRONMENTAL PRACTICES

Mulch/organic matter

Annual/bi-annual leaf drop results in a good buildup of organic matter under the trees.

Soil stabilization

The well developed lateral root system helps to bind fragile sandy soils and maintain coastal shores, especially during storm surges and extreme high tides. It has been specifically planted for soil conservation in India and Tanzania.

Crop shade/overstory

Mature trees cast a heavy, wide shade, when not in their brief deciduous phase. Tropical almond is only suitable for providing crop shade to the most shade tolerant crops such as cocoa (*Theobroma cacao*).

Alley cropping

Tropical almond may be used in intercropping systems while the trees are still young (up to about 3 years old) and with comparatively wide-spaced alleys, e.g., 6–9 m (20–30 ft) apart. During the final 3 years of the gardening phase in a rotational gardening or shifting cultivation, rows of tropical almond can be grown together with the crops, prior to conversion to a forest plantation (and serving as improved fallow).

Homegardens

It is a good species for inclusion in homegardens at the rate of one to three trees per garden, providing nuts for local consumption from an early age, coupled with reasonably good stability during strong winds and cyclones.

Improved fallows

The tree makes an excellent species for inclusion in mixed-species improved fallow plantings with a duration of at least 20–25 years to allow for production of timber.

Windbreaks

Tropical almond is an excellent species for inclusion as an upper to midstory layer in windbreaks.

Animal fodder

The foliage is suitable for feeding tasar or katkura silkworms. In the Caribbean, the fruit is an important food for birds and many wild mammals, and it is also consumed by various livestock, including pigs.

Windbreak of tropical almond and beach she-oak (*Casuarina equisetifolia*). PHOTO: C. ELEVITCH

Woodlot

The tree is a good species for inclusion in a mixed or single-species woodlot for provision of timber and/or nuts.

Native animal/bird food

The fruits are consumed by birds and bats.

Wildlife habitat

The trees provide good wildlife habitat, being among the tallest trees in beach forests. Small birds sometimes nest in the lower branches.

Bee forage

The flowers yield nectar that is attractive to honeybees.

Coastal protection

This a species of choice for coastal protection and soil stabilization, including beach stabilization just above the level of spring high tides. Key attributes for these roles include high salt tolerance (both foliar and soil), good cyclone resistance, surface rooting habit, and regular shedding of leaves that provide a moderately long-lasting mulch layer under the tree.

Ornamental

It is an attractive, long-lived tree well suited to ornamental and amenity plantings where space permits. It is especially suited to provision of shade in coastal open spaces, public parks, and along roadside verges.

USES AND PRODUCTS

The tasty kernels or nuts of tropical almond have traditionally been incorporated, albeit in modest quantities, into the diet of peoples in coastal areas throughout much of the Asia-Pacific region. The nuts may be consumed fresh shortly after extraction from the shell or else preserved by smoking and consumed up to a year later. In some areas the nuts are mainly a snack food consumed by children, with the fleshy fruit also sometimes being consumed. In other areas tropical almond nuts were highly regarded as a human food source. Types with larger kernels and softer shells were selected and preferentially propagated and maintained in parts of Melanesia. Localities noted for good nut types include South-West Bay, Malekula (Vanuatu); Santa Cruz Islands (Solomon Islands); and Mussau Islands, Bismarck Archipelago, and Iwa Island, Marshall Bennett Group (Papua New Guinea).

In coastal areas the timber is often used in local building but is not well suited to high-decay situations (such as contact with the ground). The timber is traditionally used to make various items including canoes and drums, and as a fuelwood. The tree also has a wide range of traditional non-wood product uses. Tannin is extracted from the bark, leaves, roots, and fruit shell. The large leaves are used as wrapping material. A black dye is obtained from the bark, fruit, and foliage. It's leaves and bark have a wide range of medicinal uses.

At present the main planting of the species is for amenity plantings for coastal protection and shade, with smaller plantings of selected types for nut production. The nuts of the species remain an important local food source, and it is highly regarded as a building timber in parts of the Pacific, including Vanuatu and Samoa.

Fruit

Children sometimes consume the outer flesh of agreeable fruit types. In the Philippines a wine is made by fermenting mature fruits.

Superior nut morphotypes selected in Solomon Islands and introduced to Tonga in 2002. PHOTOS: K. AKEN

Nut/seed

The nuts may be consumed fresh after extraction from the shell or preserved by drying or smoking and consumed up to a year later. In some local markets in Melanesia the fresh kernels are sold in bundles or skewered on sticks (palm frond spines). Kernels are easily damaged during extraction and start to mold within 1–2 days at ambient temperatures. The sun-dried kernels yield 38–54% of a bland, yellow oil that is edible but becomes turbid on standing.

Medicinal

The leaves have many medicinal uses including diaphoretic, anti-indigestion, and anti-dysentery. An infusion of the young leaves or scraped bark is occasionally taken as a potion for treating mouth infections in Tonga and Samoa and is used in the Cook Islands to bathe fractures. Young leaves are used in the Philippines to cure headache and colic. The bark is used as an astringent in dysentery and thrush.

Timber

The sawn timber has a wide range of end-uses including general building construction, especially interior purposes such as flooring and furniture. Larger sound logs are suitable for veneer and plywood manufacture. The wood is not suitable for long-term ground contact.

Fuelwood

The wood is suitable for use as fuelwood.

Craft wood/tools

Traditional wood uses in the South Pacific include kava bowls, tool handles, clubs, walking sticks, and drums.

Canoe/boat/raft making

The wood is traditionally used to make canoe hulls and paddles in the South Pacific. The wood is also used in boatbuilding.

Wrapping/parcelization

The leaves are infrequently used to wrap and carry food.

Tannin/dye

The bark and leaves (as well as fruit shells and roots) are rich in tannins and may be used for staining/coloring fabrics including tapa, tanning leather, and ink-making.

Oil/lubricant

Trials have been conducted to admix kernel oil into diesel fuel.

URBAN AND COMMUNITY FORESTRY (By Craig R. Elevitch)

Tropical almond is a popular ornamental and shade tree throughout the tropics. The trees has a beautiful, broad, pagoda-like canopy and attractive leaves. Part of the appeal of the species as an ornamental is the bright red-orange-yellow color of the leaves before each annual defoliation. In addition to its amenity services, the tree produces tasty nuts, traditional medicines, dye, and timber, all of which can be utilized from trees growing in urban areas. It withstands coastal conditions, including heavy salt spray and strong winds, and therefore is most commonly found in coastal urban areas. It is widely adaptable to various soils, including infertile sandy soils.

Size in an urban environment

In urban environments, the tree typically reaches 15–25 m (50–80 ft) tall with a broad canopy similar in diameter to the height of the tree. The trunk can grow to 1.5 m (5 ft) in diameter at breast height. For urban environments, this is a large tree, which needs to be pruned regularly to control its size in more confined areas.

Rate of growth in a landscape

With care and in favored environments, trees can grow up to 2–4 m/yr (6.6–13 ft/yr) for the first few years, although growth rates closer to 1 m/yr (3.3 ft/yr) are more typical.

Root system

The root system is deep in sandy substrates. In soils with shallow water table, it can develop an extensive surface root system that could interfere with maintenance activities, such as mowing. The formation of a buttressed trunk can lift sidewalks, foundations, curbs, pipes, etc., making it inadvisable to plant the tropical almond near such structures.

Products commonly used in a Pacific island household

The nuts are edible both raw and cooked, although eating quality and kernel size are variable. The nuts are an important food when in season in Vanuatu. In other areas such as Samoa, Tonga, New Guinea, and the Solomon Islands, they are eaten rarely or just nibbled on by children. In Hawai‘i, few people are aware that the kernel is edible. The difficulty of extracting the kernel, variable eating quality, and absence of large-kernelled varieties may explain the lack of use of the nut in many areas. The outer flesh of the seed is also edible, although it is usually fibrous and not tasty. Fruits are cracked open to extract the kernel by a sharp blow to the edge or by hitting the pointed apex with a hammer.

The leaves, bark, and fruit skin are used medicinally and are also used to make a black dye.

The wood is used for construction, crafts, and canoes. It is an attractive, moderately durable timber well suited to interior uses, such as framing, paneling, flooring, and furniture. It also makes good firewood.

Light requirements

Its seedlings tolerate light shade (0–25%), although the tree performs best in full sun.

Water/soil requirements

Tropical almond grows best in sands and loamy sands, but it can grow very well in silts, loams, and clays. It is also known to grow in the poor-quality fill that is often found in urban areas (Francis 1989).

Life span

As an ornamental, tropical almond is expected to live about 60 years (Francis 1989) and up to 100 years in suitable environments.

Varieties favored for use in homegardens or public areas

There are many forms found regionally (see "Variability" above). There has been long-term domestication and selection of large-kernelled forms in parts of PNG, Solomon Islands, and Vanuatu. These nut morphotypes are favored for home and village gardens.

Seasonality of leaf flush, flowering, fruiting

Trees lose their leaves once or twice a year during dry periods. Trees generally flower and fruit once annually, although in many areas such as Hawai'i, Fiji, and Tonga, flowering and fruiting take place continuously throughout the year.

Clockwise from top left: horizontal form of pruned tree, Apia, Samoa; pollarded tree, North Kohala, Hawai'i; tree in homegarden alongside mango, breadfruit, and rain tree, Apia, Samoa. PHOTOS: C. ELEVITCH

Exceptional ornamental values

The large, dark green leaves are attractive and showy, especially prior to seasonal shedding. As new leaves appear, the bright green new growth is also conspicuous and attractive. In its preferred seaside environments, the deep shade cast by the tree is often very welcome to beachgoers. The broad canopy is readily identifiable and appreciated as shade. Large trees with buttressed trunks 1 m (3.3 ft) in diameter or more can make spectacular community landmarks and gathering places.

Use as living fence, hedge or visual/noise barrier

The form of the tree, with a single dominant trunk and horizontal spreading branches, does not lend itself to hedges or barriers.

Birds/wildlife

Birds and bats consume the fruit.

Maintenance requirements

In urban environments requiring a tidy appearance, the seasonal leaf and fruit drop necessitates regular removal of debris from underneath trees. Where the size of the tree must be controlled, such as in a small homegarden, the tree can be shaped at an early age to a desirable size. In this case the main stem can be cut at a desired height, favoring horizontal branches. In Samoa and elsewhere, the lower branches of the trees are sometimes weighted down so that the tree will be a more attractive or effective shade tree.

The tree can also be pollarded to control the height and canopy diameter. In pollarding, a framework of several stems is formed at a desired height by pruning the tree during its early development. These stems are then pruned back heavily every 2–5 years.

Tropical almond does not require fertilizer except in the most infertile soils. It tolerates drought, but performs better in consistently moist conditions.

Nuisance issues

In urban areas the loss of leaves once or twice a year may be considered "messy," but the preceding change of leaf color before dropping can be spectacular. The flowers have a slightly fetid odor, although the smell is rarely strong enough to be considered a nuisance. The trees also tend to grow rather large for urban environments.

Hazards

Although the tree is a coastal species and adapted to withstand storm winds, branches can snap in high winds (Walter and Sam 2002). Therefore trees should be planted well clear of building structures.

Common pest problems

Many insects and larvae feed on the leaves, including rose beetles, but trees usually recover well from periodic infestations.

COMMERCIAL PRODUCTS

The main commercial products of tropical almond are sawn timber for local use, especially in house and building construction, and kernels for human consumption.

Timber

The heartwood of tropical almond is variable in color, often brown to reddish-brown, with a wide, rather indistinct band of lighter colored sapwood. The timber is smooth, lustrous, elastic, tough, moderately hard, and medium-coarse in texture, often with an irregular or twisted grain. The wood is moderately dense, e.g., 530–540 kg/m^3 (33–34 lb/ft^3) at 12% moisture content. The timber has been variously reported as seasoning rapidly with a moderate level of degrade or else as not easily seasoned. The timber is readily sawn, but interlocked grain tends to pick up during planing. Other machining characteristics are as follows: shaping, boring, and mortising are fair; turning is poor; sanding, resistance to screw splitting, and nailing properties are good.

Nuts

In Vanuatu one local company purchases tropical almond kernels from around the country for US$6–7 per kg (US$2.73–3.18/lb). The kernels are checked for quality, dried, and retailed in 40 g (1.4 oz) jars in Port Vila supermarkets for more than US$80 per kg (US$36/lb). Demand is high, and the company would like to purchase 1000 kg (2200 lb) of kernels per year (equivalent to 30–50 mt [27–45 t] of fruits). In Port Vila and Loganville markets, fresh tropical almond kernels are sold in bundles or skewered on sticks (palm frond spines/midribs) for the equivalent of US$12–17 per kg (US$5.45–7.73/lb).

Spacing

Timber

An appropriate initial spacing for commercial production of timber in monocultural plantings is 3 x 5 m (10 x 16 ft) (equivalent to 667 stems/ha [270 stems/ac]). Wider inter-row spacing could be used to reduce weeding costs. Intercropping with short-term crops could be done with a tree spacing of 3 x 8 m (10 x 26 ft) (i.e., 417 stems/ha

Left: Nuts skewered onto palm leaflet midribs and sold in Port Vila market, Vanuatu; pictured: author Lex Thomson. PHOTOS: K. AKEN **Right: The late Justin West standing among 2–3-year-old tropical almond trees he planted in a small plantation outside Port Vila, Efate, Vanuatu.** PHOTO: B. EVANS

[169 stems/ac]). The final density for sawlog production is about 150–200 stems/ha (61–81 stems/ac). A suitable area for commercial production would be 10 (or more) hectares (25+ ac), but even small woodlot areas of about 1 ha (2.5 ac) could be grown on a commercial basis by groups of smallholders to supply local saw mills.

Nuts

A wide spacing is recommended, coupled with pruning out the lead shoot to encourage low, wide-spreading lateral branching. The suggested spacing is 8–9 x 8–9 m (26–30 x 26–30 ft), i.e., 123–156 trees per ha (50–63 trees/ac).

