

# Bambara groundnut

## *Vigna subterranea* (L.) Verdc.

Proceedings of the workshop on  
Conservation and Improvement of Bambara Groundnut (*Vigna subterranea* (L.) Verdc.)  
14–16 November 1995  
Harare, Zimbabwe



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editors*



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Citation:

Heller, J., F. Begemann and J. Mushonga, editors. 1997. Bambara groundnut (*Vigna subterranea* (L.) Verdc.). Promoting the conservation and use of underutilized and neglected crops. 9. Proceedings of the workshop on Conservation and Improvement of Bambara Groundnut (*Vigna subterranea* (L.) Verdc.), 14–16 November 1995, Harare, Zimbabwe. Institute of Plant Genetics and Crop Plant Research, Gatersleben/Department of Research & Specialist Services, Harare/International Plant Genetic Resources Institute, Rome, Italy.

ISBN 92-9043-299-3

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## Foreword

Humanity relies on a diverse range of cultivated species; at least 6000 such species are used for a variety of purposes. It is often stated that only a few staple crops produce the majority of the food supply. This might be correct but the important contribution of many minor species should not be underestimated. Agricultural research has traditionally focused on these staples, while relatively little attention has been given to minor (or underutilized or neglected) crops, particularly by scientists in developed countries. Such crops have, therefore, generally failed to attract significant research funding. Unlike most staples, many of these neglected species are adapted to various marginal growing conditions such as those of the Andean and Himalayan highlands, arid areas, salt-affected soils, etc. Furthermore, many crops considered neglected at a global level are staples at a national or regional level (e.g. tef, fonio, Andean roots and tubers, etc.), contribute considerably to food supply in certain periods (e.g. indigenous fruit trees) or are important for a nutritionally well-balanced diet (e.g. indigenous vegetables). The limited information available on many important and frequently basic aspects of neglected and underutilized crops hinders their development and their sustainable conservation. One major factor hampering this development is that the information available on germplasm is scattered and not readily accessible, i.e. only found in 'grey literature' or written in little-known languages. Moreover, existing knowledge on the genetic potential of neglected crops is limited. This has resulted, frequently, in uncoordinated research efforts for most neglected crops, as well as in inefficient approaches to the conservation of these genetic resources.

This series of monographs intends to draw attention to a number of species which have been neglected in a varying degree by researchers or have been underutilized economically. It is hoped that the information compiled will contribute to: (1) identifying constraints in and possible solutions to the use of the crops, (2) identifying possible untapped genetic diversity for breeding and crop improvement programmes and (3) detecting existing gaps in available conservation and use approaches. This series intends to contribute to improvement of the potential value of these crops through increased use of the available genetic diversity. In addition, it is hoped that the monographs in the series will form a valuable reference source for all those scientists involved in conservation, research, improvement and promotion of these crops.

This series is the result of a joint project between the International Plant Genetic Resources Institute (IPGRI) and the Institute of Plant Genetics and Crop Plant Research (IPK). Financial support provided by the Federal Ministry of Economic Cooperation and Development (BMZ) of Germany through the German Agency for Technical Cooperation (GTZ) is duly acknowledged.

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## Preface

This workshop was jointly organized by the Department of Research and Specialist Services, Harare, Zimbabwe, and the International Plant Genetic Resources Institute, Rome. Financial support for the workshop was provided by the neglected crops project, funded by the German Federal Ministry of Economic Cooperation and Development (BMZ).

## Opening Address

***D. Mungate, on behalf of the Hon. D. Norman, Minister of Agriculture***

Mr Chairman, Distinguished Delegates, Ladies and Gentlemen –

I would like to welcome you all to this workshop, for which the goal is to improve awareness among scientists of their mutual problems and of the possible approaches to solving them, as well as strengthening international cooperation on bambara groundnut. I would like to extend my welcome to those participants from various African and European countries, and from international organizations. I would also like to take the opportunity to thank the International Plant Genetic Resources Institute (IPGRI), the Department of Research and Specialist Services for organizing this workshop, and the German Federal Ministry of Economic Cooperation and Development, who sponsored the event.

The specific objectives of the workshop are to:

- (i) exchange information on conservation and utilization of genetic resources on bambara groundnuts;
- (ii) identify gaps and constraints in the conservation and use of this crop;
- (iii) foster collaborative activities among scientists and to consider the establishment of a network, and
- (iv) develop an African plan of action for the conservation, use and research of bambara groundnut.

Bambara groundnut, locally known as ‘nyimo’ (Shona) or ‘indlubu’ (Ndebele), is an indigenous African crop that has been cultivated in Africa for centuries. It is a highly nutritious plant, which plays a crucial role in people’s diets. The crop is now grown in the continent from Senegal to Kenya, and from the Sahara to South Africa and Madagascar. However, bambara groundnut remains one of the crops that is most neglected by the scientific community. It is commonly referred to as a ‘poor man’s crop’, and the plant has never been allocated a large-scale research programme. Yet empirical evidence and the results of specific research programmes indicate that bambara groundnut is a crop with considerable promise. As one of the two most drought-tolerant legumes, it deserves greater attention than it has received to date. Indeed, efforts should be intensified to conserve, improve and utilize genetic resources in general in Zimbabwe and the rest of Africa in a sustainable manner.

It has been shown that farm yields are in the region of 500 kg/ha, yet under research conditions, this figure can be raised to 4000 kg/ha. The difference, Mr Chairman, lies in selecting high-yielding varieties and using well-researched agronomic practices. The challenge, therefore, is to narrow this gap and improve food security at household level. It is acknowledged that bambara groundnut can be used for relish and stock fodder. It can also be used as a soil conditioner, owing to its ability to fix much-needed nitrogen in the soil. Unconfirmed observations indicate that the crop can suppress *Striga* species, a parasitic weed found in sandy soils. The great majority of humans are now living off a maximum of 12 plant species, compared with 100 000 edible plant species during the primitive ages. This is because of the introduction of modern farm machinery and transport methods, which have led farmers to concentrate on a few crops. A small group of usually very high-yielding cereal and legume crops have replaced most of the heterogeneous local landraces. World food production has been boosted by modern farming methods, but at a considerable price, which may even be greater in the future. Many heterogeneous

local varieties of crop species have been lost forever. The loss of local species or landraces means an irreversible loss of invaluable genetic diversity, including the traits for local adaptation to the site where the species or variety evolved.

