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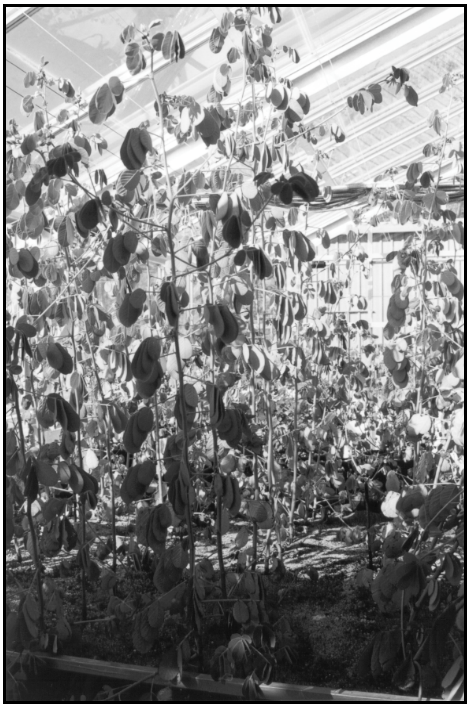

Senna tora gum production in Australia

A report for the Rural Industries Research and Development Corporation

by *David Cunningham and Kerry Walsh*

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Foreword

Seed gums (galactomannans) are widely used for a variety of industrial applications. The Australian market is supplied entirely by imports costing tens of millions of dollars per year. Carob, guar, and Senna gums are currently used to supply the bulk of this demand. However, inconsistency of supply and price has driven industrial users to search for alternative sources of supply.

Senna tora/obtusifolia may be grown commercially for medicinal uses in Korea, but are presently harvested from the wild for gum production in India. The use of *Senna tora/obtusifolia* gum has been protected by a patent, held by BFGoodrich, however this protection will lapse in 2002. Therefore, there is the potential to initiate production in Australia, however data was needed on the economic viability of such an undertaking under Australian conditions.

This study has recommended that commercial exploitation of this legume species for gum production requires a yield of at least 2.6 tonnes seed/ha at a farm gate price of $250/ha to achieve a gross margin to match that of wheat (or 2.0 tonnes/ha to match barley). These yields were not achieved in the glasshouse or field studies of this study, but there is potential to reach this level with attention to agronomic practice and varietal selection.

This project was funded from industry revenue which was matched by funds provided by the Federal Government. Other RIRDC projects relating to seed galactomannan production in Australia include:

- Potential for seed gum production within Australia (UCQ-12A)
- Carob agroforestry in the low rainfall Murray valley (UCS-14A)

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Peter Core
Managing Director
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- Marie Vitelli of the Tropical Weeds Research Centre (DNR) for provision of *Senna tora* seed and advice on cultivation.

Abbreviations

ANZFA	Australia New Zealand Food Authority
AQIS	Australian Quarantine and Inspection Service
BRI	Queensland Herbarium (EPA)
CQU	Central Queensland University
CRCIPB	Cooperative Research Centre for Industrial Plant Biopolymers
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DPI	Department of Primary Industries (Queensland Government)
DPIF	Department of Primary Industries and Fisheries (Northern Territory Government)
DNR	Department of Natural Resources (Queensland Government)
EPA	Environmental Protection Agency (Queensland Government)
PAW	Parks and Wildlife Commission (Northern Territory Government)
RLPA	Rural Lands Protection Act (Queensland)
TBC	Tropical Beef Centre
TWRC	Tropical Weeds Research Centre (DNR)

Contents

Executive Summary

Seed gums (galactomannans)are classed as a 'thickener/vegetable gum' in foods and are also used in a range of non-food applications including textile and paper manufacturing. The main sources of seed gums on the world market are carob (locust bean) and guar. An increasingly important gum is sourced from *Senna tora* and *Senna obtusifolia* in India. Australia currently imports all of its seed gum requirements, the bulk of which are used as a gelling agent in canned pet foods. *Senna tora* and *Senna obtusifolia* are established in Australia as weeds, infesting approximately 600,000 hectares in coastal north and far north Queensland. The patent covering the use of *Senna tora/obtusifolia* gum in canned pet foods will expire in September 2003. As the patent expires, industry users will encourage production in areas other than India to diversify supply options. It is therefore strategic to consider the potential for production of this gum in Australia at this time.

S*enna tora* seed was sourced from within Queensland and multiplied in glasshouse trials. Bioclimatic analysis of weed distributions indicated that low temperatures would limit the growth of the plant to the coastal tropics of Australia.

A field harvest was conducted on wild *Senna obtusifolia* to demonstrate the feasibility of mechanical harvesting. Glasshouse estimates were low at 0.8 tonnes/hectare, too low to support a viable industry on a conservative estimated return of $250/tonne seed in the economic model used. However, experimental yields of up to 2.6 tonnes/hectare are reported overseas and should be possible here, given attention to agronomy and cultivars. At a yield of 2.0 tonnes/hectare cropping of *Senna tora* would be commercially viable, returning a gross margin equivalent to that of barley in Central Queensland. At 2.6 tonnes/hectare the gross margin would equal that of wheat.

A growers group could negotiate with pet food industry users regarding contract pricing. However, establishment of an industry in Queensland would require legislative change with respect to the weed status of these species. Sourcing seed stock from international distributions to establish a breeding program is advised before attempting large-scale cultivation.

Introduction

Vegetable gums are becoming increasingly common in foods as they play important roles in both the manufacturing process and the mouthfeel or texture of the products. At present there are 38 additives classed as 'thickener/vegetable gum' which have been approved for use in Australian food (ANZFA 1999). Sixteen of these are starches in various forms, nine are seaweed extracts, three are synthesised by bacteria and three are exudates from the branches of trees. Two of the vegetable gums are sourced from seeds and are known as seed gums or galactomannans. Seed galactomannans are competitively priced in comparison to other vegetable gums. They are unmodified natural products with some health benefits and are widely accepted by consumers. It is likely that their use in foods will continue to increase and that new food uses and products will be developed.

The world market for vegetable gums used in foods was estimated at US$10 billion in 1993 (Coppen 1995), the majority being the seaweed gums and the starches. Virtually all of Australia's requirements for vegetable gums are met by imports costing an estimated AU$40 million a year, carob gum imports alone cost some AU$10 million a year Australia-wide (CRCIPB 1996). The volume and value of *Senna tora/obtusifolia* gum imported into Australia is uncertain since many types of industrial gum are grouped under the same import code used for statistical records.

Galactomannans are polysaccharides stored in the seeds of many plants of the legume family. These polymers of mannose and galactose are the functional components of seed gums. Carob (additive code 410) and guar (412) are the only seed gums currently approved for use in Australian food. Tara (417) and *S. tora*/*obtusifolia* ('cassia') gum (no international additive code) are relatively new seed gums which are used in foods overseas.

Seed galactomannans are used in a wide range of food products and processes to thicken solutions, form an aqueous gel with other polysaccharides and prevent syneresis (the separation of liquid from a gel that is caused by contraction). The concentration of seed gum in foods varies, typical concentrations of 0.5-1.0% can achieve the same viscosity as starches at 4.0-6.0%. Seed gums are commonly used in conjunction with carrageenan (407) from seaweed, or xanthan gum (415) from bacteria. The interaction between the seed gum and the other polysaccharide results in a stronger, more elastic gel, or higher viscosity, than that produced using either gum by itself.

Some of the many foods containing galactomannans are ice cream, other milk-based products and desserts, mayonnaises, dressings, sauces and deep-frozen foods. Non-food uses of galactomannans include lubrication of oil drills, waterproofing of underwater explosives and as a flocculant in paper and textiles manufacturing (Dea and Morrison 1975, Coppen 1995).

One feature of galactomannans is that although they are comprised of simple sugars they are not digested by human enzymes. They are commonly used in diet or 'lite' foods since they add texture and a creamy mouthfeel to foods but pass through the body undigested. Guar has even been marketed as a diet tablet which swells in the stomach to alleviate the sensation of hunger. While this use may be of dubious health value, galactomannans do have some dietary value as soluble fibre. For diabetics, galactomannans also have the benefit of slowing the passage of food in the stomach thereby slowing the resorption of sugars such as glucose.

S. tora/obtusifolia gum is used internationally and in Australia as a source of vegetable gums mainly for the pet food and textile industries. The product is currently exclusively made by BFGoodrich, and is marketed as 'cassia gum' or 'Diagum™ CS'. It is made from the processed seed of both *S. tora* and *S. obtusifolia* collected from wild populations of these plants in India.

'*Cassia tora*' and 'gum', are included in 48 US patents dating from 1976 to 1999, most relating to sulphonamide herbicide formulations proven to control *Cassia tora* and other weed species (Table 1). Only five patents refer to the use of the seed gum from the plant. BFGoodrich (owner of Freedom Chemical Company and Diamalt) holds the patent for the use of *S. tora/obtusifolia* gum in conjunction with carrageenan, the main use of the product in foods. This patent application was first made in

Germany on 30 September 1983 and a patent (Bayerlein *et al.* 1984) filed with the Australian Patent Office on 20 September 1984. This use of the product in Australia will not incur royalties from September 2003. As the patent expires, industry users will encourage production in areas other than India to diversify supply options.

Table 1. Results of search of *US Patent & Trademark Office Full Text and Image Database* for '*Cassia tora*' and 'gum', 48 patents (1976-1999), entries in bold text represent seed gum applications.

Patent no.	Title
5,114,463	Pyrimidine derivatives and herbicidal compositions containing the same
5,087,289	Alkanoic acid derivatives and herbicidal compositions
5,081,244	Pyrimidine derivatives, processes for their production, and herbicidal method and compositions
5,041,154	Benzoxazine compounds useful as herbicides
5,019,151	2-phenoxyprimidine derivative and herbicidal composition
4,985,066	2-phenoxypyrimidine derivative and herbicidal composition
4,969,949	Pyrimidine derivatives, processes for their production and herbicidal compositions containing them
4,968,340	Alkanoic acid derivatives and herbicidal compositions
4,952,686	**Soluble dried cassia alloy gum composition and process for making same**
4,946,495	2-phenoxypyrimidine derivative and herbicidal composition
4,932,999	Pyrimidine compounds, and herbicidal method and compositions
4,931,088	Novel 2-nitro-5-(substituted phenoxy)benzohydroximic acid derivatives
4,923,501	Pyrimidine derivatives, processes for their production, and herbicidal method and compositions
4,919,846	Detergent composition containing a quaternary ammonium cationic surfactant and a carboxylate anionic surfactant
4,906,285	Pyrimidine derivatives and herbicidal method and compositions
4,902,832	2-Substituted phenyl-4,5,6,7-tetrahydro-2H-isoindole-1,3-diones, and their production and use
4,900,352	2-Phenoxypyimidine derivative and herbicidal composition
4,889,552	2-Phenoxypyrimidine derivative and herbidical composition
4,840,811	**Process for producing colorless, odorless and tasteless cassia endosperm flour**
4,830,662	Agricultural sulfonamides
4,826,700	**Gelling agents and thickeners based on cassia-galactomannans**
4,820,332	Herbicidal sulfonamides
4,818,278	Agricultural sulfonamides
4,770,691	2-(4',6'-di-substituted pyrimidine-2'-yl)oxy- or thio-benzoic acid
4,755,216	Agricultural sulfonamides
4,753,659	**Derivatives of cassia tora polysaccharides and their use**
4,740,619	Phenylhydrazonocyclohexanone oximes
4,721,520	Agricultural sulfonamides
4,689,072	Agricultural sulfonamides
4,687,507	Agricultural sulfonamides
4,668,278	Benzotriazoles, and their production and use 4-halophenyl-tetrahydrobenzotriazloes as herbicides
4,661,475	**Gelling agents and thickeners based on Cassia-galactomannans**
4,647,303	Agriculture sulfonamides
4,643,759	Herbicidal sulfonamides
4,627,873	Agricultural sulfonamides
4,595,409	Substituted phenyl-4,5,6,7-tetrahydro-2H-isoindole-1,3-diones, and their production and use
4,592,978	Agricultural sulfonamides
4,591,378	Agricultural sulfonamides
4,564,384	Agricultural sulfonamides
4,545,808	Herbicidal sulfonamides, compositions and use
4,536,576	Agricultural sulfonamides
4,454,335	Substituted benzene sulfonyl isocyanates as intermediates to herbicidal sulfonamides
4,451,283	5-Oxo-2,5-dihydro-1,2,4-triazines
4,394,506	Agricultural sulfonamides
4,383,113	Agricultural sulfonamides
4,378,991	Herbicidal o-aryl or alkarylsulfonylureas
4,367,089	Fungicidal carbamates of triazole ethanols (or ethenols)
4,348,219	Herbicidal sulfonamides

Many plants have been chemically analysed for their potential as a source of seed gums, and results for over 120 species have been reported in the public domain. *S. tora/obtusifolia* and tara gum are the latest seed gums on the world market. These industries depend on harvesting of wild *Senna* (in India) and tara (in Peru), and have not yet progressed to crop cultivation. *S. tora/obtusifolia* gum is approved for food use in Europe, Japan and the USA. Tara is approved for food use in Europe. At present, *Senna* gum is used only in petfoods in Australia while tara is not known to be used in any applications in Australia.