Both nuts and timber

Suggested spacing is close within rows (e.g., 2 m [6.6 ft]) and wide between rows (e.g., 8 m [16 ft]). This gives an initial spacing of 625 trees/ha (253 trees/ac), which is eventually thinned down to a final spacing of about 150 trees/ha (61 trees/ac) by removal of poorer formed individuals in one or two non-commercial thinning operations at age 3–6 years.

Management objectives

The aim of management for timber production is to produce high-quality sawlogs within an economically feasible and attractive time frame; e.g., a rotation period of 20–25 years. This will include use of selected genetic material, regular maintenance in early years including frequent removal of creepers, and one or more thinnings to maintain site control and concentrate wood increment on better-formed stems. Progressive pruning of lower whorls of branches up to a height of about 12 m (39 ft) may be required to produce less knotty sawlogs of higher value. Such pruning should be done in several steps, to maintain at least two-thirds of the canopy leaf area at any one pruning.

Design considerations

For production of nuts, it is recommended that plantings be located in areas with good access to major marketplaces, so that extracted kernels can reach the market quickly without risk of spoiling.

Advantages and disadvantages of growing in polycultures

Tropical almond has the potential to be well suited to growing in polycultures with other fast-growing timber species such as *Endospermum medullosum*. The fast-growing but smaller *Flueggea flexuosa* could be interplanted and harvested after 7–10 years to provide durable poles.

Intercopping with cassava and other crops on Santo, Vanuatu. PHOTO: L. THOMSON

Yields

Timber

There is no data available concerning growth rate over the projected rotation length of about 20–25 years. It is likely that good-quality, well maintained plantations on fertile sites grow at about 15–20 m^3/ha/yr (215–286 ft^3/ac/yr).

Nuts

Significant amounts of fruits are produced 3–5 years after planting, with regular fruiting once or twice a year depending upon latitude, location, and health of the tree. Kernel yield is estimated to be about 5 kg (11 lb) per tree per year (or about 0.5 to 1 mt/ha/yr [0.18–0.36 t/ac/yr]), but yields might be double that for selected genetic stock grown on high-quality sites.

Processing required

The greatest obstacle to the commercial marketing of the nut is its low kernel content and the lack of on-farm commercial storage technologies that would allow fruits to be processed in villages and the high value kernels to be transported to central processing units. For nut production, the flesh should be removed manually from fruits on-farm, and the nuts should be at least partly dried to remove surface moisture. This will considerably reduce the bulk and weight of material to be transported without spoilage to market and reduce the risk of spoilage. Drying and smoking of nuts on-farm would add considerable value and produce a more durable product with a considerably extended shelf life.

Market

Timber

Markets for planted tropical almond timber are the local timber markets for general-purpose timbers.

Nuts

The size of the international market for nuts is likely limited. However, tropical almond nuts (along with *Canarium indicum* nuts) have the potential to behave as under-supplied niche commodities with a highly inelastic demand, commanding a price equivalent to macadamia nuts (currently more than US$10/kg [US$4.55/lb]) wholesale, i.e., 2.5 times the price of mainstream nuts such as almonds, providing packaging and quality are similar. High-value niche markets and value could be secured and enhanced by organic certification, promotion of tropical almond as an exotic commodity, and direct internet-based marketing. Marketing opportunities and constraints for Pacific tree nuts depend on quality control, packaging, continuity of supply, and targeting marketing toward specific groups, such as tourists.

INTERPLANTING/FARM APPLICATIONS

Example system 1

Location

Temotu Traditional Tree-based Agriculture (Santa Cruz Islands, Solomon Islands).

Description

Tropical almond is planted as an outer boundary tree on the windward side of multi-species ,multistory agroforestry plots to protect more vulnerable species against sea spray and wind.

Yields/benefits

Fuelwood, timber, and kernels.

Spacing

About 5–8 m (16–26 ft) within rows.

Example system 2

Location

Shark Bay, Santo, Vanuatu.

Description

Newly developed, experimental system started in January, 2000. There are no data available on yields. The benefit of intercropping is that while farmers receive early returns, while waiting for the trees to start bearing nuts. Good weeding ensures high survival and rapid early growth of trees.

Crop/tree interactions

During the first 2 years, various traditional root and leaf crops are grown as intercrops with similar production to pure cropping systems.

Spacing

Spacing is 5 x 5 m (16 x 16 ft) or 400 trees per hectare (160 trees/ac).

PUBLIC ASSISTANCE

See general extension links at:
http://www.traditionaltree.org/extension.html

Top: 2.5-year-old tropical almond trial planting at Shark Bay, Santo, Vanuatu. PHOTO: K. AKEN **Bottom: same Shark Bay planting as above at 5 years old; this tree has reached 20 m (65 ft) in height.** PHOTO: L. THOMSON

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Species Profiles for Pacific Island Agroforestry (www.traditionaltree.org)

Terminalia catappa (tropical almond)

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Acknowledgments: The authors and publisher thank Dale Evans, John Francis, Heidi Johansen, Diane Ragone, Secretariat of the Pacific Community-Plant Protection Service, and Art Whistler for their input. Photo contributions by Kron Aken and J. B. Friday are greatly appreciated.

Recommended citation: Thomson, L.A.J., and B. Evans. 2006. *Terminalia catappa* (tropical almond), ver. 2.2. In: Elevitch, C.R. (ed.). Species Profiles for Pacific Island Agroforestry. Permanent Agriculture Resources (PAR), Hōlualoa, Hawai'i. <http://www.traditionaltree.org>.

Sponsors: Publication was made possible by generous support of the United States Department of Agriculture Western Region Sustainable Agriculture Research and Education (USDA-WSARE) Program; SPC/GTZ Pacific-German Regional Forestry Project; USDA Natural Resources Conservation Service (USDA NRCS); USDA Forest Service Forest Lands Enhancement Program; State of Hawai'i Department of Land & Natural Resources Division of Forestry & Wildlife; Kaulunani, an Urban Forestry Program of the DLNR Division of Forestry and Wildlife and the USDA Forest Service; and Muriel and Kent Lighter. This material is based upon work supported by the Cooperative State Research, Education, and Extension Service, U.S. Department of Agriculture, and Agricultural Experiment Station, Utah State University, under Cooperative Agreement 2002-47001-01327.

Series editor: Craig R. Elevitch

Publisher: Permanent Agriculture Resources (PAR), PO Box 428, Hōlualoa, Hawai'i 96725, USA; Tel: 808-324-4427; Fax: 808-324-4129; E-mail: par@agroforestry.net; Web: <http://www.agroforestry.net>. This institution is an equal opportunity provider.

April 2006
ver. 2.1

Terminalia richii (malili)

Combretaceae (combretum family)

malili **(Samoa)**

Lex A. J. Thomson

IN BRIEF

Distribution Samoa, American Samoa, and Niue.

Size Large tree 25–35 m (80–115 ft) tall at maturity.

Habitat Lowlands and lower montane rainforest, in maritime, humid tropical, seasonally wet climates; annual rainfall of 2050–3250 mm (80–130 in) and elevations up to 830 m (2700 ft).

Vegetation Associated with remnants of tall native canopy forest and secondary forest.

Soils Fertile, neutral, well drained, heavy textured, and of basaltic origin.

Growth rate Moderate to moderately fast height growth: 2–2.5 m/yr (6.6–9 ft/yr) in early years; 1.3–1.5 m/yr (4.3–5 ft/yr) after 14–22 years; diameter increment: 1.8–2.1 cm/yr (0.7–0.8 in/yr) after 14–22 years.

Main agroforestry uses Soil stabilization, windbreak, improved fallow.

Main products Timber, fuelwood.

Yields 10–13 m^3/ha/yr (143–186 ft^3/ac/yr) (estimate).

Intercropping Root crops during establishment.

Invasive potential Little potential for invasiveness.

PHOTO: L. THOMSON

Remnant tree, south ʻUpolu, Samoa.

INTRODUCTION

Malili (*Terminalia richii*) is typically a straight, long-boled forest tree to 25–35 m (80–115 ft) tall native to the Samoan archipelago (Samoa and American Samoa) and Niue in the central South Pacific. It is found in lowland and lower montane rainforest, sometimes emergent above the forest canopy. The climate in its native habitats is maritime, humid tropical, with a distinctive wet season (November–April) and a dry season (May–October). It occurs up to an elevation of 830 m (2700 ft). The soils are mainly of basaltic origin (or, rarely, derived from limestone) and typically fertile, neutral, well drained, and heavy textured.

The wood has excellent working and machining properties and is suitable for a wide range of interior uses as well as general construction. In Samoa, malili is a very well regarded timber species and it has been extensively logged in most parts of its natural range. The species is now uncommon throughout its range, and steps need to be taken to ensure that remaining genetic resources are conserved.

The species has potential for timber plantation development in the lowland humid tropics, as a moderately fast-growing, general-utility timber species with a demonstrated resistance to tropical cyclones and short periods of drought. It also has good potential in various agroforestry systems, including wide-spaced alleys (e.g., interplanted with *Flueggea flexuosa*), boundary plantings, woodlots, and long-rotation, improved fallows.

While malili trees stand up well to cyclones, it takes at least 3 years to set a heavy fruit crop after two major cyclones in successive years. Until recently its wider planting was hampered by the difficulty in obtaining seed, in part because of the lengthy period for trees to bear fruit following major cyclones. Its biological characteristics ensure that it will not become an environmental weed. More research is required to ascertain the extent of genetic variation and to optimize propagation techniques, both from seed and cuttings.

DISTRIBUTION

Native range

The tree is indigenous to the Samoan archipelago, and it was formerly found on Niue (where it is now extinct in the wild). In Samoa, malili occurs mainly as individual trees in scattered locations over a wide elevation range from lowland to montane forests.

Current distribution

Malili was never abundant in Samoa, and it has become less frequent as a result of agricultural activities, especially on 'Upolu. The formerly good stands of malili in central 'Upolu (about 730 m [2400 ft] elevation) and southwestern 'Upolu (50 m [164 ft]) have been largely cleared, and most remaining stands are highly disturbed. It was introduced at Colo-I-Suva, Fiji for trials and recently re-introduced to Niue.

BOTANICAL DESCRIPTION

Preferred scientific name

Terminalia richii A. Gray

Family

Combretaceae (combretum family)

Common names

malili (Samoa)

Size

Malili develops into a large tree up to 25–35 m (80–115 ft) tall and 15–20 m (50–66 ft) in crown diameter, sometimes emergent above the forest canopy.

Typical form

The canopy is tiered with branches in horizontal false whorls becoming irregular with age. The bole is usually long and straight, with small steep buttresses in old trees.

Flowers

The flowers are arranged in axillary spikes at the ends of branchlets. Individual flowers are small, yellowish-white, the calyx five-lobed and star-shaped, with 10 long anthers. In open situations malili trees first flower at around 6–8 years of age. Flowering occurs after the flush of new leaf growth from September to January. In Samoa, flowers and fruits develop about 1–2 months later on Savai'i compared with 'Upolu, with the main flowering period on Savai'i taking place from November to January.

Leaves

The adult leaves are simple/entire, lanceolate, (5–) 6–13 cm ([2–] 2.4–5.1 in) long by (2–) 2.5-5 cm ([0.8–] 1–2 in) wide, discolorous, dark shiny green above and light green below. Young leaves are larger, up to 27 cm x 7.5 cm (11 x 3 in). The new shoots and young leaves are covered in silvery to light-rusty, short, silky hairs. The tree is briefly deciduous and may be completely leafless from late June to early July.

Fruit description and time to bearing

The time from flowering to fruit maturity is about 4–5 months. In Samoa the fruiting season is from December to March (usually December–early February on 'Upolu and February–March on Savai'i). The fruits are ovoid, flattened on one side, with a thin flesh covering a single stone, ca. 3 x 2 cm (1.2 x 0.8 in), green, ripening to reddish-purple.

Seeds

Surveys of traditional knowledge indicated that several species of pigeons, doves, and bats were both pollinators and seed dispersers for the species.

Bark description

The bark is grey, shallowly and longitudinally furrowed to tessellated and persistent. With age, the bark of specimens in forest situations becomes covered in an attractive patchwork of different colored lichens and mosses (including dark green, light bluish grey, pink, and whitish).

Rooting habit

Trees appear to have a spreading, near-surface lateral root system, presumably complemented by deep sinker roots.

Similar or look-a-like species

The genus *Terminalia* comprises about 150–250 tropical tree species. *T. complanata* from Papua New Guinea and the Solomon Islands is most closely related to malili (Smith 1971) and is also considered a useful timber species. The *T. complanata* group includes two other PNG species, *T. sogerensis* and *T. longespicata* (Coode 1969).

How to distinguish from similar species/look-a-likes

T. complanata differs from *T. richii* in its thicker leaf blades




Top left: Leaves (note: slightly broader-leaved form than typical). PHOTO: L. THOMSON **Top right: Flowers and immature fruit.** PHOTO: J. LARMOUR **Bottom right: Bark.** PHOTO: L. THOMSON **Bottom left: Ripe fruit on tree.** PHOTO: J. LARMOUR which are conspicuously glandular/pustulate above, less persistent hairs on foliage and inflorescences, shorter petioles (7–15 mm compared with 10–30 mm [0.27–0.59 in compared with 0.4–1.2 in]) and shorter inflorescences (7-14 cm compared with 10-20 cm long [0.27–0.55 compared with 0.4–0.8 in]). *T. richii* is easily distinguished from the other three native *Terminalia* species in Samoa (i.e., *T. catappa*, *T. glabrata*, and *T. littoralis*), by its smaller, narrower, lanceolate leaves.

GENETICS

Variability of species

There is no published information and little is known about variation in malili. One survey indicated variation in leaf size among trees, but the extent to which this character is under genetic control is unknown (François Martel and Associates 1998). Some trees have broader leaves.

Known varieties

There are no recognized varieties.

ASSOCIATED PLANT SPECIES

The main native habitats include lowland and lower montane rainforest. Due to the effects of logging, agricultural clearing, and cyclones, it is increasingly found in more open secondary forest associations. The principal associated tree species are in the genera *Calophyllum, Canarium*, *Dysoxylum*, *Planchonella*, *Pometia*, and *Syzygium*.