In our attempts to increase production, we are consciously reducing the biodiversity that took millions of years to achieve. This process of genetic erosion has depleted the gene pool available for natural selection processes. If it is unchecked, genetic erosion reduces genetic resistance and at the same time increases the vulnerability of agricultural crops to sudden and abrupt changes in climate or weather, or to the appearance of new pests and diseases. Underlying the devastating potato famine which ravaged Ireland in the 19th century and caused some 2 million Irish people to starve to death is the extremely narrow genetic base of the potato cultivated at that time in Europe, as the Food and Agriculture Organization of the United Nations (FAO) has reported.

It is my view that if we are not careful, history will repeat itself. Ways must be found to control the genetic erosion currently occurring in our agricultural systems. To achieve this, we need to maintain collections of representative samples of local landraces of bambara groundnut for possible future use. The crop could also be improved by replacing natural with artificial selection. Such strategies involve altering the genetic composition of a plant, so that they become more ergonomically productive, and easier to harvest and process. Scientists could improve crop yield by increasing the harvest index. Yields of cereals such as wheat, maize and rice have been increased primarily by raising the weight of grain relative to the straw.

Another improvement strategy involves grain quality. In theory each crop could be improved in different ways, such as by the enhancement of nutritional composition and cooking quality. An improved crop should resist waterlogging, drought, pests and diseases too, and these problems also need to be addressed by researchers and breeders.

The ability of plants to symbiotically fix atmospheric nitrogen is another aspect of their cultivation which deserves the attention of crop breeders. A rigorous breeding programme could be embarked on with a view to improving the nitrogen-fixation capacity of the existing varieties of bambara groundnut, on which subject few studies have been recorded to date. As nitrogen fixation is increased, soils will become more productive. This will in turn increase food production, particularly on African soils, which have a low inherent fertility compared with European soils.

In summary, while crop improvement strategies are desirable to increase productivity and hence food security at the household level, there is an even greater need to conserve genetic diversity. Bambara groundnut is one example of a crop where the farmer still maintains some diversity. The onus is therefore on the scientific community to increase research on bambara groundnut and to facilitate conservation of such diversity.

But what precise role can researchers play to achieve this objective? A starting point might be the collecting, characterization, classification and storage of germplasm in genebanks. Members of the Southern African Development Community (SADC) have genebanks in Zambia and Zimbabwe for this specific purpose. However, mechanisms need to be put in place whereby material may be returned to farmers periodically, to enable them to maintain the genetic diversity of their crops and determine their natural resource use.

The challenge is a great one, and I look forward to reading the proceedings of your workshop. May I now declare the workshop officially open. I hope that you will enjoy your discussions and your stay in Zimbabwe.



## Introduction

**A.E. Goli**

IPGRI, Cotonou, Benin

It is my pleasure on this occasion to say a few words on behalf of Dr Geoffrey Hawtin, Director General of the International Plant Genetic Resources Institute (IPGRI), and also on behalf of Dr Franck Attere, IPGRI Regional Director for Sub-Saharan Africa.

IBPGR (International Board for Plant Genetic Resources), IPGRI's predecessor, was established in 1974 as a CGIAR centre, and operated under the administration of FAO. Its major activity was originally the collecting and conservation of crop germplasm for future use. With the increasing degradation of the environment, however, IBPGR progressively expanded its role. It became a fully independent institute in 1994, and was renamed IPGRI. The structure of the institute comprises three thematic groups (Germplasm Maintenance and Use; Genetic Diversity; Documentation, Information and Technology), based at headquarters in Rome, and five regional groups across the continents (America; Asia, the Pacific and Oceania; Europe; Western Asia and Northern Africa; Sub-Saharan Africa). The regional office for Sub-Saharan Africa is based in Nairobi, with a local office for West Africa in Niamey, Niger [Ed. note: now in Cotonou, Benin].

IPGRI has four principal objectives in its mandate:

- (i) to assist countries, particularly developing nations, to assess and meet their needs for conservation of plant genetic resources, and to strengthen links with their users;
- (ii) to strengthen and contribute to further international collaboration in the conservation and use of plant genetic resources;
- (iii) to develop and promote improved strategies and technologies for plant genetic resource conservation, and
- (iv) to provide an international information service on plant genetic resources.

Distinguished participants, it will be apparent to you that the present gathering falls within the second objective of IPGRI, i.e. the development of international collaboration on the conservation and use of bambara groundnut genetic resources. It is well known that bambara groundnut is an indigenous crop to this continent, and is widely grown by rural communities in many African countries. Yet at the same time, bambara groundnut is a crop that is neglected by our research centres.

A substantial effort to improve bambara groundnut has not been made, and yet our countries possess all the genetic diversity needed for the improvement for this crop, of importance to Africa's future. It is precisely because action needs to be taken in this regard that we are assembled here this morning.

Once again, on behalf of IPGRI's Director General and the Regional Director for Sub-Saharan Africa, I wish you every success with this timely workshop on bambara groundnut.

## Bibliographical Review

**A.E. Goli**

IPGRI, Cotonou, Benin

### Introduction

Bambara groundnut is a popular crop in the whole of Sub-Saharan Africa. Its cultivation seems to have preceded the introduction of the common groundnut (*Arachis hypogaea*), of American origin. In many traditional farming systems, it is found intercropped with cereals and root and tuber crops. Bambara groundnut is reported to have been carried as far as India, Sri Lanka, Indonesia, the Philippines, Malaysia, New Caledonia and South America, particularly Brazil (Rassel 1960), but it seems that the present degree of cultivation outside Africa is negligible.

### Taxonomy and origin

Bambara groundnut belongs to the family Leguminosae, subfamily Papilionoideae, although further refinement of its taxonomy has been subject to some controversy. The crop is first mentioned in the 17th-century literature (Marcgrav de Liebstad 1648), where it is referred to as 'mandubi d'Angola'. In 1763, Linnaeus described it in *Species Plantarum*, and named it *Glycine subterranea*, in accordance with his system of nomenclature. Du Petit-Thouars (1806) found the crop in Madagascar, under the vernacular name 'voanjo', subsequently written as 'voandzou' in French. He then proposed the name *Voandzeia subterranea* (L.) Thouars, which was widely used by subsequent researchers for over a century. Recently, detailed botanical studies were undertaken by Maréchal *et al.* (1978), who found great similarities between bambara groundnut and plant species of the genus *Vigna*. This confirmed studies done by Verdcourt, who seized the opportunity in 1980 to propose the current name *Vigna subterranea* (L.) Verdc.