Mesquite (*Prosopsis* species) is another potential source of seed gums. Research in Brazil went as far as pilot-scale processing of the seed for gum production but as yet there has been no mesquite gum traded on the world market (Coppen 1995). Mesquite was introduced to Australia in the early 1900s and has since become a serious woody weed, a factor which would probably impede its commercialisation here and in many parts of the world.

For decades Australian researchers have investigated the potential to produce seed gums locally. Of the seeds gums, carob has the longest history of use in industrial processes. In fact, people have used the carob tree in various ways for around 4000 years. The whole pods are a nutritious stockfeed and the dried pulp (carob powder) is used as a flavouring, for example as a substitute for chocolate. A native of the Mediterranean, the carob tree is suited to many parts of Australia and was first planted here in the 1890s. The first experimental orchards were established in the 1970s in South Australia but as yet there has been no local harvests of carob seed for gum production. Guar (*Cyamopsis tetragonolobus*) has also been grown on a small scale in Australia for decades without developing as a commercial seed gum crop. Renewed interest in local sourcing has led to further trials of guar in Queensland with a view to local production and processing of seed gums.

S. tora and *S. obtusifolia* are established in Australia as weeds. *S. obtusifolia* in particular is problematic, infesting approximately 600,000 ha in coastal north and far north Queensland. Mackey *et al.* (1997) estimate that $1 million each year is expended on the control of *S. obtusifolia*, primarily on chemical control of the plant in the sugar cane industry. No estimate of economic cost has been made for *S. tora* which is relatively rare in Australia.

No analysis has been made of the potential to crop *S. tora/obtusifolia* in Australia and to produce *Senna* gum locally. There is little experience with the agronomy of the plant overseas as it is currently harvested from wild stands for seed gum production. The aim of the current study was to investigate the agronomic potential of *S. tora* as a new crop in Australia.

1. Utilization of gum and by-products

Senna tora gum is a cream-yellow powder obtained after removing the seed coat and germ of *S. tora* and *S. obtusifolia* seed and washing, grinding and sieving the endosperm (Figure 1). The product is currently manufactured exclusively by BFGoodrich companies (Freedom Chemical and Diamalt) and marketed as 'Diagum™ CS' and a food grade product named 'Diagum™ CS Refined' (Anon. 1995, Freedom Chemical n.d.). Diagum is marketed as either 100% *S. tora/obtusifolia* gum or as a mixture with other gelling and thickening agents (Hallagan *et al.* 1997).

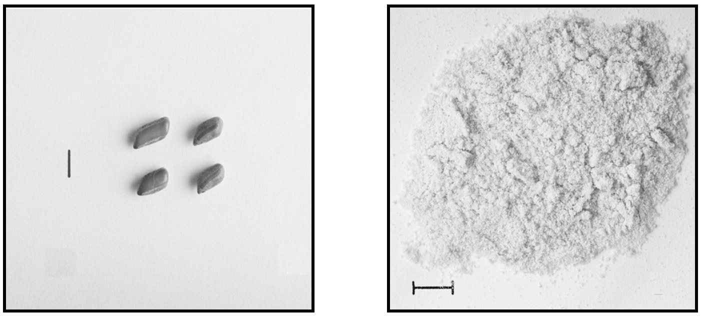


Figure 1. *Senna tora and Senna obtusifolia* seed (left panel) and *Senna tora/obtusifolia* gum (right panel) (scale bars 3 mm and 5 mm).

S. tora/obtusifolia gum is useful in numerous food and feed applications in combination with other gums such as carrageenan or xanthan. One of the main applications is in the manufacture of canned pet food where the gum is used primarily as a gelling agent to aid in both the processing stages and final presentation of the product. The concentration of seed gums in pet food varies, but is typically approximately 0.25% (w/w) (Hallagan *et al.* 1997). Another gelling agent such as carrageenan is usually used in approximately equal amounts to produce a synergistic effect in the formation of the gel (Bayerlein *et al.* 1984, Vilastic Scientific 1998). Food applications of *S. tora/obtusifolia* gum include gel formation and viscosity modification in products such as cheeses, yoghurts and sauces. It is used in the manufacturing of air fresheners and derivatives of the gum are used in textile printing, the paper industry and oil drilling applications (Freedom Chemical n.d.).

Seed of both *S. tora* and *S. obtusifolia* is used for other (non-gum) purposes. Medicinally active compounds extracted from the seed include the anthraquinones chrysophanic acid, emodin, physcion and obtusin (Kim and Cho 1989). These compounds are considered undesirable toxins in the manufactured gum. *S. tora* seed has been used in China as a source of aperient, antiasthenic and diuretic agents, while in Korea the seed extract is taken for protection of the liver (Wong *et al.* 1989). Seed extract is used as a purgative and vermifuge in the Philippines (cited in Mackey *et al.* 1997) and in India, the seeds and leaves are used as laxatives and in the treatment of fungal skin disorders (Jain n.d.).

Herbal products containing *S. tora/obtusifolia* and other plant extracts include a health drink marketed as *Enjoi Beverage* (Asian Nutritional). Other products named *Fevera* (Reach4Life) and *Antimicrobia* (Natural Link) are intended to reduce fevers. A herbal formula containing *S. tora/obtusifolia* is marketed as *Cholestra* (Reach4Life), which is claimed to "clean the blood by nurturing the kidneys and liver while fighting aging and aging-related ailments". Similar formulations are marketed as *CholLess Tea* (Natural Ways), *Therapeutica* (Virtual Health Store) and *Women's Mood Enhancer* (HerbaSway) (Figure 2).

The value of the medicinal market for *S. tora* is difficult to determine. Giraudon and Willaert (1983) note that 2500 t/yr of *S. tora/obtusifolia* seed is exported from India to Japan where an extract is used in the production of tonic drinks by Mitsui Japon. While this type of product is available internationally it is unclear how much is used globally or how much, if any, is imported into Australia.

Figure 2. Examples of herbal formulations containing *Senna tora*: From left to right, *Cholestra*, *Fevera*, *Therapeutica* and *Women's Mood Enhancer*.

The seeds and leaves of *S. tora/obtusifolia* are used as a food source in times of famine in India, South America and Africa (Barrett 1990, Freedman 1998), apparently without toxicological problems. Since *S. tora* is absent from Africa (Randell 1995), the plant eaten in Africa would be *S. obtusifolia*. Both plants are used as a coffee substitute in some parts of the world and the leaves are used as a tea in parts of India (Freedman 1998).

The plants are more commonly used for stock feed than human food. Toxicity may be a problem where the plants are used in feed due mainly to the presence of anthraquinone glycosides. These compounds can be partially removed by soaking in hot water. The seed may be used as cattle feed (Desai and Shukla 1978), or as an ingredient in poultry feed (Katoch and Bhowmik 1983). The use of powdered leaf material as an ingredient in carp feed has also been investigated, with positive results (Manissery *et al.* 1988).

2. Gum manufacture

BFGoodrich (through Freedom Chemical) has previously manufactured *S. tora/obtusifolia* gum at plants in Allach, Germany and Vernon, France. Prior to mid-1997 the seeds were dehusked in India and the splits (endosperm) exported to Europe for processing into gum. 'Indiamalt', a manufacturing plant in Baroda (Vadodara), India, has been on line since mid-1997 and produces *S. tora/obtusifolia* gum for global distribution. It represents a joint venture between Freedom Chemical and Kamlakant Chhotalal Exporters (KCCO). The plant is capable of producing 4000 t/yr of gum. A subsidiary of KCCO known as Bardoli Agro Industries organises the collection of the seed from wild stands and processes it into 'splits' (endosperm) to be milled into the gum flour by Indiamalt (Anon. 1995, Freedom Chemical n.d.).

The manufacturing process is not well described in the literature. Freedom Chemical (n.d.) states that "the polysaccharide endosperm is separated from the rest of the seed by traditional milling methods and then purified". Giraudon and Willaert (1983) and Hallagan *et al.* (1997) describe the pre-1997 method although there are some gaps in the description (Figure 3). The pods harvested in India were threshed to remove the seed and processed to remove stones, dust and debris using separators. The harvest was (and apparently still is) carried out manually by women and children obtaining seed from weed populations of *S. tora/obtusifolia* growing in pastures and on the edges of forest areas. At the first processing facility, a guar gum mill in India, the grains were fed into a rotation roaster and heated to 180-200 °C for about 30 seconds. While the seeds were hot, hulling machines pulverised the husk and germ and separated them from the harder, intact split. The remaining germ or meal, consisting of 24% fat and protein (w/w), was used in stockfeed products by a milk cooperative.

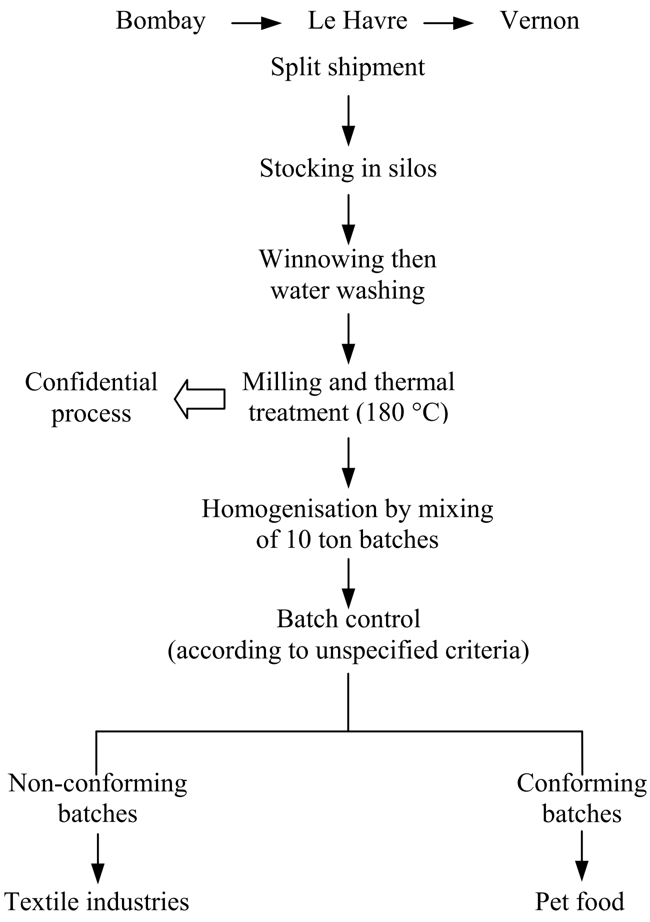


Figure 3. Pre-1997 method of Diagum production (translated from Giraudon and Willaert 1983)

The amount of endosperm as a proportion of the seed is probably variable between provenances and between seasons. While Giraudon and Willaert (1983) and Hallagan *et al.* (1997) estimate that *S. tora* endosperm comprises 20% of the seed weight, Farooqi *et al.* (1978) report a figure of 23.0%. Soni (1997) reports that the endosperm comprises 29-31% of the seed weight, the testa 40-42% and the germ 28-29%. While seasonal and genetic factors will influence endosperm yield, the lower estimates may also reflect low recovery of gum in the process of sifting out contaminants.