Associated species commonly found in native habitats

Associated species in Samoa include *Adenanthera pavonina*, *Calophyllum neo-ebudicum*, *Cananga odorata*, *Canarium vitiense*, *Dysoxylum* spp. (including *Dysoxylum samoense*), *Garuga floribunda*, *Hibiscus tiliaceus*, *Inocarpus fagifer*, *Intsia bijuga*, *Manilkara samoense*, *Myristica fatua*, *Neonauclea forsteri*, *Pouteria samoensis*, *Pometia pinnata*, and *Syzygium* spp. (including *S. inophylloides*).

Species commonly associated in modern times or as recent introduction

In more recent community forestry plantings in Samoa it is most commonly being planted with *Swietenia macrophylla* and/or *Flueggea flexuosa*.

ENVIRONMENTAL PREFERENCES AND TOLERANCES

Climate

The climate in its native habitats is maritime, humid tropical with a distinctive wet season (November–April) and a dry season (May–October).

Elevation range

5–830 m (16–2700 ft).

Mean annual rainfall

2050–3250 mm (80–130 in).

Rainfall pattern

The tree prefers climates with summer rainfall.

Dry season duration (consecutive months with <40 mm [1.6 in] rainfall)

None.

Mean annual temperature

24–27°C (75–81°F).

Mean maximum temperature of hottest month

26–31°C (79–88°F).

Mean minimum temperature of coldest month

21–24°C (70–75°F).

Minimum temperature tolerated

In its natural habitats the lowest temperatures are only 14–17°C (57–63°F), but *T. richii* is likely to be able to tolerate temperatures down to about 7°C (45°F).

Soils

Malili prefers fertile, well drained, neutral clay loams but is adapted to most soil types of volcanic origin. It also occurs on slightly alkaline skeletal soils overlying coralline limestone.

Soil texture

It prefers medium to heavy soils (loams, sandy clay loams, clays, clay loams, and sandy clays).

Soil drainage

Best growth is on freely draining soils, but it can grow on wet/periodically waterlogged sites.

Soil acidity

The tree grows in neutral soils (pH 6.1–7.4).

Special soil tolerances

It grows in apparently skeletal, rocky soils, but these are of basaltic origin and may overly deeper soils that are accessible to the root system.

Tolerances

Drought

Unknown.

Full sun

It grows fastest in full sun.

Shade

The tree tolerates 0–25% shade. Seedlings tolerate moderate shade levels but require high light levels to grow rapidly, and sapling and mature trees prefer full or nearly full sunlight.

Fire

Unknown.

Frost

It is likely to be damaged by low temperatures, i.e., less than 7°C (45°F).

Waterlogging

Some populations may have moderate waterlogging tolerance, as it is found on moist sites with poor drainage on ʻUpolu.

Salt spray

It is reported to be sensitive to salt spray.

Wind

Malili is highly tolerant of both steady winds and cyclone damage. It was found to be the most cyclone resistant plantation species in Samoa following the major cyclones Val and Ofa in the early 1990s. Its high cyclone resistance was again proven during cyclone Heta in early 2004: on Savaiʻi, malili plantings of various ages suffered only minor damage besides that from falling trees of residual overstory of other tree species. Malili plants suffered very few broken tops, but in rocky, rather open sites at Falelima a small percentage (<10–20%) of saplings were blown over.

Abilities

Regenerate rapidly

Field observations suggest that malili regenerates fairly well under natural conditions, with numerous seedlings being recorded near mature trees.

Self-prune

Good self-pruning habit in forest-grown trees, but open-grown trees may retain some lower branches.

Coppice

Seedlings and younger specimens coppice strongly. Coppice ability is unknown in mature trees.

GROWTH AND DEVELOPMENT

Growth rate

Malili is fast growing in its early years, e.g., 2–2.5 m/yr (6.6–8 ft/yr) in annual height increment, thereafter growing at a steady and moderately fast rate. Plots of 14- and 22-year-old trees had mean annual increments of 2.1 and 1.8 cm (0.8 and 0.7 in) dbh and 1.5 and 1.3 m (4.9 and 4.3 ft) height, respectively (Neuteboom 1977, Pouli et al. 1995).

Flowering and fruiting

Open-grown malili trees are expected to yield light to moderate seed crops commencing at about 8–10 years of age.

Reaction to competition

No data available.

PROPAGATION

The species is readily propagated from seed. Mass vegetative propagation by rooted cuttings is also feasible. Clones can be developed either from seedlings or from basal coppice resulting from felling or girdling selection-aged trees. Seed production may be non-existent or greatly reduced in the 2–3 years following major successive cyclones, so ongoing planting programs for this species need to be based on a combination of seedlings and rooted cuttings.

Propagation by seed

Seed collection

In Samoa, the timing of fruit maturation varies between locations. Fruits ripen first in low-altitude locations on northern ʻUpolu and much later at higher altitudes on Savaiʻi. Mature fruits, indicated by their turning reddish-purple, should preferably be collected directly from the tree, as fallen fruits are prone to be heavily attacked by insects. Fruits may be removed from the trees by either the use of a catapult to secure a line over seed-bearing branches and pulling the branch down or by climbing the tree (using appropriate safety equipment). The catapult is most effective in trees occurring in open situations and may be used to remove fruit-bearing branches up to a maximum of about 30 m height.

Seed processing

The fleshy outer covering should be removed from the seed/nut shortly after collection. There are about 2600 seeds per kg (5700 seeds/lb). The germination rate for fresh seed is typically 35–40%.

Seed storage

Unknown. The seed storage behavior is likely to be orthodox, but seeds appear to lose viability fairly rapidly in storage.

Pre-planting treatments

Germination has not been improved to any extent by pretreatments such as nicking seeds or soaking them in water overnight.

Growing area

Seeds are germinated in a freely draining potting mix in germination trays in a protected area under cover, such as a shade house. Seedlings are progressively moved to higher light levels, e.g., 33% shade after transplanting, then 25% shade for 1–2 months, and then full sun for 1–2 months prior to outplanting.

Seedlings in nursery, 'Upolu, Samoa. PHOTO: L. THOMSON

Germination

Germination is rather slow and typically occurs sporadically over a long period of several months. Shortly after seeds germinate, and before their roots are about 2 cm (0.8 in) long, they are transplanted into final pots.

Media

Seedlings should be grown in a standard potting mixture or fertile, freely draining loam to clay loam, preferably with good levels of organic matter. It is recommended that a controlled-release, complete fertilizer be added at a rate of 12 g/l (1.6 oz/gal) into the potting mixture. This will ensure rapid, healthy seedling growth, including post-planting.

Time to outplanting

The time from germination to outplanting is about 4 months.

Approximate size

Plants should be about 25 cm (10 in) tall at outplanting; smaller seedlings about 20 cm (8 in) high may also be used.

Guidelines for outplanting

Seedlings should be outplanted at the onset of the wet season, typically early December in the South Pacific. The typical sequence for seedling production is January–March, seed collection; April–June, germination; July–November, nursery phase; November–January, field planting.

Vegetative propagation from cuttings

Seedling hedges of better phenotypes should be developed by regular cutting back to a height of about 20–30 cm (8–12 in) or by laying seedlings flat, pinning, and cuttings back new shoots. Multi-node, semi-hardwood cuttings should be treated with rooting hormone (0.8% IBA powder), set in washed river sand, and rooted under mist. Tip and hardwood cuttings may be also be used. The success rate for juvenile cutting material averages 30–60%, but rooting percentage is highly variable among individual clones, ranging from less than 10% to greater than 60%.

DISADVANTAGES

The main limitation to the wider use of malili in Samoa in experimental or operational plantings is its poor flowering and fruiting, especially for 2–3 years following severe cyclones, and low germination of typically less than 50% in the nursery.

The current planting rate is low (less than 10 ha [25 ac] per year) owing to the lack of viable seed of the species. The scale of future planting of malili is hard to predict, but together with poumuli (*Flueggea flexuosa*) and mahogany (*Swietenia macrophylla*) it is expected to become a major timber plantation species in Samoa.

Potential for invasiveness

Several biological characteristics of malili, including late onset of reproductive maturity and inability to regenerate in closed forests, will ensure that it will not become an invasive or environmentally weedy species when planted outside of its natural range.

Diseases and pests

The tree may succumb to butt rot, possibly caused by the fungus *Phellinus noxius,* and the leaves are highly susceptible to rose beetle (*Adoretus versutus*).

Host to crop pests/pathogens

Unknown. Other *Terminalia* species may be host to citrus fruit-piercing moth.

AGROFORESTRY/ENVIRONMENTAL PRACTICES

Mulch/organic matter

Annual leaf drop produces a good organic matter build-up under trees.

Soil stabilization

The excellent cyclone resistance, surface rooting habit, lower stem buttressing, and small-medium leaves which break down at an intermediate rate combine to make this a species of choice for soil erosion control.

Crop shade/overstory

Malili is only suitable as an overstory tree for more shade-tolerant crops.

Alley cropping

It is suitable for wide-alley cropping in farming systems using rotational gardening or shifting cultivation.

Homegardens

Good cyclone stability makes this a reasonable choice for planting near homes, but overall it is not well suited to homegardens due to large size, moderately heavy shade levels, and lack of non-wood products for home use.

Improved fallows

Malili is an excellent species for inclusion in mixed-species improved fallow plantings with a duration of at least 30 years (to allow for production of timber).

Boundary markers

It is an excellent species for boundary marker plantings due to longevity and stability.

Windbreaks

Where space permits, malili is an ideal species for inclusion as a middle to upper layer in windbreaks.

Native animal/bird food

It is a good source of food for native pigeons and doves, many of which are highly regarded wild foods in Samoa and Niue. It also provides food for the endangered and protected manumea, the national bird of Samoa.

Ornamental

Malili is an attractive tree for amenity and ornamental plantings in larger, public spaces.

USES AND PRODUCTS

The main traditional uses for malili were for production of canoes and as timber in local building construction (non-ground contact situations). It was also favored as a tree for staking out during pigeon hunting season, as the fruits are attractive to these birds.

Timber

Malili is one of the lighter colored, lighter weight Samoan hardwoods having low shrinkage and excellent working and machining properties. The wood is a light- to medium-density hardwood (550 kg/m^3 [34 lb/ft^3] at 12% moisture content). It is suitable for a wide range of interior uses including paneling, cabinetwork, and furniture, as well as


Reintroduced trees on Niue. PHOTO: L. THOMSON

general construction. It was traditionally used in house construction. However, its present day use in the timber and building industries in Samoa is very limited due to its rarity.

Malili is an indigenous tree species with major plantation potential. Key attributes include production of a good utility timber, moderately fast growth, excellent stem form, and adaptation to local South Pacific conditions, including periodic severe cyclones. Its wider planting is being encouraged and promoted by the forestry departments in the countries of its native origin.

Fuelwood

The wood is suitable for use as fuelwood.

Canoe/boat/raft making

It was traditionally used for canoe building in Samoa.

COMMERCIAL PRODUCTS

The main commercial product of malili is sawn timber for local use, especially in house and building construction.

Spacing

An appropriate initial spacing for commercial production in monocultural plantings of malili for timber production is 3 x 3 m (1111 stems per ha [450 stems/ac]). Wider interrow spacings and/or intercropping systems could be used to reduce weeding costs, e.g., 2.5 x 8 m (8 x 26 ft) (500 stems per ha [200 stems/ac]). The final stocking for sawlog production will be about 150–200 stems per ha (60–80 stems/ac). A suitable area for commercial production is ten or more hectares, but even small woodlot areas of about 1 ha (2.5 ac) could be grown on a commercial basis by groups of smallholders for supply to local sawmills.

Management objectives

The aim of management is to produce high-quality sawlogs within an economically feasible, attractive time frame, e.g., a rotation period of about 30 years. This will include use of selected genetic material, regular maintenance in early years including frequent weeding and removal of vines, and one or more thinnings to maintain balance of site control and concentrate wood increment on better formed stems. Pruning of lower whorls of branches, up to a height of 6–12 m (20–40 ft), may be required to produce better quality, less knotty sawlogs.

Advantages and disadvantages of growing in polycultures

Malili is expected to be highly compatible with production of durable poles of the smaller *Flueggea flexuosa*, which could be interplanted and cut at about 7–10 years. The commercial rotation length of malili is likely to be either more than some prospective timber species (e.g., *Endospermum medullosum*) or less than others (e.g., *Swietenia macrophylla*, *Syzygium inophylloides*, and *Pometia pinnata*). Accordingly, malili may not be especially compatible for growing with these species for commercial timber production.

Yields

There is no data available on growth rate over a projected rotation length of about 30 years. It is likely that good

Left: Eight-year-old plus trees at Masamasa, Savai'i, Samoa. Right: 27-year-old planted stand at Falelima, Savai'i, Samoa. PHOTOS: L. THOMSON

quality plantations grow at about 10–13 m^3/ha/yr (143–186 ft^3/ac/yr).

Market

Markets for planted malili timber are the local markets for general-purpose timbers, and vary considerably in volume. For example, in Samoa, malili plantings have the potential to replace imports of *Pinus* and declining local production from native forests of *Pometia* and other species.

INTERPLANTING/FARM APPLICATIONS

Malili is being planted in community agroforestry plantings in northern 'Upolu and western Savai'i in Samoa. The planting spacing is 8 m (26 ft) between rows and 4 m (13 ft) within rows. This allows intercropping for 3–4 years with traditional root crops including taro (*Colocasia esculenta*) and tamu (*Alocasia macrorrhiza*).

PUBLIC ASSISTANCE

See general extension links at:
http://www.traditionaltree.org/extension.html

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Species Profiles for Pacific Island Agroforestry (www.traditionaltree.org)

Terminalia richii (malili)

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Acknowledgments: The author and publisher thank Tito Alatimu, John Larmour, Tolusina Pouli, and Ken Robson for their input. Photo contributions by John Larmour are greatly appreciated.

Recommended citation: Thomson, L.A.J. 2006. *Terminalia richii* (malili), ver. 2.1. In: Elevitch, C.R. (ed.). Species Profiles for Pacific Island Agroforestry. Permanent Agriculture Resources (PAR), Hōlualoa, Hawai'i. <http://www.traditionaltree.org>.