Investigators interested in the origin of bambara groundnut (Dalziel 1937; Jacques-Felix 1946; Rassel 1960; Hepper 1963; Begemann 1988a) all agreed that the crop originated from the African continent. The common name actually appears to be derived from a tribe, the Bambara, who now live mainly in Mali. The exact area of origin of the crop in Africa has been a matter of debate, however. No spontaneous or wild forms of the crop have been found in Mali, although Guillemain *et al.* (1832) reported the probable occurrence of wild forms in nearby Senegal. Bambara groundnut was found by Dalziel in its genuinely wild state in 1901, in the North Yola province of Nigeria. He reported that Ledermann also found the wild plant the same year, near Garoua in northern Cameroon. Dalziel's finding was confirmed by Hepper in 1957. The distribution of wild bambara groundnut is now known to extend from Jos Plateau and Yola in Nigeria, to Garoua in Cameroon, and probably beyond.

As further confirmation, Begemann (1988a) carried out detailed analyses of the seed-pattern diversity within the large collection of bambara groundnut at IITA. He found that samples collected less than 200 km from the putative centre of origin, between Yola and Garoua, consistently showed a greater seed-pattern diversity. Diversity indices for the number of days to maturity, pod length, number of stems per plant and internode length, were comparatively higher for accessions from Nigeria

and Cameroon. His conclusion confirmed the hypothesis that the centre of origin of bambara groundnut is in the region of northeastern Nigeria and northern Cameroon.

### The plant

Bambara groundnut is a herbaceous, intermediate, annual plant, with creeping stems at ground level (Fig. 1a). Differences in the length of internodes result in bunched, intermediate (semi-bunched) and spreading types. The general appearance of the plant is bunched leaves arising from branched stems which form a crown on the soil surface. Stem branching begins very early, about 1 week after germination, and as many as 20 branches may be produced. Each branch is made up of internodes, and those near the base are shorter than the more distant ones. The plant has a well-developed tap root with profuse geotropic lateral roots. The roots form nodules for nitrogen fixation, in association with appropriate rhizobia. Leaf and flower buds arise alternately at each node. Leaves are pinnately trifoliate, glabrous with erect petiole, thickened at the base. Two stipels subtend the terminal leaflet, while only one is assigned to each of the two lateral leaflets. The oval leaflets are attached to the rachis with marked pulvini. The terminal leaflet is slightly larger than the lateral leaflets, with an average length of 6 cm and an average width of 3 cm.

The flowers are borne on hairy peduncles, which arise from the nodes of the stems. Usually, two flowers are attached to the peduncle by pedicels. A good knowledge of the flower structure is essential for breeding the crop. Important observations have been reported by Doku and Karikari (1971a). The flowers are typically papilionaceous (Fig. 1b). The peduncles reach their maximum length at the initiation of pod formation, but their pedicels reach theirs at the time of anthesis. The interval between the opening of successive flowers in a raceme varies from 24 to 48 hours; that of flowers on the same peduncle does not exceed 24 hours, but rarely do they open at the same time. When flowers open during the early hours of the morning, they are yellowish-white, but towards the evening, the colour changes through various shades of yellow to brown. Flowers that are produced towards the end of the plant's life are usually light brown.

The flower has a pair of hairy epicalyces. The calyx consists of five hairy sepals (four on the upper side and one on the lower side). The four upper sepals are almost completely joined, while the lower sepal is largely free. The epicalyx and calyx completely enclose the corolla in the early budding stage. The epicalyx drops off during the course of entry of the fertilized flower into the soil, but the calyx persists on the developing pod. The standard encloses the wing and keel until the flower opens. When the standard petal opens, it is bent over to about half its length. There is a hollow at the tip of the keel, through which ants occasionally enter both the unopened and open flowers (Doku and Karikari 1971b). The stamens are diadelphous, nine with partly fused filaments, and one isolated vexillary stamen. Upon pollination and fertilization, the peduncle elongates to bring the ovaries to or just below ground level.

Apparently, reproductive development is not completely inhibited by light. The pod grows first, and reaches its mature size about 30 days after fertilization. The seed develops in the following 10 days. Mean temperature during the seasons influences the time taken to achieve physiological maturity. Bunch types tend to mature earlier than spreading types. Fruit development has been reported to be influenced by photoperiod (Linnemann and Azam-Ali 1993). Long photoperiods delay or even prevent fruit set in some cultivars. Flowering is considered day-neutral, but

continuous light was shown to delay flowering by 6-11 days in a few genotypes (Nishitani *et al.* 1988).

The pods usually develop underground, and may reach up to 3.7 cm, depending on the number of seeds they contain. Most varieties have single-seeded pods, but pods with three seeds were frequently found in ecotypes collected in Congo (Fig. 1c) (Goli and Ng 1988). Mature pods are indehiscent, often wrinkled, ranging from a yellowish to a reddish dark brown colour. Seed colour also varies, from white to creamy, yellow, brown, purple, red or black. Various testa patterns are found, including mottled, blotched or striped, in addition to the predominantly uniformly coloured seeds (Fig. 1d).

### Uses

Bambara groundnut is essentially grown for human consumption. The seed makes a complete food, as it contains sufficient quantities of protein, carbohydrate and fat. Several workers have examined the biochemical composition of the seed (Owusu-Domfeh *et al.* 1970; Oluyemi *et al.* 1976; Oliveira 1976; Linnemann 1987). On average, the seeds were found to contain 63% carbohydrate, 19% protein and 6.5% oil. Despite the relatively low oil content, some tribes in Congo reportedly roasted the seeds and pounded them for oil extraction (Karikari 1971). The gross energy value of bambara groundnut seed is greater than that of other common pulses such as cowpea, lentil and pigeonpea (FAO 1982).

Bambara groundnut seeds are consumed in many ways. They can be eaten fresh, or grilled while still immature. At maturity, they become very hard, and therefore require boiling before any specific preparation. In many West African countries, the fresh pods are boiled with salt and pepper, and eaten as a snack. In Côte d'Ivoire, the seed is used to make flour, which makes it more digestible. In East Africa, the beans are roasted, then pulverized, and used to make a soup, with or without condiments. Bread made from bambara groundnut flour has been reported in Zambia (Linnemann 1990).