The splits were shipped to France for processing into gum. A sorting machine removed any remaining germ and husk and the splits were washed with water followed by a "special cleaning procedure" which has not been described. The washed splits were heated and milled into a flour, several batches were then mixed together to produce an homogenous product which was tested for purity (using unspecified methods). If required, a supplementary wash was carried out to reduce the level of anthraquinones including chrysophanic acid and emodin (Giraudon and Willaert 1983, Hallagan *et al.* 1997). This washing method probably involved the use of a water-miscible solvent such as ethanol, as discussed below.

The gum was tested for the toxic chrysophanic acid using an (unpublished) High Performance Liquid Chromatography (HPLC) method (Giraudon and Willaert 1983). The end products, Diagum CS and Diagum CS Refined, are supplied with a low concentration of chrysophanic acid (< 10 ppm) (Freedom Chemical n.d.). Blending of batches with high and low chrysophanic acid levels is likely to be used achieve this specification.

The additional purification steps involved in the manufacture of the refined food grade product are probably based on a US patent assigned to Diamalt (Bayerlein *et al.* 1989). This patent deals with processes for washing the ground endosperm with a mixture of water and alkanol (e.g. ethanol, isopropanol and propanol). This results in a gum which is largely colourless, odourless and tasteless and which is low in anthraquinones and related compounds.

An alternative gum extraction process is described by Renn *et al.* (1990) (assigned to FMC Corporation) in a patent dealing with the manufacture of an alloy gum composed of any *Cassia* species and xanthan (US patent 4,952,686). In the patent '*Cassia*' is used in the wide sense (pre Irwin and Barneby 1982) to include all *Cassia*, *Senna* and *Chamaecrista* (around 600 species). The patented process avoids the extra steps of separating the seed meal and testa. Ground seeds are extracted with water and the galactomannan co-precipitated with another type of gum (e.g. carrageenan). The insoluble fraction may be separated and the soluble gums precipitated with potassium chloride or by adding a water-miscible solvent (e.g. isopropanol), or the aqueous medium may be evaporated in a vacuum or with hot air. These basic principles are well documented on the laboratory scale but it is not known if any manufacturing plants use the principle for large-scale gum production.

3. Botanical description and taxonomy

Senna tora was first described as *Cassia tora* by Linnaeus in 1753. There have been several revisions of the genus *Cassia*, with the most recent (Irwin and Barneby 1982) applying the scientific name *Senna tora* (L.) Roxb. Despite this, many subsequent publications have used the base name *Cassia tora*. This can lead to confusion as *S. tora* gum is marketed as 'Cassia gum', a situation unlikely to change in the short term.

There are many common names associated with *S. tora*, of these the most common in Australia are foetid cassia and sicklepod. International common names vary between regions and according to local uses of the plant (Table 2). The common names for *S. tora* are often also used for *S. obtusifolia*. The species referred to in Australia as sicklepod is usually *S. obtusifolia*.

Table 2. Common names of *Senna tora*.

Name	Region	Reference e.g.
Sicklepod	Australia, international	Mackey *et al.* (1997)
Arsenic pod	Australia	DNR (1997)
Stinking cassia	Australia	Symon (1966)
Java bean	Australia	Lazarides and Hince (1993)
Foetid cassia	Australia, India	Symon (1966)
Foetid senna	Australia	Vitelli and Setter (1999)
Tafasa	India	Freedman (1998
Kasoda	India	Freedman (1998
Takla	India	Freedman (1998)
Sekto	India	Freedman (1998)
Chakunda	India	Freedman (1998)
Puwad	India	Giraudon and Willaert (1983)
Pawad	India	JKH (1998)
Panwar	India	Giraudon and Willaert (1983)
Charota	India	JKH (1998)
Sickle senna	Korea	Kwon *et al.* (1992)
Sirppikassia	Finland	Savela (1998)
Jue ming zhi	China	B&T World Seeds (1999)
Chinese cassia	Not stated	Randall (1999)

Senna tora is a small spreading shrub varying in height and other characters. It is usually an annual but may occasionally pereniate. The most recent botanical description is that of Randell and Barlow (1998 p. 138) as follows:

> Herbaceous perennial or sub-shrub, spreading, to 0.5 m tall, sparsely pubescent on vegetative parts, calyx and ovary, soon glabrescent. Leaves 5-6 cm long including a channeled petiole 20-45 mm long; stipules lanceolate, acicular, somewhat persistent; leaflets in 2-3 pairs spaced 10-15 mm apart, obovate, 25-55 mm long, 10-35 mm wide, increasing distally, obtuse or rounded and sometimes shortly mucronate; glands 1-2, between the lowest leaflet pairs, erect, sometimes pointed. Inflorescence subumbellate, of 1-2 flowers, axillary; peduncle 2-4 mm long; pedicels c. 10 mm long; bracts caducous. Petals 8-10 mm long. Fertile stamens 10, or 7 with adaxial staminodes; fertile filaments subequal, 1.5-2.5 mm long; fertile anthers slightly unequal, 1.5-2.5 mm long. Pod cylindric, 12-18 cm long, 2-5 mm diam., curved, entire. Seeds dull or lustrous, with a longitudinal areole.

S. obtusifolia is commonly self-pollinated before the flower opens. The style is curved inward with the stigmatic cavity facing the anthers (Irwin and Barneby 1982). Given the morphological similarity of the flowers it is likely that *S. tora* is also self-compatible. *S. tora* and *S. obtusifolia* are known to grow in association in many cases e.g. in India (Singh 1968) and in Australia (Vitelli and Setter 1999). Hybridization in the wild has not been recorded and experimental crosses are infertile (Irwin and Turner 1960, cited in Randell 1995). Vatsavaya, Raju and Rama Rao (1986) suggest that the two species flower at different times (cited in Randell 1995). This is supported by observations in Australia that *S. tora* generally flowers and senesces three to four weeks earlier than *S. obtusifolia* (Vitelli and Setter 1999).

S. tora may have evolved in Asia from a broad-podded variety of *S. obtusifolia*. Further studies (e.g. DNA analyses) are required to clarify the relationship of the two species (Randell 1995). The main botanical differences between *S. tora* and *S. obtusifolia* are that *S obtusifolia* has beaked anthers and narrow transverse areoles on the seed as opposed to the longitudinal areoles of *S. tora* (Figures 1 and 4) (Randell and Barlow 1998). Differences in the leaflet glands (Retzinger 1984), seed testa (Singh 1978) and some phytochemical characters (Upadhyaya and Singh 1986) have also been described. No differences in galactomannan yield or composition have been reported.

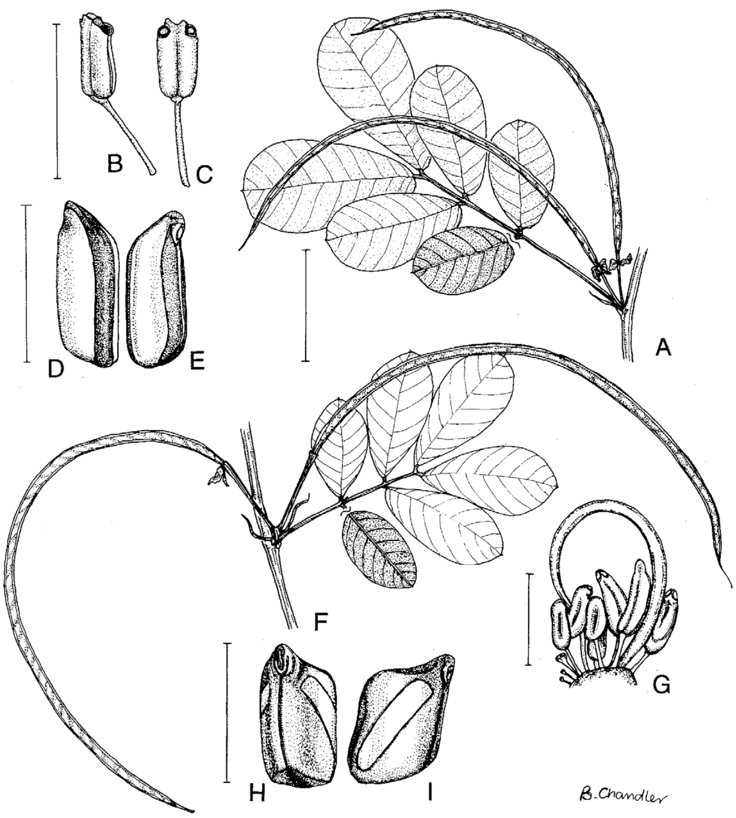


Figure 4. *Senna tora* and *Senna obtusifolia* illustrations.

A-E, ***Senna tora***
A. fruiting twig
B-C. isolated anthers showing truncate tips
D-E. seed showing broad, longitudinal areole.

F-I, S***enna obtusifolia***
F. fruiting twig
G. androecium showing three abaxial beaked anthers
H-I. seed showing narrow, transverse areole.

A and **F** show abaxial surface of one disconnected leaflet.

Scale bars:
A, **F** = 3 cm
B, **C** = 3 mm
D, **E**, **H**, **I** = 4 mm
G = 6 mm.

Reproduced from Randell and Barlow (1998 p. 136).

The dimensions of the plant in nature and in cultivation vary considerably. Mackey *et al.* (1997) cite examples from the literature showing that *S. tora* grows to a maximum height of 70 cm whilst *S. obtusifolia* can reach a height of 2.5 m. Singh (1968) demonstrated that *S. obtusifolia* was more robust in terms of growth under uniform cultivated conditions.

In agricultural terms, the shorter plant (*S. tora*) would be more manageable and efficient although the 'short' character could be bred into or induced by management practices in *S. obtusifolia*. Plants from the lower end of the size range of *S. tora* (< 20 cm high) would be unsuitable for cultivation as they would presumably yield low pod numbers and be difficult to harvest efficiently.