Sponsors: Publication was made possible by generous support of the United States Department of Agriculture Western Region Sustainable Agriculture Research and Education (USDA-WSARE**)** Program; SPC/GTZ Pacific-German Regional Forestry Project; USDA Natural Resources Conservation Service (USDA NRCS); State of Hawai'i Department of Land & Natural Resources Division of Forestry & Wildlife; and the USDA Forest Service Forest Lands Enhancement Program. This material is based upon work supported by the Cooperative State Research, Education, and Extension Service, U.S. Department of Agriculture, and Agricultural Experiment Station, Utah State University, under Cooperative Agreement 2002-47001-01327.

Series editor: Craig R. Elevitch

Publisher: Permanent Agriculture Resources (PAR**)**, PO Box 428, Hōlualoa, Hawai'i 96725, USA; Tel: 808-324-4427; Fax: 808-324-4129; E-mail: par@agroforestry.net; Web: <http://www.agroforestry.net>. This institution is an equal opportunity provider.

April 2006
ver. 2.1

Thespesia populnea (milo)

Malvaceae (mallow family)

***badrirt* (Palau); *banalo* (Northern Marianas); *bang-beng* (Yap); *kilulo* (Guam); *mi'o* (Marquesas); *milo* (Hawai'i, Marshall Islands, Samoa, Tonga); *miro* (Pitcairn Island); *miro*, *'amae* (Rarotonga, Society Islands); *mulomulo* (Fiji); *panu* (Kosrae); *polo* (Chuuk); *pone* (Pohnpei); *purau* (Tahiti); portia tree, seaside mahoe, Pacific rosewood, Indian tulip tree, cork tree, umbrella tree (English)**

J. B. Friday and Dana Okano

PHOTO: J. B. FRIDAY

Milo tree on a beach in Lahaina, Maui, Hawai'i.

IN BRIEF

Distribution Coastal areas of the Indian and Pacific Oceans; throughout Oceania.

Size Small tree typically 6–10 m (20–33 ft) at maturity.

Habitat Tropical and warm subtropical, usually found at sea level to 150 m (500 ft).

Vegetation Associated with a wide range of coastal species.

Soils Thrives on sandy coastal soils as well as volcanic, limestone, and rocky soils.

Growth rate Moderate, 0.6–1 m/yr (2–3 ft/yr) for the first few years.

Main agroforestry uses Soil stabilization, windbreak.

Main uses Craftwood, ornamental.

Yields Heartwood in 30+ years.

Intercropping Compatible with many coastal species, although it requires full sun.

Invasive potential Has potential to become an invasive weed—should not be introduced into new areas.

INTRODUCTION

Milo (*Thespesia populnea*) is one of the most important trees to Pacific Island peoples. The rich, dark wood is carved into beautiful bowls, tools, small canoes, and figures. Ropes are twisted from the bark. The trees provide protection against wind, salt spray, and the hot sun. The seeds, leaves, and bark provide medicine and food. In ancient times the trees were planted around temple sites. Today the tree is more rare than in the past because of overharvesting in some areas and increased urbanization in others. The tree is easy to grow and should be considered for reforestation and urban forestry projects in the Pacific where suitable sites are available.

Milo is a small evergreen tree averaging 6–10 m (20–33 ft) in height, with a short, often crooked stem and a broad, dense crown. It has glossy green, heart-shaped leaves and yellow hibiscus-type flowers. The tree grows well along warm coastal areas from the east coast of Africa and South and Southeast Asia to Melanesia, Micronesia, and Polynesia. It is currently naturalized in tropical climates throughout the world from the Caribbean to Africa.

The tree is valuable as a coastal windbreak because it is highly resistant to wind and salt spray and grows well in sandy, saline soils. It propagates easily and grows rapidly. It naturalizes easily and has become a weed in some areas, so it should not be planted in areas where it is not already present. The tree grows best under full sunlight and tolerates drought conditions. The heartwood is resistant to drywood termites. Milo has many uses including coastal protection, animal fodder, windbreaks, and living fences. The most common use in the Pacific today is probably as an ornamental tree, despite its valuable timber.

DISTRIBUTION

Native range

Milo is native to coastal areas of the Indian and Pacific Oceans, from East Africa and India to mainland Southeast Asia, Indonesia, and the Philippines. In the Pacific it grows from Papua New Guinea and the northern coast of Australia through the Solomons, Vanuatu, and Fiji. In Micronesia milo grows in Guam and the Mariana Islands, the Gilbert Islands (Kiribati), and in Palau, Yap, Chuuk, Pohnpei, Kosrae, and the Marshalls. In Polynesia milo is found in Tonga, Samoa, Niue, the Cook Islands, Tahiti, the Society Islands, the Tuamotos, and the Marquesas (Mueller-Dombois and Fosberg 1998).

Current distribution

Milo has been planted throughout the tropics and is naturalized in tropical climates throughout the world from the Caribbean to Africa to the Pacific. The tree is believed to have been introduced to Hawai'i by early Polynesians, but it may be native to Hawai'i. It is documented on the Hawaiian islands of Ni'ihau, Kaua'i, O'ahu, Moloka'i, Maui, and Hawai'i (Wagner et al. 1999).

BOTANICAL DESCRIPTION

Preferred scientific name

Thespesia populnea (L.) Sol. ex Correa

Family

Malvaceae (mallow family)

Non-preferred scientific names

Hibiscus populneus L. (1753)
Thespesia macrophylla Blume (1825)
Hibiscus populneoides Roxb. (1832)

Common names

badrirt (Palau)
banalo (Northern Marianas)
bang-beng (Yap)
kilulo (Guam)
mi'o (Marquesas)
milo (Hawai'i, Marshall Islands, Samoa, Tonga)
miro (Pitcairn Island)
miro, *'amae* (Rarotonga, Society Islands)
mulomulo (Fiji)
panu (Kosrae)
polo (Chuuk)
pone (Pohnpei)
purau (Tahiti)
portia tree, seaside mahoe (a name also applied to *Hibiscus tiliaceus*), Pacific rosewood, Indian tulip tree, cork tree, umbrella tree (English)

Other common names

alamo, *alamo blanco*, *carana*, *clamour*, *duartiana*, *emajaguilla*, *higuillo*, *jaqueca*, *majaguilla*, *majugua de la Florida*, *palo de jaqueca* (Spanish)
baru laut, *salimuli*, *waru laut*, *waru lot* (Indonesian)
baru, *baru baru*, *baru laut*, *bebaru*, *buah keras laut* (Malay)
bhendi, *gajadanda*, *paras-pipal*, *parsipu*, *porush* (Hindi)
feuilles d'Haiti, *motel debou* (French)
large-leaved tulip tree (trade name)
pho-thale, *po kamat phrai* (Thai)


Left: Newly opened flower. Right: Leaves and older flower. PHOTOS: J. B. FRIDAY

Size and form

Milo has a short, straight or crooked trunk and a dense crown with crowded lower horizontal branches. Height averages 6–10 m (20–33 ft) with a crown as wide as or wider than the tree is tall. Average size trees have bole diameters of 20–30 cm (8–12 in), but exceptional trees have reached 18 m (60 ft) in height with boles 60 cm (24 in) in diameter. The bark is grey and smooth to highly fissured and dark brown in larger trees.

Flowers

Flowers are a typical hibiscus shape in appearance: bell-shaped, 4–7 cm (1.5–2.5 in) in length, with five overlapping, broad, rounded petals. Color is pale yellow with a maroon spot at the base of each petal and with star-shaped hairs on outer surface. Flower stalks are 1.3–5 cm (0.5–2 in). Flowers open and close on same day, and the yellow flowers turn dark red, purple, or pink as the day progresses.

Leaves

The alternate leaves are glossy green above and paler green below. Leaf blades are heart-shaped, 10–20 cm (4–8 in) long, and 6–13 cm (2.5–5 in) broad. Leaf stalks are long, 5–10 cm (2–4 in). Leaves in the lower crown turn yellow before falling to the ground.

Fruit

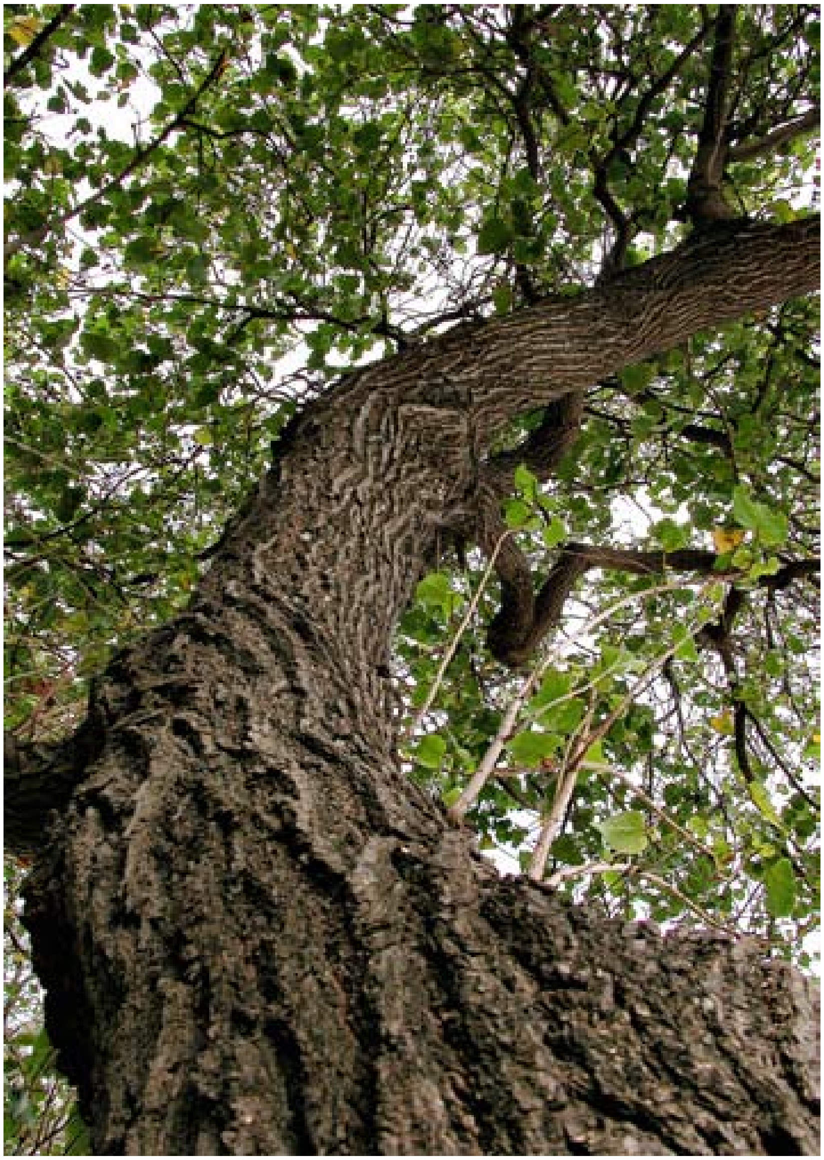
Milo fruits are brittle, dry, woody or papery seed capsules, rounded and flattened, containing five cells and several seeds. The brown or gray capsules, about 2.5–5 cm (1–2 in) in diameter and 2 cm (0.8 in) tall, grow on short stalks clustered at the ends of the branches. Mature fruits may usually be found on trees year-round.

Seeds

The brown, hairy seeds are about 1 cm (0.4 in) long and 0.6 cm (0.2 in) broad. Seeds are blown short distances by wind but are more likely to be dispersed by water. Both the lightweight fruits and seeds can float from one island to another on ocean currents. There are between 3500 and 6700 seeds/kg (1600–3045 seeds/lb) (Parotta 1994).

Similar or look-a-like species

There are 18 species of *Thespesia* throughout the tropics. *Thespesia populneodides* (Roxb.) Kosteletsky, a closely related species native to the Indian Ocean, may be distinguished by its dehiscent fruit, long pedicels, and coppery or bronzed leaves (Fosberg and Sachet 1972). Milo is often confused with the related *Hibiscus tiliaceus* (hau or seaside hibiscus). Milo may be distinguished from hau by its rounded and flattened dark brown seed capsules in upper crown. While both species have heart-shaped leaves, milo


Trunk of large tree showing common curved form. PHOTO: C. ELEVITCH

leaves are narrower than they are long, glossy, and smooth-edged, while hau leaves are often almost round and hairy on the underside, sometimes with wavy or toothed edges.

ASSOCIATED PLANT SPECIES

Milo is a tree of coastal regions of the tropical Indian and Pacific Oceans and is associated with a wide range of coastal species.

In native habitat

Milo occasionally is found in beach scrub forests along with small trees and shrubs such as hau (*Hibiscus tiliaceus*), naupaka (*Scaevola taccada*), beach heliotrope (*Tournefortia argentea*), pandanus (*Pandanus tectorius*), and noni (*Morinda citrifolia*). Milo more commonly grows in coastal high forests along with kou (*Cordia subcordata*), kamani (*Calophyllum inophyllum*), *Pisonia grandis*, Indian almond (*Terminalia catappa*), ironwood (*Casuarina* spp.), and *Barringtonia asiatica*. Native herbaceous plants commonly include *Canavalia,* beach morning glory (*Ipomoea pes-caprae*), and beach pea (*Vigna marina*) (Mueller-Dombois and Fosberg 1998). Milo may also be found at the edges of mangrove forests. It does not grow naturally in upland high forests.

As introduction to Pacific islands

In coastal areas milo may grow in mixed agroforests of breadfruit, coconut, pandanus, tamarind, noni, and mango. In Hawai‘i, milo trees are frequently found growing alongside several introduced coastal tree species, including ironwood (*Casuarina equisetifolia*), Indian almond (*Terminalia catappa*), and beach heliotrope (*Tournefortia argentea*).

ENVIRONMENTAL PREFERENCES AND TOLERANCES

Habitat

Milo is a tree of tropical and warm subtropical climates. It is purely a coastal species and is not found any great distance inland.

Elevation range

Sea level to 150 m (500 ft); in Hawai‘i it grows as high as 275 m (900 ft), although it is probably planted at higher elevations.

Mean annual rainfall

500–4000 mm (20–160 in). In very dry areas milo survives by tapping underground water.

Rainfall pattern

Grows in climates with summer, winter, or uniform rainfall patterns.