Seeds can also be pounded into flour and used to make a stiff porridge, which is often kept for a long period (Holm and Marloth 1940). Roasted seeds can be boiled, crushed and eaten as a relish. Another common use of bambara groundnut is to make a paste out of the dried seeds, which is then used in the preparation of various fried or steamed products, such as 'akara' and 'moin-moin' in Nigeria (Obizoba 1983). Another favorite Nigerian dish is 'okpa', which is a doughy paste that is wrapped in banana leaves and boiled. In Ghana, the beans used to be canned in gravy at GIHOC cannery in Nsawam. The product was thus available throughout the year, and over 40 000 cans of various sizes were produced annually (Doku and Karikari 1971a; Begemann 1986a).

Recently, a trial of bambara groundnut milk was carried out which compared its flavour and composition with those of milks prepared from cowpea, pigeonpea and soybean (Brough *et al.* 1993). Bambara groundnut was ranked first, and while all milks were found to be acceptable, the lighter colour of the bambara groundnut milk was preferred. Bambara groundnut has long been used as an animal feed, and the seeds have been successfully used to feed chicks (Oluyemi *et al.* 1976). The haulm was found to be palatable (Doku and Karikari 1971a), and the leaves were reported to be rich in nitrogen and phosphorus, and therefore suitable for animal grazing (Rassel 1960).



**Fig. 1.** a. Bambara groundnut – growth habit; b. bambara groundnut flowers and stems; c. bambara groundnut pods; d. bambara groundnut – various seed colours and testa patterns.

### Genetic resources

Bambara groundnut germplasm is abundant in Sub-Saharan Africa, as the crop is grown in every tropical region of the continent. So far, wild relatives of cultivated bambara groundnut have only been found in northeastern Nigeria and northern Cameroon. It is believed that the crop originated from this part of the continent. Electrophoretic studies conducted by Howell (1990) did not reveal a significant difference between the cultivated genotypes and the supposedly wild forms, and it was concluded that the wild plant might simply be an escape from the cultivated ecotype. Successful intraspecific hybridization has not yet been reported in bambara groundnut, despite growing interest in the crop. This could limit full exploitation of the available diversity.

The major germplasm collection held by IITA has been characterized and evaluated, and the results are presented in this section. A few other countries such as Zambia have also characterized their germplasm. Countries or institutions holding important and reliable collections of bambara groundnut are listed in Table 1.

The large collection of IITA has been gathered from countries across Sub-Saharan Africa. The provenance of the various accessions is indicated in Table 2.

Bambara groundnut seeds are orthodox, and can be stored at temperatures below 0°C. IITA maintains its base collection in a cold room at -20°C, while the collection for distribution is kept in another cold room operating at 5°C and 30% RH. Most national programmes maintain their collections for medium-term conservation at temperatures above 0°C. Deep freezers are successfully used for conservation of the base collection in a number of countries. Examples are Ghana, Niger and Zambia. Problems reported in some countries are frequent and prolonged power failures, or breakdowns of the refrigerating systems. Efforts have to be made by those countries to provide standby generators and qualified technicians for maintenance of the

equipment. Although the collection may not be entirely characterized in some national programmes, the accessions, as well as their passport data, are readily available in the countries or institutions listed in Table 1. Part of the main collections (i.e. IITA and Zambia) are compiled in the International Bambara Groundnut Database (available on the Internet via <http://www.dainet.de/genres/bambara/bambara.htm>).

The collections of bambara groundnut available in most national programmes may not reflect all the diversity existing in the respective countries. The crop germplasm is often collected in an opportunistic manner. Plant collectors use a collecting mission for a major crop to include sampling of bambara groundnut. For example, scientists at IITA have usually collected bambara groundnut samples during collecting missions for cowpea or rice. Collecting missions primarily devoted to bambara groundnut need to be organized in many countries producing the crop. Where no research programme on the crop exists, an expedition organized by the International Bambara Groundnut Network should be organized to save those ecotypes that are in the process of extinction. Begemann (1988a) emphasized that the existing germplasm collections hold insufficient population samples from Chad, Ethiopia, Niger and Sudan.

**Table 1. Countries or institutions holding bambara groundnut collections<sup>†</sup>.**

| Country/institution <sup>‡</sup>            | No. of accessions |
|---|-------------------|
| Benin                                       | 3                 |
| Botswana                                    | 26                |
| Burkina Faso                                | 143               |
| France, ORSTOM                              | ca. 1000          |
| Ghana, University of Ghana                  | 80                |
| Ghana, SARI                                 | 90                |
| Ghana, PGRC                                 | 166               |
| Guinea                                      | 43                |
| Kenya, National Genebank                    | 6                 |
| Kenya, KARI                                 | 2                 |
| Kenya, National Museums                     | 2                 |
| Mali  | 70                |
| Mozambique                                  | 12                |
| Namibia                                     | 23                |
| Nigeria, IITA                               | 2035              |
| Nigeria                                     | n.a.              |
| Niger                                       | 79                |
| South Africa, Grain Crops Institute         | 198               |
| South Africa, Institute for Veld and Forage |                   |
| Utilization                                 | 117               |
| South Africa, Department of Agriculture     | 20                |
| Tanzania, NPGRC                             | 22                |
| Zambia, University of Zambia                | 463               |
| Zambia, NPGRC                               | 124               |
| Zimbabwe                                    | 129               |

<sup>†</sup> Compiled from information provided by workshop participants, and the FAO Early Warning System on Plant Genetic Resources databases.

<sup>‡</sup> See Appendix D for full addresses of institutions.

n.a. = no data available.

**Table 2. Countries of origin of the bambara groundnut accessions held at IITA**

| Country                  | No. of accessions | Country      | No. of accessions |
|--------------------------|-------------------|--------------|-------------------|
| Benin                    | 27                | Mali         | 28                |
| Botswana                 | 5                 | Niger        | 33                |
| Burkina Faso             | 97                | Nigeria      | 310               |
| Cameroon                 | 207               | Senegal      | 36                |
| Central African Republic | 103               | South Africa | 1                 |
| Chad                     | 70                | Sudan        | 7                 |
| Congo                    | 42                | Swaziland    | 11                |
| Cote d'Ivoire            | 4                 | Tanzania     | 28                |
| Ethiopia                 | 1                 | Togo         | 139               |
| Gambia                   | 11                | Zimbabwe     | 245               |
| Ghana                    | 120               | Zambia       | 284               |
| Kenya                    | 2                 | Unidentified | 101               |
| Madagascar               | 49                |              |                   |
| Malawi                   | 59                | <b>Total</b> | <b>2008</b>       |

### Breeding

Doku and Karikari (1971c) studied the evolution of bambara groundnut as a species. These authors' observations of 27 genotypes in Ghana led them to conclude that the cultivated bambara groundnut originated from *Vigna subterranea* var. *spontanea* and evolved through a series of gradual changes. Those include switching from open to bunched growth habit, from outbreeding to inbreeding, and a reduction in shell thickness. From the cytological point of view, all that is known is that the species has a chromosome number of  $2n=22$ , like many other grain legumes.