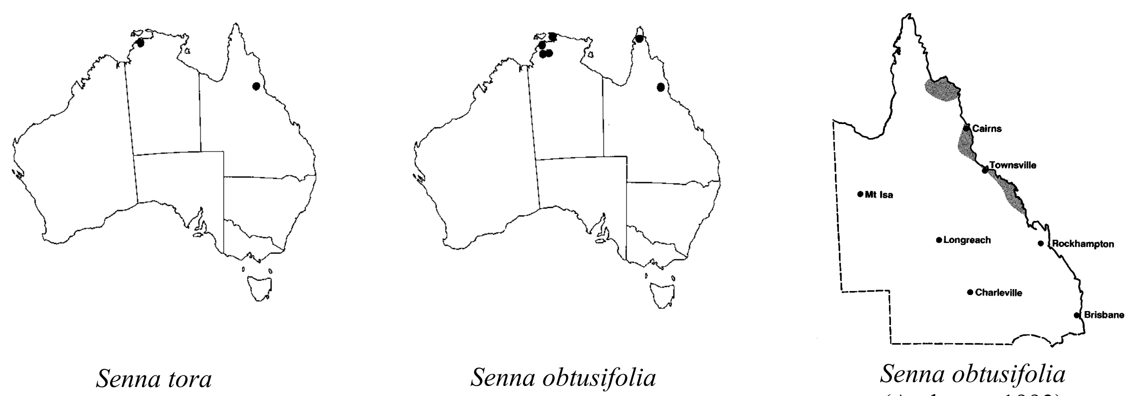
4. Known distribution and weed status

Senna tora is probably native to the Asia-Pacific region but has spread to a pan-tropical distribution. *S. obtusifolia* is probably native to the Americas but has also spread to a pan-tropical distribution and has become widely naturalized in northern Australia (Figure 5) (Randell and Barlow 1998). *S. tora* has been recorded in the following countries and regions:

- Arabia (particularly Oman)
- Australia
- Cambodia
- Fiji
- Futana Islands
- Guam
- India
- Indonesia
- Jamaica
- Laos
- Malaysia
- New Guinea
- Pakistan
- Samoa
- Singapore
- Southern China
- Thailand
- Tonga
- Vanuatu
- Vietnam
- The Philippines
- The Solomons

(Symon 1966, Waterhouse and Norris 1987, Barrett 1990, Mackey *et al.* 1997)

In Australia, *S .tora* has become sparingly naturalized in Queensland, the Northern Territory and possibly Western Australia (Figures 5 and 6, Table 3). It was first recorded in Australia in 1871, in the Darwin area (Symon 1966) and the earliest Australian Herbarium collection was made at Port Darwin in 1888 (Table 3). White (1917) includes a local report from the Johnstone River area in north Queensland that *S. tora* "was introduced as a green manure, and now grows on roadsides, emitting from leaves, &c., an offensive smell." *S. obtusifolia* was apparently introduced during World War 2, also in the Darwin area. It has been recorded as a weed since 1961 in the Northern Territory and 1963 in Queensland (Mackey *et al.* 1997).



Senna tora (Randell and Barlow 1998) | *Senna obtusifolia* (Randell and Barlow 1998) | *Senna obtusifolia* (Anderson 1993)

Figure 5. Examples of previously published distribution maps of *Senna tora/obtusifolia* in Australia.

Both *S. tora* and *S. obtusifolia* are prohibited plants in Western Australia (Randall 1999). *S. obtusifolia* has not been recorded in Western Australia, and only a single occurrence of *S. tora* has been noted, at a quarantine wash-down facility at Kalumburu (Mackey *et al.* 1997). Both plants have been recorded in the Northern Territory although *S. obtusifolia* is far more common. *S. tora* is not on the current list of vascular plants in the N.T. and is not known to weeds officers in the territory (Grant Flannagan, DPIF, pers. comm. 1999).

S. tora is sparingly naturalized in Queensland with the few confirmed distributions limited to high rainfall, coastal areas of Queensland between Mackay and Cairns (Table 3). Publicly available weeds information (DNR 1997) indicates that *S. tora* is apparently not declared. Mackey *et al.* (1997) report that it is not declared (p. 5) and that it is declared (p. 31). However, under the provisions of the *Rural*

Lands Protection Act (RLPA) Amendment 1 (1997), *S. tora* is included with *S. obtusifolia* and has the same declaration status (Steve Csurhes, DNR, pers. comm. 2000). It is illegal to transport or commercialize declared weeds, hence the restrictions of the RLPA would impose a major limitation on the development of *S. tora* or *S. obtusifolia* as a field crop.

S. obtusifolia is a declared plant, and occurs commonly, in coastal parts of Queensland north of Mackay including Bowen, Burdekin, Cairns, Cardwell, Cook, Douglas, Hinchinbrook, Johnstone, Mackay, Mulgrave, Pioneer, Proserpine, Sarina, Thuringowa and Townsville. In these areas, it is declared under two categories, P3 - the area of infestation must be reduced and P4 - infestations should be prevented from spreading. In all other areas of Queensland the weed is classed as P2 - where the plant must be destroyed (DNR 1997).

Table 3. Previously confirmed distributions of *Senna tora* in Australia. Abbreviations: Fl. Aust = Randell and Barlow (1998), BRI = the Queensland Herbarium, TBC = the Tropical Beef Centre, TWRC = the Tropical Weeds Research Centre.

Source	Specimen	Locality	Year
Fl. Aust		NT, Port Darwin	1888
BRI	17860	Qld, Innisfail, Johnstone river	1917
BRI	17858	Qld, Johnstone river	1918
BRI	17410	Qld, South Johnstone	1937
BRI	196948	Qld, East Palmerston c. 20 miles SE of Millaa Millaa	1952
BRI	17859	Qld, Brooks Rd via Millaa Millaa	1960
BRI	17862	Qld, Ingham, Victoria Hill CSR dairy farm	1960
BRI	17864	Qld, Samford	1964
BRI	17857	Qld, Portion 23 11 miles W of Innisfail parish of Johnstone	1965
BRI	17861	Qld, Innisfail	1969
BRI	3422	Qld, Gordonvale	1972
TBC		Qld, Mackay, along Bruce Hwy a few km from Glenella	1972
BRI	346966	Qld, Beerwah Research Station E475 R15-7 (PL 287)	1979
BRI	343038	Qld, Mandarana, 16 km WNW Of Mackay Pioneer Shire	1980
TWRC	MA 31	Qld, 'The Orient', Ingham	1985
TWRC	MA 99	Qld, Tom Mauloni's, Donkin Road, Mena Creek	1990
TWRC	MA 101	Qld, Bellenden, L. Henry's property, past sawmill	1990
TWRC	MA 102	Qld, King Ranch, Davidsons Rd, via Euramo	1990
TWRC	MA 111	Qld, Gordonvale, Napier's, 4.2 km along Goldsborough Rd, and 5 km along Gilles Highway	1990
TWRC	MA 118	Qld, 1.8 km from Julatten, paddock opposite Julatten sportsground	1990
BRI	625374	Qld, Earlando Bay 28 km NW Of Airlie Beach	1992
Fl. Aust		WA, Kalumburu	-
Fl. Aust		Qld, East Palmerston, c. 32 km SE of Millaa Millaa	-

5. Seed sourcing

To establish a glasshouse trial of S*enna tora* in Australia a small number of viable seeds (around 100) was required. Two approaches were followed to obtain seed, purchasing from overseas and collecting from local weeds. Since *S. tora* and *S. obtusifolia* plant are not usually cultivated deliberately there are no recognized varieties or cultivars developed specifically for seed gum production.

Since *S. tora* is a weed under active control in Australia, the Australian Quarantine and Inspection Service (AQIS) restrict any importation of the seed. Small amounts of seed can be imported for research work conducted in an AQIS approved quarantined glasshouse or laboratory.

5.1. Commercial seed suppliers

Australian and international seed catalogues were searched for both *Senna tora* and *Cassia tora*. Seven international companies claimed to be able to supply the seed (Table 4) but *S. tora* seed was not available from any Australia seed suppliers. B & T World Seeds were contracted to provide *S. tora* seed. However, the seed provided by their collectors was in fact *S. obtusifolia*. The export of viable *S. tora* seed from India is restricted (R.K. Katyal, Indo World Trading Corporation, pers. comm. 1999) hence Indo World, and presumably other Indian companies, cannot supply seed to Australia.

Table 4. International seed suppliers listing *Senna tora* seed.

Company	URL	Country	Price
B & T World Seeds	b-and-t-world-seeds.com	France	$70 / 100 g
Global Plants & Seeds Emporium	www.infomeditainment.com/seeds	Germany	$8/20 seeds
Herbs USA	www.herbsusa.com	USA	Not listed
Indo World Trading Corporation	www.indo-world.com	India	Not listed
Trident Creation	www.bicserve.com/htm/trident	India	Not listed
Moorthy Traders	www.moorthytraders.com	India	Not listed
JKH Exports	www.jkhexports.com	India	Not listed

5.2. Australian researchers, extension officers and seed collectors

The distribution of *S. tora* in Australia was established from published records and herbarium specimens (Table 3, Figure 6). The timing of flowering established from herbarium records varies from January to August in north Queensland. The 24 records of the plant in Australia date from 1888 to 1992 and the locality descriptions are generally vague (Table 3). The plant is usually an annual which dies in late winter and spring and exists for several months of the year only as a seedbank within the soil, although Mackey *et al.* (1997) report that the plant may pereniate if slashed. Since *S. tora* is rare in Australia and the time of flowering and fruit set varies considerably between years, the probability of finding wild populations in the field was considered to be low. Given these limitations a 'phone/fax/email' approach was considered both more efficient and more likely to be successful than a field excursion targeted at past collection sites.

Based on previously recorded incidences of the plant, researchers, extension officers and weeds officers from 15 organisations or departments were contacted (Table 5). A standard request for information and/or seed was produced and included an identification guide to distinguish the rare *S. tora* from the ubiquitous *S. obtusifolia* (Appendix A). This information sheet was circulated by fax to selected target groups.

Each of the organizations listed in Table 5 had at least some knowledge of the weed 'sicklepod', although this was generally limited to *S. obtusifolia*. *S. tora* is less well known and where it is known it is considered to be rare. *S. obtusifolia* was common throughout coastal regions of Queensland from Sarina north to Townsville in 1999/2000. No wild occurrences of *S. tora* were identified in 1999/2000 in either Queensland or the Northern Territory (Figure 6). This does not mean that the plant no longer exists in Australia, in many cases a weeds officer will record an outbreak of sicklepod and immediately begin control measures without distinguishing which species is involved.

Table 5. Organizations contacted regarding distributions of *Senna tora*.

Organization	Group (s)
Queensland Department of Natural Resources (DNR)	Land Services (Mackay)
	Tropical Weeds Research Centre (Charters Towers)
Queensland Environmental Protection Agency (EPA)	Queensland Herbarium (BRI)
Queensland Department of Primary Industries (DPI)	Tropical Beef Centre (Rockhampton)
	DPI (Mackay)
	DPI Forestry (Cardwell)
Mackay City Council	Parks Department
Bureau of Sugar Experiment Stations (BSES)	Herbert research station (Ingham)
	Proserpine extension office
	Innisfail extension office
	Sarina extension office
Central Queensland University (CQU)	Centre for Land and Water Resource Management
	Plant Sciences Group Seedbank Project
Northern Territory Department of Primary Industries and Fisheries (DPIF)	Horticulture
Parks and Wildlife Commission of the Northern Territory (PAW)	Botany

A collection of approximately 100 pods containing a total of between 1000 and 1500 seeds was provided by the Tropical Weeds Research Centre (TWRC) in Charters Towers, a section of the Queensland Department of Natural Resources (DNR). This seed had been collected from plants grown in a shade tunnel to a height of around 50 cm at the TWRC from 7 October 1997 to 8 April 1998. The original seed source was from plants collected in the wild in coastal north Queensland. The weight of 100 seeds was 1.847 ± 0.022 g (mean and standard error of three replicates). Based on these results the average seed mass is 18.5 mg and 100 g would consist of approximately 5400 seeds.