Dry season duration (consecutive months with <40 mm [1.6 in] rainfall)

Up to 8 months

Mean annual temperature
20–26°C (68–79°F)

Mean maximum temperature of hottest month
26–28°C (79–82°F)

Mean minimum temperature of coldest month
18–26°C (64–79°F)

Minimum temperature tolerated
2°C (36°F)

Soils

Milo thrives on sandy coastal soils, but also grows on volcanic soils, soils derived from limestone, and rocky headlands. It does not do well on upland, acidic clays.

Soil texture
It tolerates light to heavy soils (sands, sandy loams, loams, sandy clay loams, clays, clay loams, and sandy clays).

Soil drainage
The tree grows in freely draining soils and in coastal areas with occasional tidal inundation.

Soil acidity
Milo prefers neutral soils with pH 6.0–7.4.

Special soil tolerances
It tolerates saline soils.

Tolerances

Drought
Once established, milo has a deep taproot and can tolerate long periods of drought.

Full sun
Milo prefers full sun.

Shade
Seeds germinate in light shade but plants will not grow well.

Frost
Milo tolerates light frosts at the extremes of its range.

Waterlogging
Milo is occasionally found at the edges of mangrove

Milo tolerates heavy salt spray and periodic inundation with brackish water. PHOTO: C. ELEVITCH swamps and at the high tide line and will tolerate occasional inundation.

Salt spray

Milo is very tolerant of salt spray.

Wind

It tolerates steady coastal winds, although isolated trees may show some leaf loss and flagging in windy locations.

Abilities

Regenerate rapidly

Milo regenerates rapidly from seed and forms thickets.

Self-prune

Milo does not self-prune well, tending to develop crooked stems with stout, low branches that persist as part of the main structure of the tree.

Coppice

It regrows after pruning, although slowly.

Other

Milo is highly resistant to drywood termites.

GROWTH AND DEVELOPMENT

In suitable locations milo establishes well and grows rapidly. Mature trees are large and usually gnarled, and spreading rather than tall and stately.

Growth rate

Height growth is moderately fast, 0.6–1 m/yr (24–39 in/yr) for the first few years.

Flowering and fruiting

Milo flowers last only a day. In cooler areas, flowering occurs from early spring to late summer, whereas flowering is year-round in warmer climates. Flowering may begin in trees as young as 1–2 years old.

Yields

Milo has never been grown in a plantation system where yields of timber have been calculated. Trees may take 25–40 years to grow large enough to have enough heartwood for carving.

Rooting habit

Milo's shallow roots tend to spread on the surface, espe-

A thicket of milo naturally regenerating near a beach in Hilo, Hawai'i. PHOTO: J. B. FRIDAY cially in shallow, rocky, or occasionally flooded soils. In porous soils, milo will rapidly develop a long taproot to tap deep water sources.

Reaction to competition

Milo is an aggressive competitor in the sun but will not grow well in the understory of other trees.

PROPAGATION

Milo is generally propagated by seed, although it can also be propagated by stem and root cuttings and by air-layering. Seeds are usually plentiful and initial growth is fast, making milo a relatively easy tree to grow. Containers need to be deep enough to contain the vigorous taproot without allowing it to spiral.

Seed collection

Seeds may be collected at almost any time of year. The capsules stay on the trees for some time after ripening and may be hand-picked or knocked off trees with sticks or pruning hooks. Freshly fallen capsules may be picked up from the ground under trees. Only mature seed from dried capsules should be collected.

Seed characteristics

If capsules are not completely dry they may be sun-dried for a day or two. The brittle seed capsules may be crushed by hand and the seeds extracted. Larger batches may be crushed inside burlap bags and the seeds cleaned from the chaff by winnowing or blowing. Discard seeds with insect holes or that are soft when squeezed.

Seed storage

Seeds retain viability when dried and stored; such storage behavior is also known as "orthodox." There are 3500–6700 air-dried seeds per kilogram (1600–3000 seeds/lb). Seeds may be stored at room temperature in sealed containers for short periods of time. Refrigeration may prolong seed life, but as fresh seed us usually available, long-term seed storage is usually not necessary.

Pre-planting treatments

No seed pretreatment is required, but germination can be hastened by abrading the seed coat with sandpaper or nicking it with a sharp knife or nail clippers and soaking the seeds overnight in cool water. Care must be taken not to injure the seed embryo.

Green and dried seed capsules still on branch. PHOTO: J. B. FRIDAY

Dried seed capsules and seed. PHOTO: J. B. FRIDAY

Growing area

Milo should be grown in partial to full sunlight. Some cover is useful to protect the seedlings from hard rains right after germination.

Germination

Germination begins in 8 days and may extend to 10 weeks. Germination of fresh seed should be 65–80%. Seeds may be pre-germinated in moist towels and then transplanted into growing containers.

Left: Pregerminated seeds sprouting in growing containers. Right: Kim Wilkinson shows seedlings ready for outplanting. PHOTOS: C. ELEVITCH

Media

The potting medium must be well drained. A soilless potting mix of peat moss, cinder, perlite, or vermiculite is recommended. The medium should be amended with slow-release fertilizers or compost. Milo develops a long taproot, so pots must be large enough so that the roots do not circle the bottom of the container, at least 20 cm (8 in) deep. Root-training containers or copper-coated poly bags are preferred if available. Seeds should be planted about 5 mm (0.2 in) deep and covered with a thin layer of potting mixture. Containers can be topped with a thin layer of coarse sand to discourage weeds. Seedlings should be watered daily, although overwatering should be avoided. As seedlings develop they should be spaced wider to promote strong stem development, full leaf growth, and good air circulation.

Time to outplanting

Trees are ready to be outplanted when they reach 15–25 cm (6–10 in) in height, in about 12–16 weeks. Seedlings should be hardened off with reduced watering and exposure to full sunlight for 4–6 weeks before being outplanted.

Approximate size at time of outplanting

Seedlings ready for outplanting are approximately 40–50 cm (16–20 in) in height. Seedlings usually grow slowly for the first 6–10 weeks, then grow more rapidly.

Guidelines for outplanting

Seedlings need to be protected from drying out on the way to the planting site, which means protecting them from sunlight, wind, and heat. It is better to keep seedlings in their containers until planting. Refrigeration is not recommended. Weed control of planting sites is essential, and watering aids initial establishment.

Other comments on propagation

Bare-root seedlings may also be used. Wildlings are frequent along coastal areas, and these may be transplanted if they can be uprooted with little damage to the roots. Stump plantings have also been used, where bareroot or wild seedlings are uprooted and cut back to 1 cm (0.4 in) above the root collar before transplanting. This method allows the roots to recover before new leaves develop. Milo may also be propagated using branch or shoot cuttings, although propagation from seeds is preferred. Shoots or branch cuttings of up to 2 m (6.6 ft) length and 10 cm (4 in) diameter have been used (Parotta 1994), although smaller cuttings are preferred and produce healthier trees.

DISADVANTAGES

While the heartwood of milo is a prime carving wood, the trees usually are too small and crooked to produce much sawn lumber. Little is known about the growth rates and possible timber production from milo. Coastal areas in the Pacific where milo grows are being rapidly lost to urbanization, and the tree is becoming less common.

Potential for invasiveness

Milo has the potential to become an invasive weed and should not be introduced into areas where it is not already present. The tree has naturalized in Florida and the Caribbean, where it was introduced as an ornamental. In Florida it is considered a problem weed both in natural areas and in cultivated landscapes. The tree seeds prolifically, and seeds are easily dispersed by ocean currents. It grows in dense thickets that tend to exclude other plants but do not produce trees of a size that would make harvesting attractive. The tree has taken over beaches used by nesting sea turtles in the West Indies.

Diseases and pests

Milo is susceptible to fungal leaf spot (*Lophodermium* sp.) in Hawai'i and several other fungi and bacteria throughout the world. The tree is also susceptible to a fungal root and stem rot caused by *Phellinus noxius.* The fungus appears as diseased patches and a thick brown sheath around infected roots (Hanum and van der Maesen 1997). In India the fungus *Fomes pachyphloeus* causes heart rot.

Host to crop pests/pathogens

Milo is a host to several important pests of cotton, including the cotton stainer bug (*Dysdercus* sp.), the cotton boll weevil (*Anthonomus grandis*), *Pyroderces simplex*, and the Indian dusky cotton bug (*Oxycarenus laetus*). For this reason the tree has been eradicated from and outlawed in West Indian islands where cotton is an important crop.

Other disadvantages or design considerations

Growth is modest or poor on many sites. Milo is not adapted to inland areas or upland acid clay soils. The species has failed to survive or grow well in plantation trials in Hawai'i on deep, acid soil at 380 m (1250 ft) elevation with 2000 mm (80 in) rainfall at 'Ōpae'ula, O'ahu; on deep, acid soil with 2000 mm (80 in) rainfall at 150 m (500 ft) elevation at Maunawili, O'ahu; or on thin, acid soil derived from organic matter over 'a'ā lava rock at elevation 180 m (600 ft) and rainfall 4000 mm (160 in) at Waiākea, Hawai'i. All trials were fertilized and planted in single-species blocks.

Milo creates large amounts of litter both from fallen leaves and fallen seed capsules, which may detract from its use as an urban ornamental.

AGROFORESTRY/ ENVIRONMENTAL PRACTICES

Mulch/organic matter

Milo provides abundant leaf litter for use as mulch in sandy, coastal sites.

Soil stabilization

Milo anchors sandy coastal soils and protects them from erosion. The tree is used to stabilize bunds for ponds for prawn production (Hanum and van der Maesan 1997)

Homegardens

Since ancient times, milo has been planted around houses in the Pacific islands for shade and ornament.

Living fences

Milo has been used as a living fence post.

Windbreaks

Milo is an excellent windbreak in coastal areas due to its dense crown and tolerance of wind and salt spray.

Animal fodder

Leaves have been used as animal fodder.

Coastal protection

Milo tolerates droughty sandy soils, brackish water, waterlogging, wind, and salt spray, and so is an excellent species for coastal protection.

Ornamental

Milo provides dense shade and attractive leaves and flowers and so is a favored ornamental in tropical areas. It is a tough tree and can survive the poor drainage and hot, dry conditions common to urban areas.

Homegarden in Nukualofa, Tonga. PHOTO: C. ELEVITCH

USES AND PRODUCTS

Milo continues to be an important shade and ornamental tree in the Pacific. The wood is prized by craftspeople and carvers.

Leaf vegetable

The young leaves and green fruits are said to be edible as vegetables when cooked.

Medicinal

Milo has been used many ways in traditional medicines in Polynesia and South Asia. In Fiji, a decoction of the leaves has been used in treating coughs and headaches. In Samoa, an infusion of the bark has been used to treat intestinal diseases. In Tonga, a drink made from the leaves and bark is used to treat fevers in teething children. It should be kept in mind that traditional cures are rooted in specific cultures and will likely not be effective when taken out of context. Various parts of the plants have high tannin contents and plant extracts have been shown to have anti-bacterial and anti-viral activity.

Beautiful/fragrant flowers

The attractive yellow flowers add to milo's appeal as an ornamental tree.

Craft wood/tools

Milo has beautiful wood that has been used since ancient times for bowls, utensils, jewelry, furniture, carved figurines, and other craft items. The ancient Hawaiians favored milo for calabashes and poi bowls, along with kou (*Cordia subcordata*) and kamani (*Calophyllum inophyllum*). Unlike koa (*Acacia koa*) wood, the wood of milo does not impart a flavor to food. The heartwood is reddish brown to dark brown or black with light brown to cream-colored sapwood. The wood texture is fine, with a streaked or wavy figure and straight or wavy grain. The interlocked grain may produce a ribbon figure when the wood is quartersawn. The specific gravity is moderate to high, 0.44 to 0.89 (27.5–55.4 lb/ft^3) air-dried, averaging around 0.6 (37.4 lb/ft^3). The wood only shrinks slightly in drying. It is easy to work, polishes well, and is very durable. The wood contains an oil that adds to its luster but may affect the drying of oil-based finishes.

Canoe/boat/raft making

Large trees were made into small canoes in ancient times in Hawai'i, although koa (*Acacia koa*) was the preferred wood for canoe building (Abbott 1992). Milo's durable wood is also used for boat building in South Asia and elsewhere in the Pacific.

Free-form vase turned and carved from milo wood by Ralph Michaelis, Hawai'i. PHOTO: R. MICHAELIS

Rope/cordage/string

The outer bark may be used for rope and the inner bark for finer cordage, although it is inferior to hau (*Hibiscus tiliaceus*) for this purpose. The bark is also used for caulking.

Wrapping/parcelization

Milo leaves are used as food wrapping in West Africa.

Tannin/dye

In old Hawai'i, a dye made from the seed capsules yielded a yellowish green color (Krauss 1993). The wood may also produce a yellow dye used to dye wool in East and Southeast Asia, and the leaves are used to make a black dye for pandanus in Tuvalu (Clarke and Thaman 1993). The bark contains high levels of tannins and has been used for tanning leather.

Oil/lubricant

Lamp oil may be made from the seeds.

Ceremonial/religious

In the traditional religion of Tahiti the milo tree was associated with the god of prayer and chanting and was therefore planted around temples (Neal 1965). Branches were attached to canoe masts as a token of peace in Tahiti, and the leaves were used by priests in ceremonial offerings (Clarke and Thaman 1993).

WOOD PROPERTIES
(contributed by C. Barton Potter)

The wood of the milo tree is stable and attractive and has been fashioned into a wide variety of functional and decorative items in whatever country it grows. It is known to be a premier carving wood because, although dense, the wood can be cut to fine detail. So well known is milo wood that when a milo tree is cut, the wood seldom goes to waste. Unfortunately, like the black walnut on the mainland U.S., unprotected mature milo trees have been known to be illegally harvested for their wood.

Quality

Wood of young trees and young branches (under 20 years or so) tends to have a greater proportion of sapwood to heartwood. Wood from relatively younger trees and branches is less stable, less dense, less resistant to bugs, and, most would agree, less attractive than wood from mature trees. As the tree matures, the pale sapwood becomes clearly differentiated from the heartwood and accounts for an increasingly smaller proportion of the mass of the branch or bole. Wrist-sized branches in a mature tree may have a significant amount of heartwood, while thigh-sized branches in young trees may be devoid of heartwood. Thus, tree age is an asset that tends to improve the stability, durability, and character of milo.