Reports on critical genetics and the breeding of bambara groundnut are limited. Through many years of successive cultivations, farmers have selected genotypes with desirable traits, such as high yields and bunched habit (Smartt 1985). Plants with a bunched growth habit are easier to harvest than the spreading types. Even in agricultural research, to date, breeding of bambara groundnut has focused on selection between and within population samples, for yield performance, disease resistance and drought tolerance. During characterization of the bambara groundnut collection at IITA, single plants or entire accessions were selected on the basis of their vigour, resistance to fungal diseases and seed yield. A total of 25 promising accessions were retained for further yield trials at two locations in Nigeria and one location in Burkina Faso. Yields varied from one year to another, with a strong location effect being observed. Nonetheless, accessions such as TVSU 751, 879, 922, 1034 and 1231 (Goli and Ng 1988) and TVSU 395, 401, 501, 674, 942 and 1162 (Begemann 1988a) performed reasonably well.

A useful tool in plant breeding for selecting delicate traits is the analysis of correlations among measurable characters, done using the results of the collection characterization at IITA. Highly significant correlations between pairs of traits can be exploited.

Bambara groundnut's geotropic pod development makes breeding through artificial hybridization difficult, and such breeding has yet to be carried out. Strategies involving crosses between different ecotypes could be used to increase the yield potential, or to incorporate valuable genes into desirable cultivars. Unfortunately, no reports on such experiments are available. An attempt was made at IITA to intercross genotypes differing in seed coat and petiole colour; hand-pollination was carried out at different times in the day, but without success (Goli *et al.* 1991; Begemann, pers. comm.).

Yet, Doku and Karikari (1971b) indicated that pollen maturity and stigma receptivity both occur just before or soon after the standard and wing petals open. Doku (pers. comm.) used boric acid in an unsuccessful attempt at making hand-crosses.

### Agronomy

Cultivation of bambara groundnut on a large scale and in pure stand is not very common. The crop is mostly grown by women, intercropped with major commodities such as maize, millet, sorghum, cassava, yam, peanut and cowpea. Grown in rotation, bambara groundnut improves the nitrogen status of the soil (Mukurumbira 1985).

Bambara groundnut thrives better in deep, well-drained soils with a light, friable seedbed (Johnson 1968). Many farmers grow the crop on a flat seedbed, but the use of ridges or mounds is also common in a few countries. Planting density is usually low in farmers' fields, especially when crops are not in rows. In experimental plots, recommended plant density ranged from 6 to 29 plants/m<sup>2</sup> (Rassel 1960). Farmers do not normally apply chemical fertilizers to bambara groundnut fields. The nitrogen requirement is met by natural N<sub>2</sub> fixation, as indicated by several nodulation studies (Doku 1969a; Somasegaran *et al.* 1990). Yield increase as a result of phosphate or potassium application has not always been confirmed (Johnson 1968; Nnadi *et al.* 1981).

Bambara groundnut has a reputation for resisting pests, and compares favourably with other legumes such as groundnut or cowpea in this regard. In humid environments, however, fungal diseases such as *Cercospora* leafspot, *Fusarium* wilt and *Sclerotium* rot are common (Billington 1970; Begemann 1986b, 1988a). In such circumstances, spraying with the fungicide benlate (1 kg/ha) has proved beneficial.

Viral diseases are widespread in most environments, especially in areas where other grain legumes such as cowpea are grown. Common diseases are cowpea mottle virus (CMeV) and cowpea aphid-borne mosaic virus (AbMV) (Ng *et al.* 1985). A combination of unusually heavy virus attack and *Cercospora* leaf spot on one particular accession (TVSU 218) resulted in zero yield during a trial at Kaboinse, Burkina Faso (Goli *et al.* 1991).

Harvesting of bambara groundnut is done by pulling or lifting the plant. For the bunched-habit type, most pods remain attached to the root crown. Detached pods left in the ground are collected manually. In a dry environment, harvesting takes place when the entire foliage dries up. In humid ecosystems, however, pod-rotting or early seed germination (in the pod) may take place while the leaves are still partially green. Harvesting is then recommended before full foliage drying.

Harvested pods are air-dried for several days before threshing. The raw product is sold at markets, as pods or seeds. In dry areas, materials for planting the following season are usually kept by farmers as pods. This reduces or eliminates attacks by insects.

### Future prospects

Bambara groundnut is a promising commodity which needs more publicity, both as a crop and as a food. Even in tropical Africa, few people in the forest zones are aware of its existence. It should be emphasized that it is a low-cost, dependable crop that grows in harsh environments where many other crops fail. Its high nutritive value should also be made known to the general public, and, in particular, to the rural poor. However, to ensure the wider adoption of bambara groundnut, the general mode of consumption of the crop needs improving. Modern processing methods would enable distribution of bambara groundnut to non-producing areas.