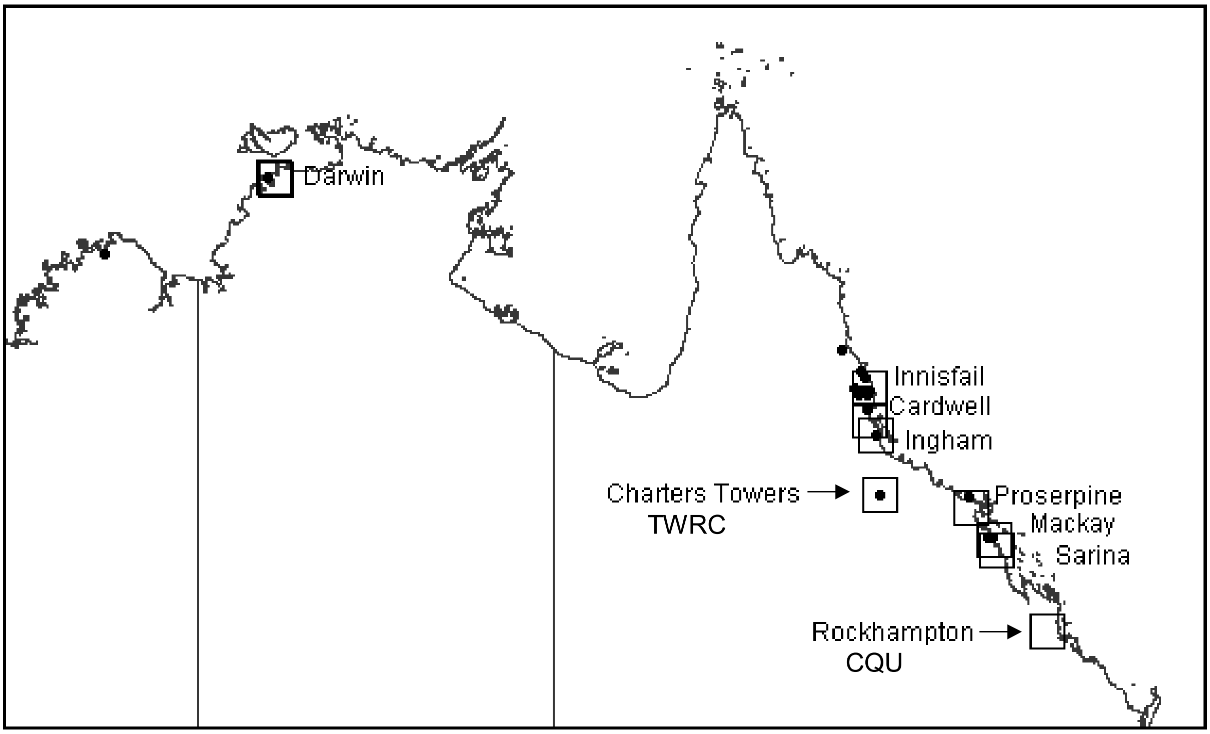


Figure 6. Historical distributions of *Senna tora* in Australia (solid circles) and regions contacted in 1999 (open squares). The Charters Towers site represents cultivated plants at the Tropical Weeds Research Centre.

6. Site selection

6.1. Weed control issues

As noted in section 4, In Queensland S*enna obtusifolia* is declared under two categories in areas where it is naturalized, P3 (area of infestation to be reduced), and P4 (prevent from spreading). In all other areas of the state the plant is classed as P2 (destroy all occurrences).

An approach to site selection for further field trials could be to grow *S. tora* within field plots located within a Shire where it is declared P3/P4 (i.e. an area where *S. tora* is already naturalised and not subject to eradication efforts). P3/P4 shires are Bowen, Burdekin, Cairns, Cardwell, Cook, Douglas, Hinchinbrook, Johnstone, Mackay, Sarina, Thuringowa, Townsville and Whitsunday. If a suitable site could be found within a P3/P4 shire, it would be necessary to liaise with regional land protection staff to check that the area is not within a local region where Council is actively controlling the plant. A suitable location would be where the plant is already growing wild and is not being controlled (Steve Csurhes, DNR, pers. comm. 2000).

6.2. Bioclimatic analysis

A bioclimatic analysis was undertaken to estimate site requirements and potential locations, without the key assumption of the legislative restrictions discussed above.

6.2.1. Methods

The 21 historical records were geocoded by assigning a latitude, longitude and elevation to each unique site. The elevations of each distribution were determined by interrogation of a 30 arc second Digital Elevation Model (DEM), GTOPO30, produced by the EROS Data Centre of the United States Geological Survey (USGS 1997). Tiles E100S10 and E140S10 of the DEM cover continental Australia and these were downloaded via the internet (edcftp.cr.usgs.gov) then imported into ArcView (ESRI 1999). Elevations were extracted using a script downloaded from the ESRI ArcScripts website (gis.esri.com/arcscripts/scripts.cfm).

The geocoded information was analysed with the software package ANUCLIM (Hutchinson *et al.* 1998). A bioclimatic profile consisting of 35 climatic parameters was generated for *S. tora* based on the 21 confirmed distributions in Australia using the BIOCLIM element of ANUCLIM (Table 6). This profile was compared with a climate profile for the entire continent produced using the 30 arc second grid of the DEM (using the BIOMAP element of ANUCLIM). The results were mapped in ArcView and presented in Albers equal-area conic projection.

6.2.2. Results

The weed occurs in high rainfall areas, from 1036 to 3984 mm per year. The lower part of this range is atypical however, as 95% of distributions were in areas receiving around 1200 mm/yr or more, and the median rainfall was 2800 mm/yr. The temperature ranges indicate that the plant prefers warmer climates e.g. the mean minimum temperature of the coldest month was 10.5 to 18.9 °C.

Mapping the climate profile showed that the potential distribution of *S. tora* in Queensland extends to the entire coastline of Queensland north of around Bundaberg to the western side of Cape York (Figure 7). With rainfall removed as a limiting factor, the potential southern and western range is not greatly extended (Fig. 8), suggesting that rainfall alone is not limiting the distribution of the plant.

Table 6. Bioclimatic profile for *Senna tora* based on historical occurrences in Australia

Parameter		Mean	S.D.	5%	50%	95%	Max.	Min.
1	Annual mean temperature	23	1.73	20.6	23	27.3	27.3	19.9
2	Mean diurnal range (mean(monthly max-min))	9.2	0.93	8.4	9.3	12.8	12.8	8.3
3	Isothermality (2/7)	0.55	0.03	0.49	0.56	0.62	0.62	0.48
4	Temperature seasonality (CV)	0.96	0.14	0.81	0.94	1.25	1.25	0.51
5	Maximum temperature of warmest month	30.7	1.56	29.3	30.5	36.1	36.1	28.5
6	Minimum temperature of coldest month	13.8	1.89	10.8	14.2	18.9	18.9	10.5
7	Temperature annual range (5-6)	17	1.66	14.9	17	22	22	14.5
8	Mean temperature of wettest quarter	25.8	1.31	23.9	25.9	28.7	28.7	22.7
9	Mean temperature of driest quarter	20.9	1.84	17.7	21.2	25.1	25.1	17.3
10	Mean temperature of warmest quarter	26.1	1.45	23.8	26	29.8	29.8	23.1
11	Mean temperature of coldest quarter	19.2	2.07	16.4	19.4	25.1	25.1	15.9
12	Annual precipitation	2531	878	1198	2805	3984	3984	1036
13	Precipitation of wettest month	521	145	290	536	801	801	271
14	Precipitation of driest month	54	32.3	5	68	97	97	0
15	Precipitation seasonality (CV)	86	13.8	72	85	122	122	70
16	Precipitation of wettest quarter	1420	408	811	1438	2127	2141	734
17	Precipitation of driest quarter	178	101	17	233	309	311	0
18	Precipitation of warmest quarter	1081	353	385	1134	1605	1619	232
19	Precipitation of coldest quarter	235	132	27	306	381	381	6
20	Annual mean radiation	19	1.12	18.2	18.6	22.6	22.6	18.1
21	Highest monthly radiation	24.2	0.69	23.7	23.9	26.2	26.2	23.4
22	Lowest monthly radiation	14.1	1.64	13.3	13.7	19.2	19.2	13.2
23	Radiation seasonality (CV)	18	3.04	10	19	20	20	9
24	Radiation of wettest quarter	19.6	1.02	18.7	19.1	21.6	21.6	18.7
25	Radiation of driest quarter	19.7	1.14	18	19.7	22.8	22.8	17.9
26	Radiation of warmest quarter	21.4	1.16	20.5	20.9	25	25	20.5
27	Radiation of coldest quarter	15.9	1.59	15.1	15.6	21	21	15.1
28	Annual mean moisture index	0.91	0.13	0.69	0.95	0.99	0.99	0.49
29	Highest monthly moisture index	0.99	0.03	0.91	0.99	1	1	0.87
30	Lowest monthly moisture index	0.78	0.26	0.27	0.89	0.97	0.97	0.08
31	Moisture index seasonality (CV)	10	14.9	2	6	61	61	1
32	Mean moisture index of high quarter MI	0.98	0.04	0.91	0.99	1	1	0.84
33	Mean moisture index of low quarter MI	0.8	0.24	0.38	0.9	0.97	0.97	0.12
34	Mean moisture index of warm quarter MI	0.85	0.22	0.35	0.92	0.99	0.99	0.18
35	Mean moisture index of cold quarter MI	0.95	0.13	0.78	0.97	1	1	0.44

Figures 7 and 8 predict that *S. tora* would not be suited to the climate of most of inland Queensland. A field trial at Biloela failed when the plants were killed by frost, confirming the Bioclimatic prediction for that site. Comparing the two figures indicates few areas where the plant could be grown under irrigation but would likely fail to become established a weed outside of irrigated areas. This approach would need to be taken cautiously for two reasons. Firstly the model requires further validation and secondly, weeds could still establish along irrigation channels and natural creeks and rivers. There is potential to cultivate the plant outside of the indicated regions, given attention to timing of this annual crop with respect to frost.

Figure 7. Bioclimatic model showing areas suitable for *Senna tora* based on four parameters for 21 recorded weed distributions.

Mean annual rainfall	1036 - 3984 mm
Mean maximum temperature of the hottest month	28.5 - 36.1 °C
Mean minimum temperature of the coldest month	10.5 - 18.9 °C
Mean annual temperature	19.9 - 27.3 °C

Figure 8. Bioclimatic model showing areas suitable for *Senna tora* under irrigation (Figure 7 with rainfall removed as a limitation).

7. Cultivation

Senna tora is not well known in cultivation and it is probably not deliberately grown as a seed gum crop anywhere in the world. The few papers dealing with deliberate cultivation of "*Cassia tora*" as a seed crop deal with the production of medicinal compounds in Korea. "*Cassia tora*" is also grown as a green manure or feed crop in India. However, in much of the published literature on *Cassia tora*, the plant under investigation is almost certainly *S. obtusifolia* (*Cassia obtusifolia*) which is still treated as a synonym of *S. tora* in some parts of the world. In the Korean *C. tora* study reported by Kwon *et al.* (1990) the stem lengths reported were around 130-190 cm, typical of *S. obtusifolia* but more than double the previous maximum reported height of *S. tora* of 70 cm. Some of these papers are referred to here despite relating to a different species. The two species are closely related and the factors affecting germination requirements, response to fertilizer and development time are likely to be similar. Where it is unclear which species was the subject of a paper, the name *S. tora/obtusifolia* is used.

7.1. Seed storage and germination

S. tora seed has a hard, impermeable seed coat and heavy scarification is required for germination. The optimum planting depth has not been reported for the *S. tora* or *S. obtusifolia*. Given the small size of the seed a depth of about 2.5 cm is recommended. In Australian conditions, sowing could be done with a standard mechanical planter.

S. tora produces two morphologically different types of seeds simultaneously, involving closed or open 'ultrastructures' (Bhattacharya and Saha 1997). Dormant seeds (with closed 'ultrastructures') were reported to germinate at all temperatures with scarification (96%), while non-dormant seeds (open 'ultrastructures') germinated best at 32 °C. The dormant seeds were reported to retain viability longer (two years compared to one year for non-dormant).

The effect of different storage temperatures on germination has been investigated for both *S. tora* and *S. obtusifolia* by Singh (1968), who reported that the germination rate for *S. tora* was very low for seed stored at low temperatures for one year (-15, 0 and +10 °C). The germination rate after one year at 20 and 30 °C respectively was 19.5 and 39.5%. This rate was low relative to *S. obtusifolia* seed under the same conditions, which had an optimal germination rate of 68% after storage at 30 °C.

The germination rates and viability times referred to above are very low compared to those observed in this study in Central Queensland. *S. tora* seed stored at laboratory temperatures (around 22 °C) for two years had a germination rate of almost 100% when adequately scarified (unpublished data). The viability of *S. tora* seed in the soil is likely to be at least 5-10 years and possibly as long as 20 years (Mackey *et al.* 1997). It is possible that the original moisture of the seeds and the rate of freezing prior to storage affected the results reported by Singh (1968).