Pith defect

Like many trees, milo grows rapidly when young. The wood generated in this fast growing phase is less dense and enduring than the wood that is continually added to the outside of the tree as it grows older. The weaker heartwood near the center is more prone to rotting than the heartwood that is generated from approximately 15 years of age onwards. For this reason, older milo trees and branches often have a hollow center surrounded by fine, high-quality wood. This higher quality heartwood is very resistant to termites and fungal growth.

Color

Heartwood in a freshly cut log is most often pale pink, occasionally with a black ring or two that offer a nice visual highlight. On rare occasions, the heartwood of the tree is dark reddish purple when fresh cut. As milo wood cures it takes on a dark color ranging from chocolate brown to black. Articles made from freshly cut wood eventually darken as the wood seasons.

Photoreactivity

Although the heartwood is dark, exterior surfaces of furniture and artwork made of milo lighten with constant exposure to the sun. While a coating of oil, shellac, lacquer or varnish will accentuate the color, milo is particularly photoreactive and has a tendency to bleach out much sooner than other woods when left in the sun. This bleaching is only as deep as the finish and the first layer of cells of the wood, but many woodworkers and their customers have been disappointed with the color change when an article was placed in a sunny location. Finishes applied to milo tend to prematurely yellow along with the wood if articles are placed in high sunlight areas. Addition of a UV blocking agent to the finish and keeping the finished piece away from direct sunlight will prolong the length of time that a milo piece will retain its dark color.

Fragrance

Wood of the mature milo tree has a pleasing but fleeting spicy smell. That is, the fragrance mostly disappears or is not at all evident in most finished pieces.

Allergenic properties

It is common for people working with milo wood over a period of years to develop progressive skin and mucous membrane sensitivity to the dust created in sanding the wood. Typical symptoms include runny nose, itchy eyes, shortness of breath, and skin irritation.

Storage and seasoning

Milo is a close-grained hardwood and does not dry quickly. End-sealing of fresh cut logs with one of several commercial water-based paraffin products will greatly inhibit end-checking and maximize the usable wood from the logs. It is generally best to cut lumber, bowls, or craft items out of logs while the log is still green, then dry the wood.

The contrast between the light colored sapwood and the darker heartwood is a pleasing feature regarded by some as a signature of milo in finished woodwork, and it may be desirable to preserve this contrast as much as possible. If left to lie on the ground, the sapwood of milo can start to discolor within a few weeks. If logs cannot be worked soon after cutting, they are best stored off the ground, out of the sun, and with good air circulation to preserve the sapwood color.

Gluing and finishing

Milo is known to experience glue joint failures and is thought to inhibit the setup of some finishes. Best gluing results are obtained on dry wood using urea formaldehyde glues and epoxies, whereas white glues and hide glues will not give reliable bonds.

MILO LORE

The name *Thespesia* is derived from the Greek word *thespesios*, which means divine. Milo was named by Daniel Solander, a member of Captain Cook's expedition, who found it planted around temples in Tahiti.

A Hawaiian saying is

He milo ka lā'au, milmilo ke aloha.

Milo is the plant; love goes round and round.
(This was chanted by a kahuna, a traditional priest, in casting love spells.) (Pukui 1983)

A line from the *Kumulipo*, the Hawaiian creation chant, goes:

Born is the Laumilo eel living in the sea
Guarded by the Milo tree living on the land.

URBAN AND COMMUNITY FORESTRY

Milo is a medium-sized coastal tree with a dense, round crown of glossy, dark green leaves and yellow hibiscus-like flowers. It is native to the South Pacific and the Indian Ocean and was brought to Hawai'i by the early Polynesian voyagers. Ancient Hawaiians prized the dark red heartwood for making calabashes, and it is still prized by bowl turners today. Leaves, flowers, and bark have been used medicinally in South Asia and the Pacific. Milo is seen as a sacred tree in some Pacific island cultures. A popular modern ornamental and urban forestry tree, milo tolerates salt and wind very well and may be planted right down to the waterside.

Milo is one of the "canoe plants" brought to Hawai'i by the first Polynesian voyagers and grown around temples and dwelling places. Growing milo in urban and community landscapes creates a link to past island traditions.

Size in an urban environment

Open-grown trees in urban settings usually reach 10–12 m (33–40 ft) in height with a canopy spread as wide as the tree is tall. However, with its modest growth rate, it would take several decades to reach its maximum height. When the trees are grown in the open, the canopy spread can be greater than the height.

Rate of growth in a landscape

Young milo trees in landscape settings grow about 0.5–1.5 m/yr (1.6–5 ft/yr) for the first few years in both height and canopy spread. At an age of 7–10 years, growth in height slows considerably. Stem diameter growth ranges from 1 to 3 cm/yr (0.4–1.2 in/yr).

Root system

In urban forestry settings, milo has a non-aggressive root system. When planted on shallow, rocky, or occasionally flooded soils, milo trees have shallow, spreading roots. While these help the trees to survive in harsh planting conditions, they may interfere with other landscaping.

Products commonly used in a Pacific island household

Milo's dark red, glossy wood is prized for carving, fine woodworking, and bowl turning. In traditional Pacific island cultures, the leaves, flowers, and bark are used medicinally.

Light requirements

Milo grows best in full sun and casts a dense shade.

Water/soil requirements

Since milo is adapted to grow in coastal environments, it tolerates shallow, rocky, and sandy soils as well as soils that are occasionally flooded. The tree is often found growing right down to the shoreline. Unlike a mangrove, however, it will not grow in constantly standing water.

Life span

Ancient trees up to 60 cm (2 ft) in diameter exist and must be many decades old.

Varieties favored for use in homegardens or public areas

There are no selected varieties of milo.

Seasonality of leaf flush, flowering, fruiting

Milo flowers year-round. Usually flowers and green and brown (ripe, dried) fruits can be seen on a single tree.

Exceptional ornamental values

The showy yellow hibiscus-like flowers last only a day. The tree's main attraction is the heart-shaped, glossy, dark green foliage and dark brown, fissured bark.

Use as living fence, hedge or visual/noise barrier

Milo makes a good windbreak and visual barrier, especially in coastal areas. The tree forms a dense canopy, even in areas prone to salt spray. Thickets of seedlings will spring up under mature trees, which may be desirable if a hedge

Left: Trees seed prolifically and drop large numbers of the dry seed capsules. Streets and sidewalks under milo trees may need to be cleaned frequently. Right: When planted on rocky soils, milo trees have shallow, spreading roots. PHOTOS: J. B. FRIDAY

is needed but may be a nuisance under ornamental trees. A dense milo hedge makes an excellent high-surf barrier between homes and the ocean.

Maintenance requirements

Although small seedlings grown in dibble tubes are best for forestry or agroforestry plantings, relatively large milo trees grown in pots can be used in landscape settings if larger trees are desired right away. Trees up to 3.5 m (12 ft) have transplanted well from containers. Holes should be dug twice as wide as the root ball but no deeper. When planting larger seedlings grown in pots or plastic bags, it is important to loosen and straighten or cut any roots that have begun circling the bottom of the container. Use of specialized tree-growing pots will lessen the problem of pot-bound seedlings. Application of a complete fertilizer or compost can aid establishment and boost initial growth.

Milo tolerates heavy pruning, and trees will grow back even if topped or pollarded. Topping weakens trees, however, and branches on topped trees will never be as strong as the original branches. It is better to plant the trees where they can grow to their full size and then prune for form. Pollarding is a specialized style of pruning. Rather than topping a tree by cutting off large branches, arborists establish a tree's size and framework early on by cutting back young growth. New growth is subsequently cut back to the same point and eventually large "pollard heads" of woundwood are established at the branch ends. Pollarded trees require more frequent attention than topped trees but are more attractive and healthier (Shigo 1989).

Milo tends to be multiple-stemmed, and if a shade or ornamental tree is desired, the tree needs to be pruned back to a single stem. Milo will usually not grow tall enough to yield lumber without careful pruning, and even then only short sections will be potential timber because of the irregular shape of the trunk.

Milo trees grown in dry areas, as with any trees, would benefit from application of mulch and initial watering. Mulch around seedlings helps retain moisture in dry areas and keeps down weeds. The mulch should be kept well away from the trunk to avoid rotting. Once established, the trees are relatively drought tolerant.

Nuisance issues

Milo can be considered a "messy" tree and drops its dry seed capsules year-round. Milo is a prolific seeder, and a carpet of seedlings may spring up under mature trees. This may be a problem if the seedlings need to be weeded out of a ground cover. Milo wood is valuable enough that trunks of large old trees may be poached for the timber.

Hazards

None.

Common pest problems

Milo has few pest problems, and these can usually be managed by maintaining good tree health.

COMMERCIAL PRODUCTS

In Hawai'i the wood is mainly used today for bowls and other craft items. Wood turners create attractive patterns in their creations by including some of the lighter colored sapwood to contrast with the darker colored hardwood. In the Cook Islands, milo is used for carvings of traditional religious figures and decorative but useful items such as small stools. These items are sold to visitors and provide a livelihood for a few carvers and a link to the islands' culture and its past. Islanders from Pitcairn Island, having depleted local forests of milo, sail to Henderson Island once a year obtain milo and kou (*Cordia subcordata*) for carving to earn income.

Spacing for commercial production

Milo is more often grown as an ornamental tree or as a windbreak tree than for timber, and wood production tends to be incidental to the tree's other uses. When planted as a windbreak, milo should be combined with a taller, thinner-canopied tree such as *Casuarina*. The wood is valuable enough that single trees are harvested.

Management objectives

Weeding is essential until the trees become established. Watering improves survival in droughty locations. Milo is naturally very branchy, and trees should be pruned to help develop clear boles for timber production.

Poor form and slow growth make milo a questionable investment solely for timber. Careful pruning can increase yields of usable timber and thereby the economic prospects. PHOTOS: C. ELEVITCH

Advantages and disadvantages of polyculture

Milo naturally occurs as part of a mixed-species stand. It does not tolerate shading and should not be grown with other trees that will overtop and shade it.

Yield

While no numbers on an economic rotation for milo are available, trees will likely take 25–40 years before attaining a size large enough to produce usable timber. Only the heartwood is valuable, although sometimes small amounts of sapwood are included in turned or carved pieces for decorative effect.

Market

Milo lumber is cut to short lengths (60–120 cm or 2–4 ft) and narrower than usual because of the small size of the logs. Lumber in Hawai'i retails for about US$15–20 per board foot. Bowl stock, short sections of logs used for wood turning, is sold per lineal foot, with 20 cm (8 in) diameter stock selling for $48/ft, 25 cm (10 in) diameter stock selling for $84/ft, and 45 cm (18 in) diameter stock selling for $336/ft. Board foot equivalents for bowl stock work out to $25–30/bf.

INTERPLANTING/FARM APPLICATIONS

Example system 1

Location

Kīpū, Kaua'i, Hawai'i.

Description

A new plantation was established on private land in 1998 on deep, acid, clay soils (Typic Umbriorthox, USDA classification); elevation 125 m (415 ft); windy; average annual rainfall 1100 mm (43 in); temperature range 18°C to 30°C (65°F to 86°F). Trees were weeded as needed and given initial fertilization for the first 3 years.

Yields

Milo trees grew an average of 3.7 m (12.1 ft) in height and 3.0 cm (1.2 in) diameter in 4.5 years, with the tallest tree reaching 4.4 m (14.5 ft) in height and 5.3 cm (2.1 in) diameter at breast height. All 24 trees planted in the trial survived, but growth and form were only rated fair.

Crop/tree interactions

Trees were planted in a single-species stand adjacent to stands of kou (*Cordia subcordata*), kamani (*Calophyllum inophyllum*), and bamboo (*Bambusa arundinacea*).

Spacing

Trees were planted in a double row at 1.8 x 3.4 m spacing (6 x 11 ft).

Example system 2

Location

Moloka'i, Hawai'i

Description

An alley cropping demonstration was planted by the University of Hawai'i on former agricultural land on the island of Moloka'i in 1995 with milo, kamani (*Calophyllum inophyllum*), kou (*Cordia subcordata*), and kukui (*Aleurites moluccana*). The site is dry and windy, with only 460–530 mm (18–21 in) of rainfall annually, and is 150 m (500 ft) above sea level. The trees receive supplemental irrigation. The soil is classed as a Typic Torrox in the USDA classification, pH 6.5. Alfalfa for forage was grown among the trees until the canopies closed; after that, a number of shade-tolerant crops were planted, including ornamental ginger, edible mushrooms, kava, and cacao.

Yields

Tree growth was satisfactory; milo trees averaged 7.2 m (24 ft) in height with the tallest growing 8.7 m (29 ft) in 7 years. The constant high winds have caused the trees to lean over, however, and the effect of the stress on wood quality is unknown. Crop production is less than would be expected in full sun but nonetheless significant.

Crop/tree interactions

Crop yield, even for the shade-tolerant crops (except for the edible mushrooms), is reduced because of shading. However, the trees also serve as windbreaks, without which fragile crops such as kava would not grow at all. The crops receive supplemental irrigation, which also benefits the trees.

Spacing

The trees were planted in wide rows 4.5 m (15 ft) apart with 3 m (10 ft) spacing within the rows.

Example system 3

Location

Wai'anae, O'ahu, Hawai'i.

Description

This site was established in the 1960s as part of a program by the U.S. Forest Service to select trees for reforestation in Hawai'i. The site is dry, with average annual rainfall

Seven-year-old milo trees in an alley cropping system on Moloka'i, Hawai'i, with ornamental gingers grown as an understory crop. Note leaning caused by persistent trade winds. PHOTO: J. B. FRIDAY

700 mm (28 in) with prolonged summer dry periods, on a slightly acid to neutral clay soil (Lualualei series, Typic Chromustert, USDA classification). The site was 8 km (5 mi) east of the coast at an elevation of 177 m (580 ft).

Yields

Survival at 5.6 years was 93%; heights ranged from 1.85 to 4.3 m (6–14 ft) with an average height growth of 60 cm/yr (2 ft/yr).