## Country Reports

### Botswana

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#### Introduction

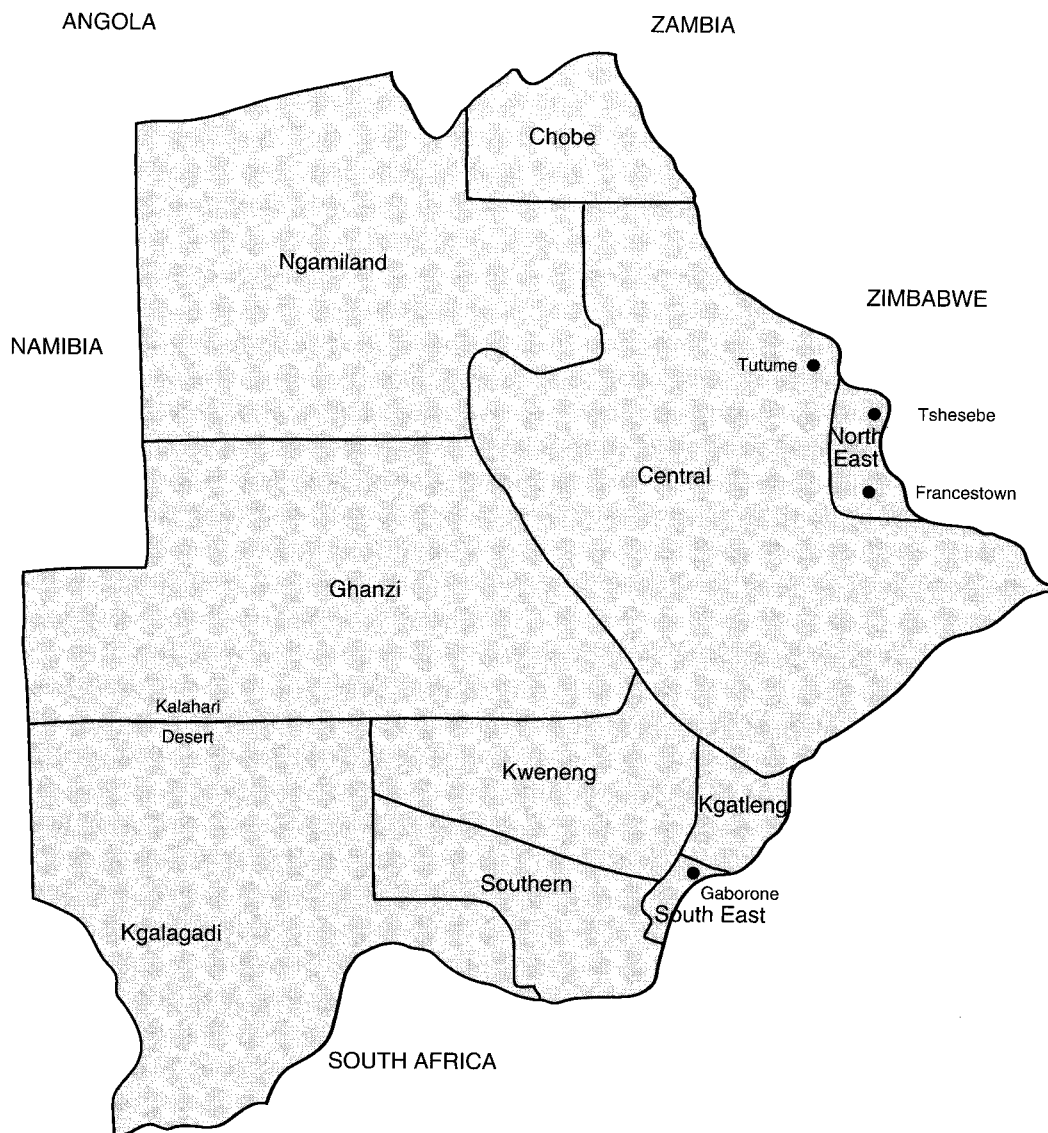
The Republic of Botswana is a landlocked country covering 582 000 km<sup>2</sup>, located between latitudes 17 and 27°S and longitude 20°E. It is bordered by South Africa to the south, Zimbabwe to the east, Angola and Zambia to the north, and Namibia to the west (Fig. 1). The average rainfall varies from a maximum of over 650 mm in the Kasane area (the Chobe enclave), located to the extreme northeast of the country, to a minimum of just under 250 mm in the Kgalagadi district, lying to the extreme southwest. The main rainy season is from November to March, with October and April as spring transition months, respectively. Almost all the rainfall occurs between October and April, with very little rainfall recorded during the winter months (May-September). Drought is a recurrent element of the climate of Botswana. Rainfall is erratic, and occurs mainly during the summer months, when evapotranspiration rates are high.

The climate of Botswana has important consequences for arable agriculture. Frequent low soil moisture levels, often below those necessary to sustain continuous crop growth, commonly result in crop failures. Consequently, dryland crop farming is limited to short-season cereals and legumes that also have inherent drought tolerance.

#### Production

One of the crops which features prominently in Botswana's farming systems is bambara groundnut (*Vigna subterranea*) (called 'ditloo' in the local language, Setswana). In the Ministry of Agriculture statistics (Ministry of Agriculture 1993), bambara groundnut is grouped with pulses, and it is therefore difficult to obtain accurate production figures. According to von Rudloff (1993), however, the crop is grown over an estimated area of 1500 ha, from which a total yield of about 400 t of seed is obtained annually. Bambara groundnut has the third highest production of the grain legumes, coming after cowpea and groundnut, and is more common in markets than mung bean (*Vigna radiata*) and tepary bean (*Phaseolus acutifolius*) (Karikari, private survey).

Throughout the country, bambara groundnut is often cultivated in mixed/intercropping systems. However, production is more concentrated in the northern and eastern parts of the country, along the railway, where population densities are relatively high and land availability limits farm size. Sorghum, millet and maize are the principal crops, grown mainly for subsistence, and these are intercropped with cowpea, bambara groundnut, melons and vegetables. In the Tutume, Francistown and Tati districts, where millet is the main cereal staple, it is usually intercropped with bambara groundnut. It is in these areas, therefore, that bambara groundnut production is most concentrated (Chaba 1994).



**Fig. 1.** Republic of Botswana, boundaries and location of bambara groundnut germplasm collecting sites.

### Uses

In Botswana, bambara groundnut is predominantly grown for human consumption. Consumers often prefer the immature seeds, which are boiled in the pod, salted, and consumed, either on their own or mixed with maize seeds. When the seeds are ripe and dry, they are pounded into a flour and used to make a variety of cakes, or are mixed with cereals and used to prepare several types of porridge. Livestock, especially goats, are very fond of the haulm, which they are allowed to graze on at the end of the season, after the pods have been harvested. The seeds of the mature black landrace are used in traditional medicine.

## Genetic resources

The first collecting and evaluation of bambara groundnut germplasm was carried out before 1947 (Ministry of Agriculture 1947). This report mentions that bambara groundnut was grown throughout what was then the Bechuanaland Protectorate, where it was never grown as a cash crop on a large scale, but was consumed chiefly as a dietary supplement and as a delicacy. The report also mentions the drought tolerance of bambara groundnut, which meant that it tended to do better on sandier soils and in the drier areas of the country.

The first trial to evaluate the yield of seven landraces was planted at the Ministry of Agriculture Research Station at Sebele in December 1958, and was harvested in April 1959. The varieties were collected from native crops and classified by seed characteristics, including colour of the testa, seed size and eye pattern. The total rainfall during the crop's growing period was 494 mm, and yields ranged from 0.163 to 0.197 t/ha. It is interesting to note that the yield of the bambara groundnut was about twice that of groundnut planted in a variety trial in an adjacent field.