7.2. Planting time and phenology

The development time and pod yields of *S. tora/obtusifolia* have been found to vary significantly with planting time. Kim and Cho (1989) demonstrated plants sown earlier in the year (April 20) flowered at around the same time as plants from later plantings (Table 7) but yielded considerably more pods (272 cf. 101 for June 20) (Table 8). These results indicate that the development time and extent are dependent on a photoperiod response and that *S. tora/obtusifolia* is a short-day plant.

Unfortunately, no seed mass yields were reported by Kim and Cho (1989). Assuming that seed mass increases with increasing pod number (supported by this study, data not shown) an increase of over 100% could be expected from sowing at the optimal time.

Table 7. Flowering characteristics of *Senna tora/obtusifolia* plants grown under different seasons in Korea (Kim and Cho 1989).

Sowing date	Initial flowering	Days to flowering	Flowering duration	Last flowering
April 20	August 6	108	42 days	Sep. 17
May 10	August 8	90	40	Sep. 17
May 30	August 9	71	40	Sep. 18
June 20	August 16	57	35	Sep. 18

Table 8. Number of flowers, fertilized ovules and pods per plant of *Senna tora/obtusifolia* grown under different seasons in Korea (Kim and Cho 1989).

Sowing date	Flower no/plant	Fertilized ovule no/plant	Pod no/plant	Fertilized ovules/flower (%)	Pods/flower (%)
April 20	469	299	272	63.7	57.9
May 10	452	281	247	61.1	56.4
May 30	441	271	244	61.4	56.8
June 20	226	135	101	59.7	47.7

Patterson (1993) reported that with 12 and 14 hr photoperiods, anthesis in *S. tora* occurred at 34 ± 1 and 46 ± 2 days from germination respectively. Under a 16 hr photoperiod, plants failed to flower. At least two weeks of short days were required for floral initiation, and six weeks were required for post-bud development. After the initial two weeks of short days, buds were reported to develop within 20 - 21 days, flowers by 30 - 40 days and pods by 35 - 43 days.

Further investigation into the effect of provenance variation for photoperiod response is required. Patterson (1993) notes that while *S. obtusifolia* from one ecotype failed to flower under 16 hr day lengths, the threshold for plants from another ecotype was 15 hr. It is possible that genetic variants of *S. tora* exist that also have different daylength responses.

For both *S. tora* and *S. obtusifolia* the main germination period in Queensland is in mid-summer following summer rains. By late summer, when flowering begins, many of the leaves shed, rendering the stem relatively bare while the pods develop until winter (Mackey *et al.* 1997). The timing of flowering and fruit set in *S. tora* in Australia has not been established. Queensland Herbarium records (24) from 1888 to 1990 indicate flowering and/or fruiting times from January to August in north Queensland. The ripening period of November to January in India (Hallagan *et al.* 1997) corresponds with May to July in Australia. *S. tora* will generally flower and senesce three to four weeks before *S. obtusifolia* in Australia (Vitelli and Setter 1999).

7.3. Planting density

The effect of planting density on growth and yield of *S. tora/obtusifolia* was investigated by Kwon *et al.* (1992). Four densities were trialled with and without vinyl mulching, 60 × 30 cm, 60 × 15 cm, 30 × 15 cm and 30 × 10 cm. The seed yield per area was highest under the 60 x 15 cm spacing and declined under the lower and higher planting densities. The least optimal spacing yielded 1.6 t/ha while the optimal spacing yielded 2.1 t/ha, a 31% increase. The species referred to in this study is probably *S. obtusifolia* as the reported stem length ranged from around 130 to 170 cm. Given that the *S. tora* is a smaller plant than *S. obtusifolia*, a higher planting density would be required to achieve comparable seed yields. A spacing of 30 × 15 cm was used in this study, which is similar to a typical spacing for guar of 40 × 10 cm (Murphy *et al.* 1996).

Spacing is not always significant in seed yields however, since a single larger, branching plant can yield as much seed as several smaller, single-stemmed plants. In trials of guar in India, planting density did not significantly affect seed, gum or protein yields per unit area (inter-row spacings of 20, 40 and 60 cm, Malik *et al.* 1981).

7.4. Seed yield

Seed yields for *S. tora* are not well documented in the literature. For *S. obtusifolia* several reports of seed yields from plants cultivated for medicinal compounds in Korea are available. Optimum seed yields for three trials were 1.3 and 2.6 t/ha (Kwon *et al.* 1990), 1.4 and 2.1 t/ha (Kwon *et al.* 1992) and 2.0 and 2.5 t/ha (Park *et al.* 1992). In each of these reports the higher yields were achieved with the use of polyethylene or vinyl mulching, the lower figure representing the maximum yield without mulching.

7.5. Irrigation requirements

The water requirements for *S. tora* and *S. obtusifolia* are not reported in the literature other than the observation that in Australia the plants are limited to high rainfall areas (i.e. more than 1650 mm per year) (James and Fossett 1982/83 cited in Mackey *et al.* 1997). This contrasts with the bioclimatic analysis reported in this study (section 6) which showed a weed distribution in areas with mean annual rainfall of 1036-3984 mm per year. Given rainfall uncertainties, a successful crop of *S. tora* in Australia would require irrigation to achieve adequate seed yields.

7.6. Fertilizer requirements

The optimum fertilizer regime for seed production in *S. tora/obtusifolia* in Korea was determined at a level of 80 kg/ha N, 60 kg/ha P_2O_5 and 60 kg/ha K_2O. At higher levels (160 kg/ha N, 120 kg/ha P_2O_5 and 120 kg/ha K_2O, seed yield actually declined (Park *et al.* 1992).

7.7. Pests and diseases

Several insect pests of *S. obtusifolia* and *S. tora* have been identified, mainly when seeking biological control agents for the weeds. One insect already being tested on the plants in quarantine in Australia is *Mitrapsylla*, a sap-feeding psyllid bug from Mexico (Vitelli and Setter 1999, Vitelli n.d.). At this early stage it is unlikely that *Mitrapsylla* will be a viable biological control organism as it has a broad host range and could infest native *Senna* species. A stem-galling weevil is also currently under investigation in Queensland as a potential biological control agent (Marie Vitelli, DNR, pers. comm., 1999).

These or any other biological control agents could make cropping of *S. tora* difficult, or at least more expensive in terms of insecticides. However, if cropping of the plant is done in inland areas which are distant from, and climatically different to, the coastal areas where biological controls are introduced, the insects may have little effect on crop plants. In any case, under cultivated conditions the crop may require only one to two insect sprays during the season, including one at flowering time.

7.8. Herbicide requirements

A herbicide application before or at sowing will be required. There may be no need for follow up sprays given the rapid early growth and coverage of the crop plant. An alternative approach is the use of polyethylene or vinyl mulching, as used in Korea for experimental cultivation of *S. tora/obtusifolia* (e.g. Park *et al.* 1992).

7.9. Harvesting

In India, any harvesting of *S. tora/obtusifolia* seed is done by hand (Giraudon and Willaert 1983). The methods of harvesting the seeds for medicinal purposes in Korea are not known but are also likely to be manual.

For commercial production of *S. tora* to be viable in Australia, the crop must be mechanically harvested. A rotary header is recommended, as it is gentler on the seed. A defoliant spray is not likely to be necessary since the leaves are shed naturally during pod ripening. Swathing may be required to minimize seed loss.

7.10. Genetic variation

Genetic diversity in *S. tora* is poorly understood. For the long-term future of any crop a broad genetic base is required to avoid inbreeding and to allow for the breeding of superior varieties for particular characteristics. It is critically important to base large-scale production on genotypes of reasonable gum yield and quality, which are suited to the local climatic and soil conditions. The size and form of the plant is also important to optimize seed yield, reduce wind damage and facilitate management and mechanical harvesting of the plant.

Given the wide geographic distribution of *S. tora* in Australia, and provided there has been multiple introductions of the plant from different sources, there may be considerable genetic diversity in the wild population. The distribution data obtained in the course of this study may be used as a starting point for future seed collections in Australia. Further distributions of the plant may be discovered in the near future as both the Department of Primary Industries and Fisheries (Northern Territory) and the Department of Natural Resources (Queensland) are undertaking studies into biological control of *S. obtusifolia*. These studies will involve field surveys that are likely to detect *S. tora* and other exotic *Senna* species.

Future development of the crop in Australia would almost certainly require import of new genetic material. This seed may be sourced from a number of different countries throughout Asia where the plant occurs (section 4).

8. Glasshouse and field experiments

8.1. Methods

Two bench trials of S*enna tora* were conducted in a quarantined glasshouse at Central Queensland University, Rockhampton. The main experiment was conducted in a tray constructed from 17 mm form ply with internal dimensions of 1.2 m × 2.4 m × 0.28 m. The dimensions of this 'field simulation' trial were eight rows 30 cm apart with eight plants in each row at 15 cm spacing (c. 22 plants per m^2). The plants on the periphery of the tray were excluded from the quantitative analyses to account for edge effects. Hence the data represent the results of 36 of the total 64 plants. Yield results were reported as the mean ± standard error.

On a second bench, 14 potted plants were grown in two rows 80 cm apart with 45 cm gaps within the rows, to multiply seed for possible future work. This bench was also used as a crude measure of seed yield of the plant with a widely spaced, branching growth habit, with essentially unlimited space for lateral growth (around 3 plants per m^2).

A soil mixture comprised of 20 parts sand, five parts coco-peat and one part vermiculite was used as the growing medium on both benches. An automated sprinkler system provided water to both benches at regular intervals with manual adjustment when required. Soluble fertilizer (Aquasol, N:P:K of 5.75:1:4.5) was applied at regular intervals.

Figure 9. Glasshouse trials of *Senna tora* at Central Queensland in March 2000, potted plants in the foreground and tray in the background.

A small plot of *S. tora* was sown on an experimental farm at Biloela, but plants were killed by frost while still in a vegetative stage.

A field harvest was conducted on wild *S. obtusifolia* weeds. The feasibility of mechanical harvesting was assessed with the use of an experimental harvester. The harvester (built by Kingaroy Engineering Works) is a small version of a conventional header specifically designed for harvesting experimental plots of a wide range of crops. The front is approximately 1.8 m wide with a cutter bar and open reel, A chain elevator takes the cut plant material to a conventional open drum. The threshed material is then passed over frog mouth sieves for cleaning and then taken by airblast to the bagging off area. All stages of this operation are fully adjustable to suit the particular crop.

8.2. Results

8.2.1. Phenology

Flowering commenced on 26 March 2000 on both benches despite the potted plants being planted 103 days earlier, harvest occurred 129 to 136 days after flowering(Table 9). Representative growth stages are shown in Figures 10, 12 and 13.

Table 9. *Senna tora* development in glasshouse conditions.

Event	tray plants		potted plants	
sowing	14 December 1999	(day 0)	2 September 1999	(day 0)
emergence	17 December 1999	(day 3)	6 September 1999	(day 4)
floral initiation	26 March 2000	(day 103)	26 March 2000	(day 206)
ripe pod harvest	2 August 2000	(day 232)	9 August 2000	(day 342)

The development time in the Central Queensland trials was longer than that reported for *S. tora* grown experimentally under 12 and 14 hr photoperiods (Paterson 1993). Day lengths were far longer during this experiment and also varied naturally over the period from Spring through to Autumn.

8.2.2. Seed yield

The seed yield in the tray plants averaged 3.6 ± 0.4 g and ranged from 0.5 to 7.2 g (Table 10). The potted plants yielded 13.6 ± 2.5 g and ranged from 2.0 to 25.0 g.

Table 10. *Senna tora* seed yields data obtained from glasshouse trials.