Crop/tree interactions

The milo was part of a multiple-species trial that included 16 other species. The fastest growing trees in the trial were *Eucalyptus camaldulensis* and *Phytolacca dioica*. Milo did not survive in another trial in the same area but at a lower elevation (75 m [250 ft]) and rainfall (500 mm [28 in]).

Spacing

Trees were planted at a 1.5 x 2.4 m (5 x 8 ft) spacing and weeded as needed but not fertilized or watered.

PUBLIC ASSISTANCE AND AGROFORESTRY EXTENSION

Milo has been identified as a priority species for further genetic research and conservation by the South Pacific Regional Initiative on Forest Genetic Resources (SPRIG).

Extension offices for agroforestry and forestry in the Pacific: http://www.traditionaltree.org/extension.html.

INTERNET

A description of the use of milo in old Hawai'i: <http://www.canoeplants.com>.

For a detailed description of milo propagation, see the Native Plants Network: <http://www.nativeplantnetwork.org>.

For photographs and overall information on milo, see the National Tropical Botanical Garden, Hawai'i: <http://www.ntbg.org/pwr/tree/>.

For a general article on milo, see Australian Native Hibiscus: <http://www.hibiscus.org/species/tpopulnea.php>.

For information on milo as an invasive species in new areas, see Identification and Biology of Non-Native Plants in Florida's Natural Areas, University of Florida: <http://www.fleppc.org/pdf/Thespesia%20polpunea.pdf>.

Examples of wood carving using milo in the Cook Islands: <http://www.atiutourism.com/carving.htm>.

Propagation tips: <http://www2.hawaii.edu/~eherring/hawnprop/the-popu.htm>.

University of Hawaii College of Tropical Agriculture and Human Resources Landscape Series <http://www.ctahr.hawaii.edu/freepubs>.

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Traditional Tree Initiative—Species Profiles for Pacific Island Agroforestry (www.traditionaltree.org)

Thespesia populnea (milo)

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Acknowledgments: The authors and publisher thank Dale Evans, John Francis, Ron Peyton, Bart Potter, Diane Ragone, and Roger Skolmen for their input. The authors thank Rogerene Arce and John Edson for sharing growth data and Craig Elevitch for supplying photographs and for editorial assistance.

Recommended citation: Friday, J.B., and D. Okano. 2006. *Thespesia populnea* (milo), ver. 2.1. In: Elevitch, C.R. (ed.). Species Profiles for Pacific Island Agroforestry. Permanent Agriculture Resources (PAR), Hōlualoa, Hawai'i. <http://www.traditionaltree.org>.

Sponsors: Publication was made possible by generous support of the United States Department of Agriculture Western Region Sustainable Agriculture Research and Education (USDA-WSARE) Program; SPC/GTZ Pacific-German Regional Forestry Project; USDA Natural Resources Conservation Service (USDA NRCS); Kaulunani, an Urban Forestry Program of the DLNR Division of Forestry and Wildlife and the USDA Forest Service; State of Hawai'i Department of Land & Natural Resources Division of Forestry & Wildlife; USDA Forest Service Forest Lands Enhancement Program; and Muriel and Kent Lighter. This material is based upon work supported by the Cooperative State Research, Education, and Extension Service, U.S. Department of Agriculture, and Agricultural Experiment Station, Utah State University, under Cooperative Agreement 2002-47001-01327.

Series editor: Craig R. Elevitch

Publisher: Permanent Agriculture Resources (PAR), PO Box 428, Hōlualoa, Hawai'i 96725, USA; Tel: 808-324-4427; Fax: 808-324-4129; E-mail: par@agroforestry.net; Web: <http://www.agroforestry.net>. This institution is an equal opportunity provider.

April 2006
ver. 3.1

Tournefortia argentea (tree heliotrope)

Boraginaceae (borage family)

amoloset **(Chuuk, Losap, Etal);** ***chen*** **(Yap);** ***evu*****,** ***roronibebe*** **(Fiji);** ***hunig*****,** ***hunek*****,** ***hunik*** **(Mariana Islands);** ***irin*** **(Nauru);** ***kiden*** **(Marshall Islands);** ***sesen*** **(Pingelap);** ***sruhsruh*** **(Kosrae);** ***tahinu*** **(Society Islands);** ***tai'inu*****,** ***tau'unu*** **(Cook Islands);** ***taihuni*** **(Niue);** ***tauhunu*** **('Uvea, Tokelau, Tuvalu);** ***tausuni*** **(Samoa);** ***tchel*** **(Carolinian in Mariana Islands);** ***te re*** **(Onotoa);** ***te ren*** **(Kiribati);** ***titin*** **(Pohnpei);** ***touhuni*** **(Tonga); tree heliotrope, beach heliotrope, velvet leaf soldierbush (English);** ***yamolehat*** **(Puluwat)**

Harley I. Manner and Craig R. Elevitch

Tree heliotrope is a wonderful tree for public places in coastal areas.

IN BRIEF

Distribution Common throughout Polynesia, Micronesia, and Melanesia; also present throughout the Indian Ocean region.

Size Typically reaches 6 m (20 ft), with similar crown diameter.

Habitat Restricted to coastal environments, 0–15 m (0–50 ft) elevation with rainfall of 300–5000 mm (12–200 in).

Vegetation Associated with strand plants.

Soils Prefers light and medium texture soils; tolerates shallow, saline, and infertile soils.

Growth rate Slow growing, <0.75 m/yr (30 in/yr).

Main agroforestry uses Screen against salt spray, coastal soil stabilization, homegardens.

Main products Medicinal, fuelwood.

Yields No data available.

Intercropping Rarely used in farm cultivation.

Invasive potential Moderate; has naturalized where introduced by people, such as Hawai'i. Rarely considered a pest.

INTRODUCTION

Tree heliotrope is native throughout the Indo-Pacific region, except Hawai'i, where it has been introduced in modern times. Where the tree is native, it is very important in traditional cultures of the Pacific islands. The species is also important for its ecological benefits, particularly as a barrier to salt spray, a windbreak on exposed coasts, and for its presumed role in coastal stabilization. It is capable of growing near the ocean in saline conditions and in nutrient-poor sands and rocky soils.

Tree heliotrope plays a significant role in the handicrafts, tools, canoe building, traditional medicine, and rituals of atoll island cultures. Unfortunately, it is not readily recognized by institutional agroforestry because it doesn't have nitrogen-fixing capabilities, grows slowly, and has limited use as a timber species. Little research has been conducted on this species in terms of its productivity, life cycle characteristics, and its potential as an agroforestry species.

This species is a strand plant; that is, it is restricted to coastal environments. Although rarely considered a pest, it has potential for invasiveness when introduced to new coastal environments. On some islands, the plant is endangered because of its use as a readily available fuelwood.

DISTRIBUTION

Native range

Tree heliotrope is an Indo-Pacific strand plant of sandy or rocky coasts, often found near to the water's edge. It is native to tropical Asia, Madagascar, tropical Australia, Malesia, Micronesia, and Polynesia (excluding Hawai'i).

Current distribution

Indigenous to most islands of the Pacific except Hawai'i where it has become naturalized and common after modern introduction. Rare in peninsular Malaysia and Singapore Island.

BOTANICAL DESCRIPTION

Preferred scientific name
Tournefortia argentea L. f.

Family Boraginaceae, borage family

Non-preferred scientific names

Argusia argentea (L. f.) Heine
Messerschmidia argentea (L. f.) I. M. Johnst.
Tournefortia arborea Blanco
Tournefortia sarmentosa sensu Christian non Lam.
Tournefortia sericea Cham.

Common names

amoloset (Chuuk, Losap, Etal)
chen (Yap)
evu, *roronibebe* (Fiji)
hunig, *hunek*, *hunik* (Mariana Islands)
irin (Nauru)
kiden (Marshall Islands)
sesen (Pingelap)
sruhsruh (Kosrae)
tahinu (Society Islands)
tai'inu, *tau'unu* (Cook Islands)
taihuni (Niue)
tauhunu ('Uvea, Tokelau, Tuvalu)
tausuni (Samoa)
tchel (Carolinian in Mariana Islands)
te re (Onotoa)
te ren (Kiribati)
titin (Pohnpei)
touhuni (Tonga)
tree heliotrope, beach heliotrope, velvet leaf soldierbush (English)
yamolehat (Puluwat)

Tree heliotrope (foreground) and *Thespesia populnea* (background) growing at water's edge at Pago Bay, Guam, indicating the trees' tolerance of saltwater. PHOTO: H. MANNER

Left: An inflorescence at the end of its flowering cycle, with fruits forming on the interior where the first flowers opened and the remaining flowers opening on the apical portions. Note a medium-size praying mantis at the lower right of the inflorescence for scale. Right: Bark is light gray or brown and deeply corrugated. PHOTOS: C. ELEVITCH

Size and form

This small to medium size, spreading tree typically grows to 6 m (20 ft). The canopy diameter is generally about 1.5 times the height. In Nauru, a size range of 2 to 12 m (6.6 to 39 ft) in height is reported.

Flowers

The inflorescence is pubescent and conspicuous, composed of numerous, small, white, sessile flowers arranged in multi-branched, terminal, paniculate or scorpeoid cymes. Its individual flowers are 6 mm (0.24 in) in diameter and 2 mm (0.08 in) in height. Both calyx and corolla are five-lobed. The tree begins flowering in several years when grown from seed. In most areas, its flowers bloom nearly continuously throughout the year. On Midway, it is reported to flower and seed from May through November (USFWS 2000).

Leaves

A conspicuous feature of tree heliotrope is its light green, silky, pubescent leaves, which have a silvery gray sheen. The slightly fleshy, obovate to oblanceolate leaves are simple, alternate, and whorled (spiraled) at the branch tips, 10 to 30 cm (4–12 in) in length, and 3 to 12 cm (1.2–4.8 in) in width.

Fruit

The smooth fruit is greenish white to brown globose, 5–8 mm (0.2–0.3 in) long (pea sized), and minutely apiculate, ultimately dividing into two to four pale nutlets. The nutlets turn light brown when dry. Two to four seeds are enclosed in a corky tissue.

Bark

The bark is light brown or gray and deeply corrugated.

Roots

Tree heliotrope has very strong vertical and lateral roots that anchor it even in the harshest coastal conditions.

Similar species

Its distinctive leaves and inflorescences make it difficult for it to be mistaken for any other species in its range.

GENETICS

The variability of tree heliotrope has not been studied. Also, no varieties have been distinguished for this wide-ranging species.

ASSOCIATED PLANT SPECIES

This species can be found as a solitary individual or as part of a strand community. In the drier northern Marshall Islands atolls, it forms a monodominant forest.

Associated native species

Tree heliotrope often forms the seaward fringe of vegetation. Associates in the strand include naupaka (*Scaevola taccada*), beach hibiscus (*Hibiscus tiliaceus*), milo (*Thespesia populnea*, portia tree), *Ipomoea pes caprae*, and *Vigna marina*.

In dry regions of the Marshall Islands, open stands of tree heliotrope are underlain by a herb layer of *Lepturus repens*, *Sida fallax*, *Portulaca* spp., and *Fimbristylis cymosa* (Mueller-Dombois and Fosberg 1998).

In Guam, this species is found on limestone slopes in association with *Pemphis acidula* and *Bikkia tetandra*.

In Kure, "a *Tournefortia* forest has developed, often reaching heights in excess of 18 feet [5.5 m] tall. *Tournefortia* generally grows between the coast and the band of naupaka ringing the island, often being the closest plant to the ocean" (Starr et al. 2001).

Young tree heliotrope leaves showing whorled arrangement and the silky white pubescence on the underside. PHOTO: H. MANNER

ENVIRONMENTAL PREFERENCES AND TOLERANCES

Climate

Tree heliotrope grows in equatorial to subtropical maritime climates of the Indian and Pacific oceans.

Elevation range

1–15 m (3.3–50 ft)

Mean annual rainfall

300–5000 mm (12–200 in)

Rainfall pattern

Grows in climates with summer, winter, bimodal, and uniform rainfall patterns.

Dry season duration (consecutive months with <40 mm [1.6 in] rainfall)

4 months, seems to be tolerant of drought conditions

Mean annual temperature

23–29°C (73–84°F)

Mean maximum temperature of hottest month

26–32°C (79–90°F)

Mean minimum temperature of coldest month

20–26°C (68–79°F)

Minimum temperature tolerated

18°C (64°F) (estimate)

Soils

This species is commonly found on sandy beaches and rocky coral limestone slopes where soils are very thin. These soils are typically shallow, well drained, and of low fertility (deficient in iron, nitrogen, potassium, and trace elements). Most of the exchange capacity of these soils is found in the soil organic matter, which is often low. The soils are mainly Lithosols and Inceptisols.

Soil texture

It prefers light- and medium-texture soils (sands, sandy loams, loams, and sandy clay loams).

Soil drainage

It requires free drainage.

Soil acidity

Neutral soils (pH 6.1–7.4)

Special soil tolerances

Tree heliotrope tolerates shallow, saline, and infertile soils.

This example of an ocean-battered tree in Kona, Hawai'i is growing on nearly bare lava where the sand has apparently been washed away from under it over the years. PHOTO: C. ELEVITCH

Salt spray

The tree is tolerant of salt spray and is often covered with luxuriant foliage even on windward coasts.

Wind

It is commonly found where winds are steady and strong.

Other

It can grow very close to the ocean, even where occasional waves wash over its root system or batter the lower trunk and roots.

GROWTH AND DEVELOPMENT

There is little direct information on the growth and development of tree heliotrope. The tree is relatively slow growing, with an estimated growth rate of less than 0.75 m (2.5 ft) per year.

Tolerances

Drought

This species is tolerant of drought, as it is present on many drought-prone islands.

Full sun

It is tolerant of more than full sunlight, because the strand environments it inhabits includes strong reflections from the sand and ocean.

Shade

No information.

Fire

No information.

Frost

It is not likely to tolerate frost.

Waterlogging

In all probability, this species is not tolerant of waterlogging, as it is not found in swamps. While it grows close to the ocean where the water table is often less than 1–2 m (3.3–6.6 ft) below the surface, in coastal locations there seems to be sufficient root aeration associated with tidal fluctuations and the porous nature of sandy soils.