The next germplasm collection was made in April 1985. The two-man collecting team consisted of a plant geneticist and an IBPGR consultant. The trip, which was funded by IBPGR, was mainly aimed at collecting groundnut, bambara groundnut and finger millet germplasm. Collecting was done in the northeastern, Tutume and Kgatleng districts, and the members of the team observed that there were three distinct types of bambara groundnut in Botswana. These were chiefly based on pericarp colour, and comprised the white, amber and black pericarp types. Bambara groundnut was found being grown on ridges, in small patches in sorghum and pearl millet fields. One-seeded types were common but two-seeded types were also found. Under severe moisture stress, where groundnut did not produce kernels, bambara groundnut produced small filled pods, revealing its drought tolerance (Mazhani and Appa-Rao 1985).

The germplasm collected (Table 1) was characterized and conserved by Mazhani.

The material collected by Mazhani (Department of Agricultural Research (DAR) collection) has been widely distributed. However, none of these varieties is known to have been officially released by the DAR.

The Botswana College of Agriculture (BCA) collection is only a recent one, and was created to obtain more materials for evaluation work, and also for the European Union-funded International Bambara Groundnut Research Project (see Dr Sarah Collinson's paper, this volume). A total of 26 landraces have been collected to date, and have been characterized using the IBPGR Descriptors List (IBPGR/IITA/GTZ 1987).

The classification criteria are as follows:

- location – area of Botswana where the seeds were collected, or where they originated (Botswana, Gaborone, Diphiri, Tshesebe, Zimbabwe, etc.)
- base colour of testa and pattern – red, black, cream, white, specked, mottled, etc.
- growth habit – bunch, semibunch, spreading
- individual collector – OM 1, OM 2, etc.
- peculiar features – short stemmed, long stemmed, leaf arrangement, venation, etc.

**Table 1. Bambara groundnut samples collected in Botswana (April 1985).**

| Collection no. | District   | Exact location |
|----------------|------------|----------------|
| MA 14          | North East | Tsamaya        |
| MA 15          | North East | Tsamaya        |
| MA 56          | North East | Masunga        |
| MA 57          | North East | Masunga        |
| MA 73          | Kgatleng   | Rasesa         |
| MA 74          | Kgatleng   | Rasesa         |
| MA 75          | Kgatleng   | Rasesa         |
| MA 76          | Kgatleng   | Rasesa         |
| MA 77          | Kgatleng   | Rasesa         |

**Description of some of the available landraces**

The following landraces have been described and evaluated over four seasons (1991-95), on the basis of the above characteristics. Other landraces not listed here are in the process of being evaluated.

***Zimbabwe Red (National Tested Seed Red – NTSR)***

The source of this seed is the National Tested Seed of Zimbabwe, and it was obtained in 1991, for the experiments contained in the EU project described in Collinson's paper. The seeds are large (100-seed weight is 53 g). Seeds are oval shaped, and have a mean length and width of 10.8 and 9.1 mm respectively, with a white hilum, but no peculiar eye characteristics. The seeds are quite uniform in colour, with very little segregation into different colours, although different shades of red do appear.

***Botswana Red (BotR)***

The Botswana Red landrace was obtained from the Botswana Agricultural Marketing Board<sup>1</sup> (BAMB). The colour of the seeds, light reddish brown, is similar to that of the Zimbabwe Red, but the seeds are smaller. It also does not have peculiar eye characteristics. Over three evaluation seasons, it has shown less seed colour segregation.

***Gaborone Red (GabR)***

All the red-seeded varieties obtained from three markets in Gaborone (the main mall, Broadhurst mall and the railway station markets) have been classified as Gaborone Red (GabR<sub>1</sub>, GabR<sub>2</sub> and GabR<sub>3</sub>, respectively).

***Gaborone Cream (GabC)***

A cream-seeded landrace obtained from the same markets in Gaborone (the main mall, Broadhurst mall and the railway station), and classified as GabC<sub>1</sub>, GabC<sub>2</sub> and GabC<sub>3</sub>, respectively.

***Diphiri Cream (DipC)***

The only landrace obtained from the southern district. This has the characteristic uniform cream colour, and has also been classified into two varieties: black eye (DipC<sub>1</sub>) and brown eye (DipC<sub>2</sub>).

<sup>1</sup> Courtesy of Mr Felix T. Mmopi, Chief Crop Production Officer.

***Tshesebe Cream (TshC)***

Tshesebe is in the heart of the bambara groundnut growing area of the northern part of the country, where the cream colour predominates. This landrace is cream with no eye pattern. Over the years, this landrace has segregated, with two white landraces identifiable from the original TshC; these have been named Tshesebe White 1 (TshW<sub>1</sub>) and Tshesebe White 2 (TshW<sub>2</sub>).

***Gaborone Black (GabB)***

Although the black-seeded landrace is not very popular with local consumers, it is more expensive than other landraces, owing to its use in traditional medicine (when eaten, it is reputed to act as a strong male aphrodisiac). It has a characteristic shiny black colour with white eyes. It segregates into other colours, especially brown, and the occurrence of both black and brown seeds in one single pod is common.

***O Motswasele (OM)***

The landraces OM1 and OM2 were named after the collector O. Motswasele (now deceased). The seeds of both are light brown in colour, and have characteristic specks of black on the seed. In OM1, the specks are concentrated around the hilum, but in OM2 they are uniformly distributed on the seed, and are described as entire specks. OM6 also has light brown seeds, but without the characteristic specks observed in OM1 and OM2.

**Variability within the landraces*****Physical characteristics***

The seeds of the landraces are all oval-shaped, and the mean seed length is 10.8 ( $\pm 0.1$  mm). The physical characteristics of all the seeds were measured as part of a project to design a commercial planter for large-scale cultivation of the crop (Nape 1995), and Zimbabwe Red (NTSR) was found to have the largest seeds. However, it has not been established that seed size is genetic, as under severe moisture stress, OM6 produced the largest seed.

***Nutritional studies***

The chemical composition of the landraces has been determined: protein content varied from 8.2 to 16.6%; carbohydrate from 51.2 to 57.0%; fat from 5.5 to 6.8%; fibre from 5.5 to 6.4% and ash from 3.2 to 4.0%. The different landraces were also high in mineral content (mg/100 g), with the following ranges: Ca 95.8-99; Fe 5.1-9.9; K 1144.7-1435.5 and Na 2.9-10.6. The dark-seeded landraces (red and black) tended to have higher nutrient and mineral contents than the light-seeded ones (cream and white) (Gibbons 1994). Local people are unaware of this fact, however, and tend to prefer the light-coloured seeds for consumption, perhaps owing to their shorter cooking time and superior flavour.