Seed yield estimate	Tray data average	Tray data maximum	Pot data average	Pot data maximum	Field harvest
g/plant (actual)	3.6 ± 0.4	7.2	13.6 ± 2.5	25.0	N/A
Crop scenario	30 × 15 cm	30 × 15 cm	80 × 45 cm	80 × 45 cm	Wild harvest
t/ha (equivalent)	0.8	1.6	0.4	0.7	0.14

8.2.3. Mechanical harvesting

The field harvest of a wild stand of *S. obtusifolia* weeds demonstrated that the *Senna* gum species could be mechanically harvested successfully (Figure 11). The yield of 14 kg of seed from an area of 40 m^2 corresponds to 137 kg/ha (Table 10). The yield was low for several reasons:

- The plants were wild weeds and not cultivated as a crop (no site preparation, irrigation or fertilizer was applied),
- The harvest time was later than optimal and many of the pods had already split, shedding their seed,
- Swathing was not done to aggregate the pods before fully ripe (this practice minimises seed loss in other dehiscent podded crops).

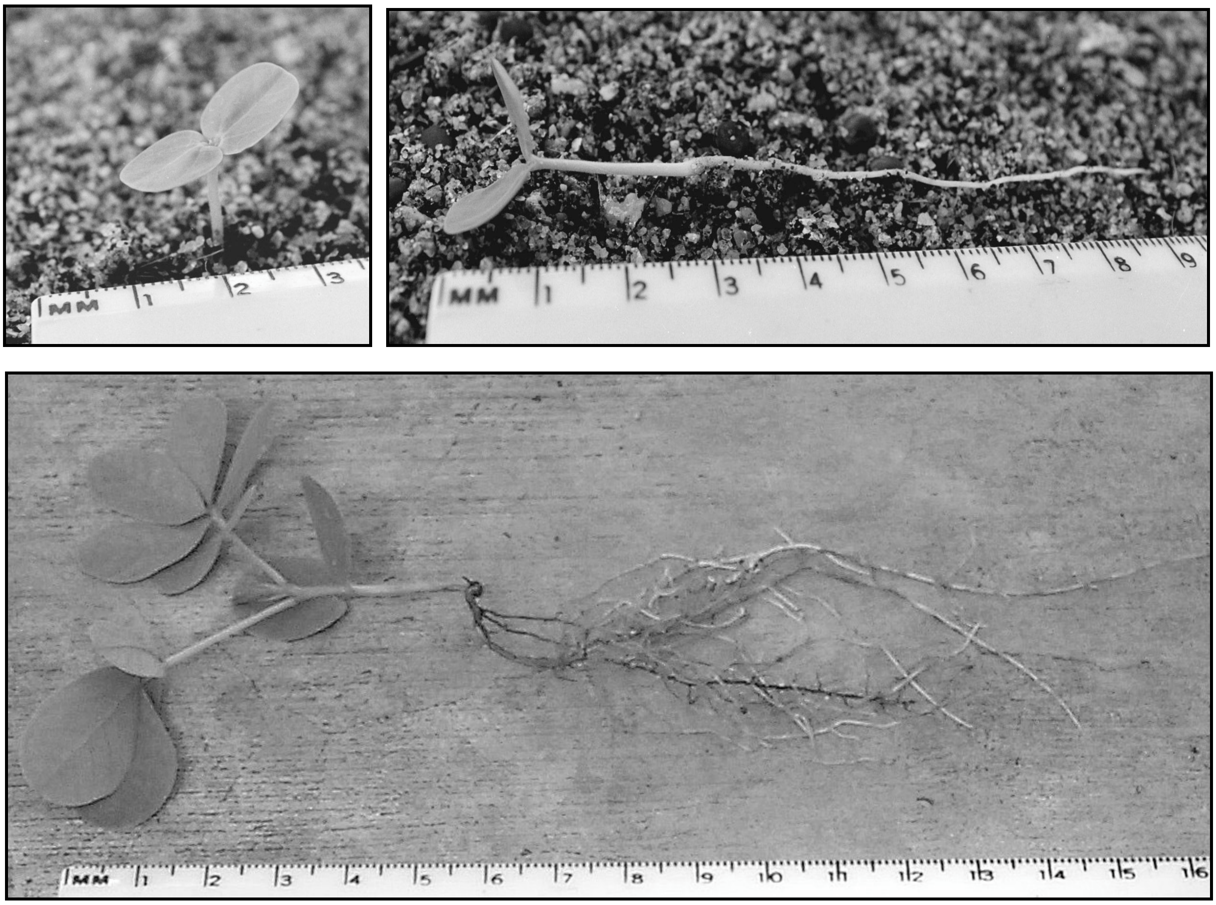


Figure 10. *Senna tora* seedlings. Clockwise from top left, newly germinated seedling, developing tap root and later, branching root system.

Figure 11. Experimental mechanical harvesting of wild *Senna obtusifolia* seed.

Figure 12. *Senna tora* plants at full height (up to 120cm) in the glasshouse tray trial, April 2000.

Figure 13. *Senna tora* potted plant with spreading growth habit resulting from wide spacing.

9. Estimated gross margin for cropping in Central Queensland

There are several possible scenarios for the development of a *Senna tora* gum industry in Australia including:

A. A wild harvest (as performed in India) of existing weed populations which are dominated by *S. obtusifolia*.

Or

B. A new irrigated broadacre crop using techniques similar to existing grain crops in Australia, producing *S. tora* seed for either

B1. A local processor dehusking the seed and exporting the splits to India or Europe for processing into gum.

Or

B2. A local processor manufacturing the gum completely for local consumption and possibly for export.

Scenario B is considered the most feasible option for Australia as a wild harvest would be extremely variable in terms of quantity and quality of seed and because wild populations of the plants are not usually located on sites which are amenable to mechanical harvesting. Manual harvesting is not an option for this type of crop in Australia because of the expense per unit harvested.

Exporting of grain for processing and subsequent importing of the finished product would not be a preferred option because of the cost of transport of whole seed. Extraction of the splits for export also allows local use of the seed meal by-product as stock feed. Dehusk the seeds on-farm in cropping areas with transport of the splits only also reduces the potential of spreading the weed via spilt seed.

Another option is the development of a local processing facility to manufacture the gum from the splits.

9.1. Assumptions

The gross margin (difference between returns and variable costs) is one measure of the financial performance of a crop. It can be used for a direct comparison between crops where there is an existing enterprise, which can be run using existing resources. The gross margin does not take into account overhead costs such as rates, electricity, insurance and interest. Another important assumption is that the owner's labour and permanent labour costs are not included.

9.2. Returns

The value of *S. tora/obtusifolia* seed has been estimated at AU$500/t based on current gum prices although this figure may drop as low as $250/t when the food/feed use patent expires (Hogan, pers. comm.). A conservative farmgate price estimate of $250/t of seed is applied in this analysis.

9.3. Costs

Cost estimates were based on gross margins published for irrigated wheat, barley and chickpea in Central Queensland by Graham Harris, a DPI agronomist. The cost figures quoted are intended to be indicative of the district and may vary considerably between properties. The costs for the field crops used in these examples were indicative of May 1999 prices.

9.3.1. Seed

The cost of seed for *S. tora* is uncertain, since there are no recognised strains developed for cropping and no large market for planting-quality seed. At a planting density of 22 plants/m, a total of 222,000 plants/ha would be required (around 4.2 kg of seed). Since no bulk prices for *S. tora* seed are available, an estimate of $30/ha is used here for the cost of planting seed based on estimates for wheat and barley seed Harris (1999a, b). Before the establishment of a *S. tora* industry in Australia the cost of planting seed would probably be higher than this. The approximate amount of seed required for various planting densities is:

- 4.2 kg/ha at 22.2 plants/m^2
- 6.9 kg/ha at 37 plants/m^2
- 9.3 kg/ha at 50 plants/m^2

9.3.2. Cultivation and planting

For wheat, barley and chickpea, a primary chisel tillage is commonly followed by three secondary chisel tillage operations in the five to six months preceding planting. This cost is estimated as $9.76/ha (primary) and $4.59/ha (secondary), totaling $23.53/ha (Harris 1999a, b, c). The operation of a seed planter is estimated as $4.54/ha for wheat and barley and chickpea (Harris 1999a, b) The preparation requirements would be similar for *S. tora* and the same estimates are used here.

9.3.3. Fertilizer and application

The typical practice for fertilizer application on wheat and barley crops is for urea and DAP (di-Ammonium Phosphate) to be applied shortly after planting. With chickpea, DAP only is applied at the same time as planting. The figures estimated for wheat and barley assume 250 kg/ha urea at $0.45/ha and 40 kg of DAP at $1.06/kg, the cost of operating the spreader is $2.10/ha in each case (Harris 1999a, b, c).

An optimum level of N for seed yield in *S. tora/obtusifolia* was been established as 80 kg/ha (Park *et al.* 1992), since urea is 46% N an amount of 174 kg/ha of urea is used here i.e. 80 kg N/ha. At the $0.45/kg, this amounts to $78.30/ha.

The cost for DAP fertiliser is estimated at $42.30/ha as for wheat, barley and chickpea (Harris 1999a, b, c). This allows for 40 kg DAP which contains less P than the optimum level of 60 kg/ha established by Park *et al.* (1992). DAP contains 20% P, 18.0% N and 1.7% S, and is generally applied at planting, with or beside the seed (Incitec 1999). A further application of fertiliser containing K and trace elements would probably be required for sustainable cropping. As with any estimate of fertiliser requirements the actual amount used will vary with the soil on the site. The cost for DAP fertiliser of $42.30/ha is used as an estimate in the current analysis.

9.3.4. Herbicide and application

Herbicide is not necessary with chickpea crops and may not be required for cropping of *S. tora* since the plant can quickly establish a ground cover and prevent the establishment of weeds. For the purposes of this estimate, a single herbicide application as used for wheat and barley (Harris 1999a, b), is included at $16.30/ha (2.1 L of MCPA herbicide at $7.05/L applied by boom spray operated at $1.49/ha).

9.3.5. Insecticide and application

Insecticide is not typically applied to wheat and barley, while for chickpea an application of Larvin insecticide (0.75 L/ha at $16.40/L) may be applied by contract aerial spray at $8.50/ha, amounting to a total cost of $20.80/ha (Harris 1999c). This figure is used here as a first estimate for the insecticide requirements of *S. tora*, although the actual requirements are yet to be determined and may vary considerably. An additional cost of $12.35/ha for scouting of chickpea crops is not included here for *S. tora*.

9.3.6. Irrigation water and application

The use of side-roll irrigation is common for wheat, barley and chickpea. In Central Queensland the volume of water required for these crops is estimated at 2.5 ML/ha and valued at $39.09/ML (i.e. $97.73/ha) (Harris 1999a, b, c). It can be assumed that *S. tora* would require a volume equal to or greater than this amount, and for this preliminary analysis the figure of 2.5 ML/ha is used. Since this is one of the major costs, second only to fertilizer, any increase in the volume or price of irrigation will significantly reduce the gross margin.

9.3.7. Harvesting

The example assumes that contract harvesting is used. If the farmer were to use their own header this may affect the cost of harvesting and the overall gross margin (Harris 1999a, b, c). The estimated cost for contract harvesting of wheat and barley at $58.33/ha is used here.

9.3.8. Summary of costs and returns

A spreadsheet was produced (in MS Excel) to explore the effects of yield and price variability on the gross margin of *S. tora* compared to existing Central Queensland crops (Table 11).