PROPAGATION

Tree heliotrope is easy to propagate by seeds, cuttings, or air-layering.

Seedlings

Seed collection

Mature seeds are available most of the year. Collect ripe fruits from the tree. Seeds are mature when the fruit turns translucent and becomes soft.

Seed processing

Remove the fleshy outer part of the fruit by rubbing them together under water. Then air-dry the seeds or plant them directly. The seeds are enclosed in a corky tissue that turns from white to brown with exposure to air.

Seed storage

Seed storage characteristics are unknown. However, because the seeds float and are dispersed by ocean water, it seems likely the seeds will live at least a few weeks in storage if kept cool.

Germination

No seed pretreatment is necessary. The seeds can be sown directly in containers 6 mm (0.25 in) deep or pre-germinated in trays. Germination takes 2–4 weeks. Seedlings can be grown in full sun or partial shade.

Ripe fruits (left) and dried seed nutlets (right). PHOTO: C. ELEVITCH

A caterpillar feeding on the flowers. PHOTO: H. MANNER

Media

A standard well drained potting medium is acceptable. Since the tree is often planted in sandy coastal environments, it may be advantageous to use some sand in the planting mix, thereby acclimatizing the tree to field conditions.

Time to outplanting

Tree heliotrope seedlings grow slowly and take 12 months or longer to reach an acceptable size for outplanting. The size at outplanting should be about 35 cm (14 in) tall, with a woody stem 10 mm (0.4 in) in diameter at the base.

Guidelines for outplanting

Due to the slow growth, seedlings should be well marked with flagging or otherwise protected from foot traffic, maintenance, etc.

Vegetative propagation

Tree heliotrope can also be propagated by standard cutting or air-layering methods. Cuttings of 15–30 cm (6–12 in) of hardened or green wood can be used, although green wood is more susceptible to rotting. Cuttings root in 3–6 weeks. Both cuttings and air-layers begin flowering within 1–2 years.

DISADVANTAGES

Scant information is available on this very useful species. Its slow growth is a drawback that hinders its use in soil stabilization in coastal regions.

Potential for invasiveness

Although listed as a weed by some sources (e.g., HEAR 2004), there is little information to suggest that this species has a high potential for invasiveness. However, it has been introduced into Hawai'i and the northwestern Hawaiian Islands (Kure, Midway, Pearl and Hermes Reef, Lisianski and Laysan Islands, and the French Frigate Shoals), where it has become naturalized and is now relatively common. Merlin et al. (1994) states that this plant is an early colonizer of hot, salty, windswept coastal environments and is succeeded by larger, slower growing trees.

In various parts of the Indo-Pacific, this species is often threatened because its wood is used for firewood for beach barbecues.

Pests and diseases

Tree heliotrope is relatively free of pests and diseases. It is, however, subject to infestation by heliotrope moth larvae. Root rot is also a problem if the soil is too wet.

AGROFORESTRY/ENVIRONMENTAL PRACTICES

Ecologically, tree heliotrope is a very important tree species in many islands of the Pacific. The tree serves as a nesting site for some ocean birds and is a valuable species in coastal protection and as a salt spray barrier.

Mulch/organic matter

Leaves are considered an important mulch on atoll islands (e.g., Kiribati).

Soil stabilization

While there is little data on this species regarding its functions, the fact that this is a pioneer species in nutrient-depleted coastal environments suggests that it may play an

A large tree in a homegarden in Tongatapu, Tonga. PHOTO: C. ELEVITCH

important role in soil stabilization.

Homegardens

It makes a good shade tree in coastal-area homegardens.

Windbreaks

As a salt-spray tolerant species, it is an important wind and salt spray barrier.

Animal fodder

The leaves are an important pig food in Tokelau and Micronesia (Nauru) (Thaman 1993).

Wildlife habitat

On Midway Island, this species serves as a nesting site for the red-footed booby (*Sula sula*) and the great frigate bird (*Fregata minor*) (USFWS 2000).

Bee forage

Flowering nearly continuously throughout the year, tree heliotrope is a good source of bee forage. The flowers also attract numerous butterflies, which inspired the Samoan name for the plant, moega pepe, "bed for butterflies."

Fish/marine food chain

The leaves are used as fish bait in Tokelau (Thaman 1993).

Coastal protection

It has excellent potential for shoreline stabilization and wind protection.

USES AND PRODUCTS

Tree heliotrope figures prominently in the cultural ecology and ritual of many atoll islanders. The leaves are often eaten as a vegetable and used as pig fodder. The wood is used in house construction, canoe parts, and handicraft items, knife and other tool handles, frames for diving goggles, gongs, and canoe bailers.

The leaves are widely used in traditional medicine and rituals, from curing childrens' rashes, diarrhea, and fish poisoning (in Nauru) to medicinal teas, steam baths, and to stop bleeding and cover bruises, to name a few. The leaves are also used to cure diseases caused by the violation of sea taboos.

Nut/seed

As a toy, the nutlets are used as "peas" in peashooters (such as hollow papaya petioles).

Leaf vegetable

Eaten as a raw "salad" by fishermen in Kiribati (Thaman 1993). In India, the leaves are also eaten raw because of their flavor, which is said to resemble parsley.

Other vegetable

Leaves are stuffed into cooking pigs in Tokelau as a spice (Thaman 1993).

Medicinal

Throughout the Pacific islands, tree heliotrope is highly valued for its medicinal properties. In Nauru, the meristem and root inner bark are pounded to prepare medicine for curing children's rashes, diarrhea, and fish poisoning (Thaman et al. 1994). In the Marshall Islands, the leaves “are used to make a medicinal tea, in steam baths, to stop bleeding, and to cover bruises” (Merlin et al. 1994).

In Kosrae, leaves are used in a medicinal steam bath as a restorative after a women gives birth (Merlin et al. 1993). The soft inner part of the bark from the “snake-shaped” roots is mixed with coconut meat and used to treat hemorrhoids (wuno in komajmaj) (Merlin et al. 1994).

In Tonga, an infusion of the leaves is taken internally to treat poisoning caused by eating tainted fish. This infusion or leaf juice is also applied to infected cuts and stings from certain poison fish (Whistler 1992b).

In Fiji, a remedy containing root extract is taken to treat rheumatism. Other plant parts are reputedly used to treat weakness following childbirth (Smith 1991).

These trees shade public tables along the shoreline in Nukualofa, Tonga (top) and Kona, Hawai‘i (bottom). PHOTOS: C. ELEVITCH

Timber

In Namoluk Atoll, Chuuk the timber is sometimes used for house posts (Merlin and Juvik 1996). In Kosrae the timber is used as a building material.

Fuelwood

The wood is burned for fuel throughout the Pacific. It is a very handy wood at beaches, which leads to its rarity in some cases. The wood is also used for making fire by friction in Kiribati.

Craft wood/tools

Throughout the Pacific, the wood is used to make gongs, canoe bailers, tool handles, and handicrafts (Whistler 1992a). In the Marshall Islands, the wood is used for handles for knives and machetes and frames for diving goggles. In Namoluk it is fashioned into diving goggles and masks (Merlin and Juvik 1996). In Kosrae, it is also used for diving goggle frames.

Canoe/boat/raft making

In the Marshall Islands and Namoluk, the wood is used for poles for connecting outriggers to canoes. It is also used for canoe hulls and parts (Thaman and Whistler 1996).

Tannin/dye

In Tahiti, the leaves are used in the preparation of a red dye (Whistler 1992a).

Cosmetic/soap/perfume

In Kiribati, leaves used as a female deodorant (Thaman 1993). In the Marshall Islands corpses are treated with crushed leaves as a preservative and to minimize odor (Merlin et al. 1994).

Garland/lei

The flower and fruit clusters make an attractive component in garlands.

Ceremonial/religious importance

In the Marshall Islands, corpses are bathed in saltwater soaked with the leaves. In Namoluk, young unopened leaves are used to treat people affected by sea spirits. Also, the immature flower stalk is used in love magic (Merlin and Juvik 1996). Also in Namoluk, the woody material near the ground is used to cure diseases caused by the violation of sea taboos (Merlin and Juvik 1996).

Ornamental

A very attractive ornamental tree in homegardens as well as a welcome shade tree on beaches and other hot, sunny community gathering places. The plant is also said to be suited for container growing as a bonsai.

Other

Crushed leaves are used to prevent fogging of diving goggles and masks.

Trees can be periodically pruned back to control their size. PHOTO: C. ELEVITCH

URBAN AND COMMUNITY FORESTRY

Tree heliotrope is an ideal tree for seaside and near-shore landscaping and public areas. It withstands the sun, wind, and salt spray, and, once established, grows with little care and is relatively free from pest and disease problems. It is particularly valued for the shade it provides in its favored coastal environments.

Size in an urban environment

The tree typically grows to 6 m (20 ft), although exceptional specimens can grow to 12 m (40 ft). The canopy is domed and spreading.

Rate of growth in a landscape

The rate of growth is moderate, about 0.75 m/yr (2 ft/yr).

Root system

It has a tough root system that allows it to persist even in harsh coastal conditions. The tree's use in homegardens throughout the Pacific indicates that the root system is unlikely to be highly competitive or cause problems in landscaping.

Products commonly used in a Pacific island household

Products from tree heliotrope are primarily used by atoll islanders. The leaves are used as a vegetable or spice, or fed to pigs. The wood is useful for an array of crafts and utility items. The leaves are used medicinally as traditional treatments for numerous ailments. The flower and fruit clusters are used in leis.

Light requirements

The tree grows best in full sun.

Water/soil requirements

Tree heliotrope is at home in sandy and limestone seashore soils. These soils are typically low in available nutrients and shallow. Even though these locations are periodically overwashed with ocean water, the tree likely does not tolerate waterlogged soils, and it requires free drainage.

Life span

The life span of the tree is unknown but is expected to be at least several decades.

Varieties favored for use in urban areas

There are no known varieties of tree heliotrope.

Seasonality of leaf flush, flowering, fruiting

The tree grows nearly continuously. It generally flowers and sets fruit continuously throughout the year.

Exceptional ornamental values

Tree heliotrope is a very attractive, medium-sized ornamental. The silky leaves, which have a silvery sheen, are distinctive. The curly inflorescences and fruit clusters are also an interesting feature. The umbrella canopy and grayish, deeply corrugated bark complete the picture of a visually attractive tree.

Use as living fence, hedge, or visual/noise barrier

Beach heliotrope will not tolerate extensive pruning or shearing, but it has been used as an untrimmed hedge or barrier plant (Staples and Herbst 2005). Given the broad canopy, such uses would require a wide planting area.

Birds/wildlife

The flowers attract bees, wasps, moths, and butterflies.

Maintenance requirements

Once established, the tree requires little maintenance such as fertilizing, pruning, or thinning. Light fertilization with a balanced organic fertilizer may be beneficial to hasten growth but is not necessary when the tree is grown in its favored seaside environments. The tree can be lightly pruned to maintain a desired shape, although it is recommended to leave substantial foliage when pruning.

Special considerations regarding leaf, branch, and fruit drop in normal conditions and storms

The tree is very wind tolerant. It does drop older leaves, which often dry out and persist as a leathery mulch.

Nuisance issues

None.

Hazards

None known.

Common pest problems

The tree is rarely affected by any pests. Where present, in Oceania including parts of Micronesia and throughout Indo-Australia, it is subject to infestation by heliotrope moth larvae (*Utetheisa pulchelloides*). Where moth damage is severe, trees can be periodically sprayed with "BT" (*Bacillus thurengiensis*) products; pyrethroids can be used as contact insecticides (S. Nelson, pers. comm.). Freely draining soil is required to avoid root rot.

Other comments about this species in urban environments

Because it is one of the few trees that will grow along sandy shorelines, it is subject to being cut down as a convenient source of firewood for beachgoers.

COMMERCIAL CULTIVATION

The commercial potential for tree heliotrope is greatest for nurseries to grow out seedlings for use in coastal stabilization, home landscaping, and street and park trees.

PUBLIC ASSISTANCE AND AGROFORESTRY EXTENSION

Extension offices for agroforestry and forestry in the Pacific: http://www.traditionaltree.org/extension.html

INTERNET

USDA, ARS, National Genetic Resources Program. Germplasm Resources Information Network—(GRIN) National Germplasm Resources Laboratory, Beltsville, Maryland. <http://www.ars-grin.gov/var/apache/cgi-bin/npgs/html/taxon.pl?412122>.

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Species Profiles for Pacific Island Agroforestry (www.traditionaltree.org)

Tournefortia argentea (tree heliotrope)

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Acknowledgments: The authors and publisher thank Dale Evans, Eileen Herring, Heidi Johansen, Diane Ragone, and Art Whistler for their input.

Recommended citation: Manner, H.I., and C.R. Elevitch. 2006. *Tournefortia argentea* (tree heliotrope), ver. 3.1. In: Elevitch, C.R. (ed.). Species Profiles for Pacific Island Agroforestry. Permanent Agriculture Resources (PAR), Hōlualoa, Hawai'i. <http://www.traditionaltree.org>.

Sponsors: Publication was made possible by generous support of the United States Department of Agriculture Western Region Sustainable Agriculture Research and Education (USDA-WSARE) Program; SPC/GTZ Pacific-German Regional Forestry Project; USDA Natural Resources Conservation Service (USDA NRCS); Kaulunani, an Urban Forestry Program of the DLNR Division of Forestry and Wildlife and the USDA Forest Service; State of Hawai'i Department of Land & Natural Resources Division of Forestry & Wildlife; USDA Forest Service Forest Lands Enhancement Program; and Muriel and Kent Lighter. This material is based upon work supported by the Cooperative State Research, Education, and Extension Service, U.S. Department of Agriculture, and Agricultural Experiment Station, Utah State University, under Cooperative Agreement 2002-47001-01327.

Series editor: Craig R. Elevitch

Publisher: Permanent Agriculture Resources (PAR), PO Box 428, Hōlualoa, Hawai'i 96725, USA; Tel: 808-324-4427; Fax: 808-324-4129; E-mail: par@agroforestry.net; Web: <http://www.agroforestry.net>. This institution is an equal opportunity provider.