Table 11. Estimated gross margins for *Senna tora* and other irrigated crops in Central Queensland

Income		
Wheat	4.00 tonnes/ha	at $159.40/tonne (on farm)
Barley	4.40 tonnes/ha	at $110.72/tonne (on farm)
Chickpea	2.50 tonnes/ha	at $328.49/tonne (on farm)
Senna tora	**2.60** tonnes/ha (*estimated*)	at $250.00/tonne (on farm) (*estimated*)

		Wheat	Barley	Chickpea	*Senna tora*
A. Total income ($/ha)		**637.60**	**487.17**	**821.23**	**650.00**
Variable costs		$/ha	$/ha	$/ha	$/ha
Seed		27.60	28.50	50.00	50.00
Cultivation		23.53	23.53	23.53	23.53
Planting		4.54	4.54	7.29	4.54
Fertiliser spreader		2.10	2.10	0.00	2.10
Fertiliser (urea)		112.50	112.50	0.00	78.30
Fertiliser (DAP)		42.30	42.30	42.30	42.30
Herbicide & application		16.30	16.30	0.00	16.30
Insecticide & application		0.00	0.00	33.15	20.80
Irrigation (2.5 ML @ $39.09/ML)		97.73	97.73	97.73	97.73
Harvesting		58.33	58.33	39.77	58.33
B. Total variable costs ($/ha)		**384.93**	**385.83**	**293.77**	**393.93**
Gross margin					
C.1	$/ha (**A**-**B**)	**252.68**	**101.34**	**527.46**	**256.08**
C.2	$/ML (**C.1**/ML/ha)	101.07	40.54	210.98	102.43

Note: figures for wheat, barley and chickpea obtained from Harris (1999a, b, c)

9.4. Outcomes

The break-even point, or $0/ha, is achieved in the model at 1.6 t/ha (Table 12). The gross margin of barley in the model ($101/ha) is achieved with a *S. tora* seed yield of 2.0 t/ha. Assuming a yield of 2.6 t/ha in the *S. tora* model produces a gross margin of $256/ha, equal to that of wheat and more than double that of barley.

At the average yield of the glasshouse tray plants, equivalent to 0.8 t/ha, cropping would not be economically viable within the parameters of the model, returning around negative $200/ha. Even taking the maximum yielding plant with 7.2 g as a representative yield (1.6 t/ha), the gross margin would be about zero. The average and maximum yield of the potted plants would return less than negative $200/ha.

Gross margin very sensitive to on-farm price. With a yield of 2.5 t/ha and seed prices of less than $200/t, the crop would not be viable (Table 12). At the current estimated seed price of AU$500/t the yields achieved in the glasshouse trial (about 1.0 t/ha) would be economically viable. As noted above however, a more likely long term price is AU$250/t.

Table 12. Effect of yield and price on gross margin for *Senna tora*

Yield	**On farm price ($/tonne)**									
(tonnes/ha)	$125	$150	$175	$200	$250	$275	$300	$325	$350	$500
1.00	-269	-244	-219	-194	-144	119	-94	-69	-44	106
1.25	-175	-206	-175	-144	-81	-50	-19	12	44	231
1.50	-144	-169	-132	-94	-19	19	56	94	131	356
1.75	-112	-131	-88	-44	44	87	131	175	219	481
2.00	-81	-94	-44	6	106	156	206	256	306	606
2.25	-50	-56	0	56	169	225	281	337	394	731
2.50	-81	-19	44	106	231	294	356	418	481	856
2.75	-50	19	87	156	294	362	431	500	569	981
3.00	-19	56	131	206	356	431	506	581	656	1106
3.25	12	94	175	256	419	500	581	662	744	1231
3.50	44	131	219	306	481	568	656	906	831	1356
	Gross margin ($/ha)									

10. Future directions

10.1. Yield and gross margin

10.1. Yield and gross margin

The seed yield achieved in the glasshouse trial of *Senna tora* was not adequate for commercial production at present, but is adequate to support further trial work with this crop. This yield would need to be tripled to enable profitable production within the parameters of the gross margin model. While tripling of the yield for *S. tora* may seem difficult, it is typical in plant domestication. For example, average wheat yields in Australia quadrupled from less than 0.5 to more than 2.0 t/ha from 1896 to 1996. While there was annual variability due to climate, the generally consistent yield increases can be attributed to breeding of superior varieties and improving agronomic practices. This level of increase was achieved after thousands of years of domestication of wheat, whereas *S. tora* has yet to be domesticated, suggesting large gains could be made quickly.

The current low yields of *S. tora* could be due to either or both poor varietal development or sub-optimal agronomic practices, most likely planting time and spacing. In both cases no systematic research was attempted in the current work, and the results reported here represent a baseline study only.

The potential for improved seed yield through agronomic practices may be estimated by analysis of Korean attempts to domesticate the closely related *S. obtusifolia*. Seed from this plant is used for medicinal compounds in Korea and is combined with *S. tora* for gum production in India. Reports of seed yields from *S. obtusifolia* range up to 2.6 t/ha (Kwon et al. 1990). Similar yields should be achievable for *S. tora* with the development of suitable varieties and agronomic practices. A doubling of yield was indicated through planting in April, rather than June, and a 30% increase was achieved by planting at a spacing of 60 × 15 cm, cf. 30 × 10 cm.

The height of *S. tora* in this trial ranged from 77 to 126 cm, extending the maximum height previously reported. Mackey *et al.* (1997) cite examples from the literature showing that *S. tora* grows to a maximum height of 70 cm whilst *S. obtusifolia* can reach a height of 2.5 m. The height and form of the plant are important both to optimize seed yield and to facilitate management and mechanical harvesting of the plant. The wide range of height and growth habits observed indicate significant potential for manipulation of the crop through breeding and management.

10.2. R&D required for development of a *S. tora* gum chain

Successful establishment of a new industry requires attention to all elements of the supply chain (Figure 14). However, the rate limiting step at this point would appear to rest in the yield of the crop.

Varietal selection should be undertaken to select plants with desirable agronomic traits, gum yield and gum quality. The agronomy of the system should be further defined in terms of planting time, planting density and fertilizer requirement.

Future R&D investment will require careful monitoring of price following the expiry of the patent on the use of the gum and the entry of new producers in the market. The major limitations on the establishment of a *Senna tora* gum industry in Australia at present are (a) the weed potential of *S. tora* and S. *obtusifolia*, and (b) the establishment of an appropriate seed refining plant.

Government and community acceptance of the weed risk of the plants is prerequisite to any further work.

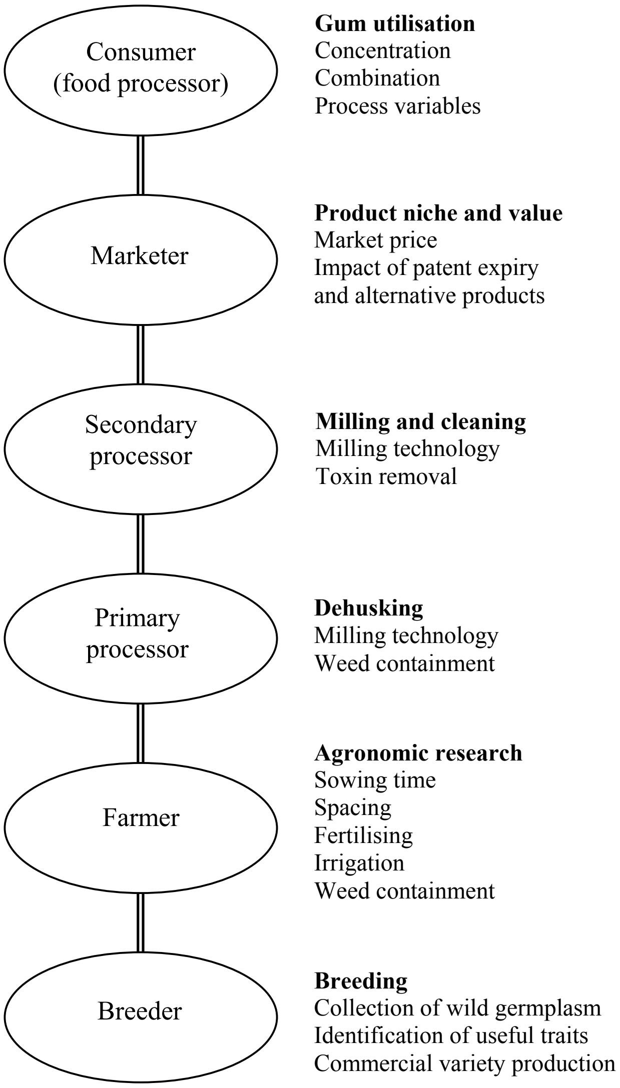


Figure 14. Potential chain for *Senna tora* gum production and R&D required at each point.

Appendix A. *Senna tora* information sheet

Wanted: *Senna tora* (*Cassia tora*, foetid cassia, sicklepod)

Senna tora is a herb or small shrub up to 0.5 m tall, it is closely related to *Senna obtusifolia* (*Cassia obtusifolia*) which is commonly known as sicklepod or arsenic weed and is a declared plant in Queensland. *Senna tora* is also an introduced species but is far less common and is not a declared plant.

In Queensland both species occur in wet tropical lowlands from Mackay to Cooktown and flower in winter (March to August).

The two species are distinguished by the anthers (truncate in *S. tora*, beaked in *S. obtusifolia*) and the seed areoles (broad and longitudinal in *S. tora*, narrow and transverse in *S. obtusifolia*).

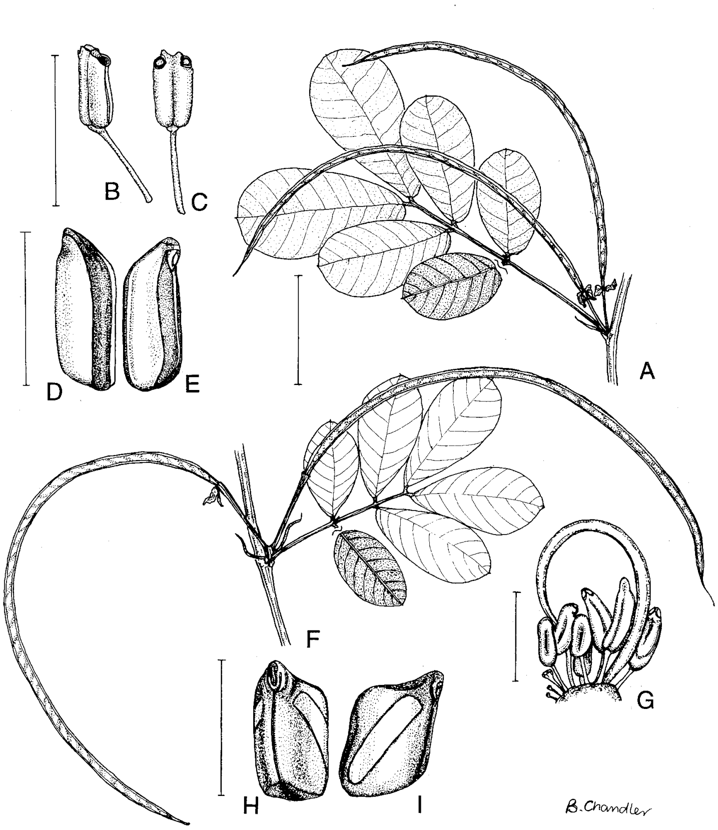
Research at Central Queensland University

Senna tora seed is required for research into its potential as a source of vegetable gums for the food industry.

Any sightings (or seeds - including a specimen of leaves, twigs, pods, flowers and a record of the location and date) should be reported or forwarded to:

David Cunningham
Plant Sciences Group
Central Queensland University
Rockhampton Qld 4702

Phone 07 4930 6584
Fax 07 4930 9255
Email davidcunningham@ozemail.com.au



A-E, ***Senna tora***
A. fruiting twig
B-C. isolated anthers showing truncate tips
D-E. seed showing broad, longitudinal areole.

F-I, ***Senna obtusifolia***
F. fruiting twig
G. androecium showing three abaxial beaked anthers
H-I. seed showing narrow, transverse areole.

A and **F** show abaxial surface of one disconnected leaflet.

Scale bars:
A, **F** = 3 cm
B, **C** = 3 mm
D, **E**, **H**, **I** = 4 mm
G = 6 mm.

Reproduced from Randell and Barlow (1998 p. 136).

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