***Growth habit***

Two growth habits occur in the landraces in Botswana: bunch and spreading. The local red and black landraces are spreading types, but the cream and white landraces are all of the bunch type. Under various spacing and irrigation conditions, Zimbabwe Red (NTSR) had a semibunch growth habit. The spreading types were also found to produce a few tillers. In actual field measurements, the spreading types could attain a canopy spread of 120 cm or more, but at average spacing of 30 x 30 cm, the bunch types did not form close canopies.

***Days to first flowering, 50% flowering and maturity***

Days to first flowering took 44-60 days after sowing, and generally within 80 days, 50% of plants had flowered. It took 120-155 days for pods to mature. The cream landrace produced more flowers and also matured earlier than the red landrace. OM6 had a tendency to germinate in the pod, if not harvested soon after maturity.

***Leaf shape and colour***

The terminal leaflet shape was characteristic for the landraces. We observed that the red and black landraces had broad leaves, and the cream and white had narrow-to-lanceolate leaves. It was difficult to distinguish the varieties by leaf colour, but in general, the primary leaf colour at maturity was deep green for the black and the red landraces, and light green for the cream varieties (Kebadumetse 1994).

***Yield of seeds and shelling percentage***

Yields were very variable: the highest yield obtained was 1.7 t/ha for Zimbabwe Red. All other red-seeded landraces had low yields. Lower yields have always been recorded for the cream-seeded landraces, and on some occasions, no yields were obtained from these landraces at all. Shelling percentage ranged from 18 to 22%, and shell thickness from 0.35 to 0.47 mm. The cream and white-seeded landraces had thinner shells and seed coats.

### **Conservation of germplasm**

The repository for all germplasm in Botswana is the Department of Agricultural Research of the Ministry of Agriculture, which has a Plant Genetic Resources Unit. All germplasm activities are coordinated by a National Plant Genetic Resources Committee (NPGRC), based at Sebele. Botswana College of Agriculture (BCA) is a member of this committee. The DAR implements all the Committee's activities, and employs a full-time curator, whose office must be liaised with on all matters relating to germplasm collecting. However, where institutions involved in research (such as BCA) have the capacity, some germplasm is maintained in *ex situ* collections. Owing to a lack of proper long-term storage facilities, the BCA collections are maintained both on-farm and under short-term *ex situ* storage conditions. Records of accessions are kept at the NPGRC centre.

### **Breeding/selection procedures**

No breeding work on bambara groundnut has been done in Botswana, although selection based on a number of agronomic characters has always been practised. For example, within each landrace, early maturing lines, bunch habit and higher number of leaves, stems, flowers, pegs and pods have been favoured. Large seed size and pods with thicker shells, as well as those containing more than one seed, were also favoured.

### **Agronomic studies**

A number of agronomic studies of the landraces have been carried out. In a series of sowing-date experiments, it was established that early sowing produced higher yields than late sowing, and also that irrigation was helpful, as irrigated crops yielded twice as much as rain-fed ones. In Botswana, however, growing bambara groundnut under irrigation does not seem feasible for a long time to come. Studies involving intercropping with cereals indicated that bambara groundnut did not withstand intercropping with maize and sorghum as it did with millet. Furthermore, the landraces responded differently; the semi-spreading ones, such as Zimbabwe Red (NTSR), did not suffer a decline in yields under intercropping with millet, whereas Tshesebe Cream (a bunch type) did (Chaba 1994).

### Diseases and pests

The major diseases affecting bambara groundnut are Fusarium wilt, which attacks the young seedlings of all landraces in wet weather, particularly under waterlogged conditions, and Cercospora leaf spot, which also has been observed on crops under irrigation. In dry weather, pod attacks by termites also have been consistently observed, and in one particular year, 1994-95, a particularly severe attack resulted in the loss of an entire crop. Root knot nematode (*Meloidogyne javanica*) also attacked the roots of the plant in sandy soils. In storage, shelled bambara groundnut seeds were extremely susceptible to attack by bruchids (*Callosobruchus maculatus*). All landraces were attacked by this pest, but the black-seeded landrace was affected less severely. The unshelled seed was extremely resistant to bruchid attack.

### Prospects

#### Gaps in existing collections

Groundnut germplasm collection in Botswana is far from being completed, and existing collections are quite limited in terms of both genetic diversity and geographic representation. At the recent Botswana International Trade Fair, held in August 1995, farmers exhibited a wide array of seeds, some of which were varieties not collected during our mission. There is therefore a need for a further exploratory collecting mission to other areas of the country not covered by the previous expedition. These areas would include the Chobe enclave, Ngamiland and the central Kalahari. Germplasm would continue to be made available to farmers and other interested parties within the country and outside.

The Botswana landraces have already been distributed among all the collaborating partners in the European Union bambara project, including Sokoine University of Agriculture in Tanzania, Njala University College, Sierra Leone, Wageningen Agricultural University, the Netherlands, and the University of Nottingham, UK. Efforts made to import germplasm from outside Botswana have yielded accessions from Malawi (16 varieties), Zambia (6 varieties) and Tanzania (2 varieties). These should be evaluated alongside the local germplasm. All the landraces we have collected within Botswana seem to tolerate long dry periods, which makes them ideal for such areas of low, erratic rainfall. On several occasions, the crop has succeeded in yielding on residual moisture, after cessation of rain, and under conditions where even sorghum failed.

#### Principal limitations

The characteristics of bambara groundnut are highly variable, particularly its yield. The poor average seed yields throughout our four evaluation seasons point to an important limitation of the crop – a lack of broad adaptation of the species and its landraces. Even where moisture deficit was irrelevant, instability was still characteristic of our bambara groundnut yields. Undoubtedly, there is genetic variation owing to factors limiting bambara groundnut's response to the environment. The Zimbabwe Red and all the cream-coloured landraces showed more stability in their seed yields than the local red and black landraces. It therefore appears that, through judicious selection and breeding, it ought to be possible to develop cultivars possessing greater flexibility or broad adaptation to specific environmental niches. Initial attempts should be made to identify those characteristics of bambara groundnut which would be required to meet the particular economic circumstances created by large-scale mechanized farming on one hand, and by small-scale cultivation by peasant farmers on the other.

#### **Improving the genetic potential of bambara groundnut**

The cultivation of bambara groundnut in Botswana suggests two ideotypes, namely:

- a bunch ideotype, for large-scale mechanized farming, where a very high plant population would be aimed at for maximum yield, and
- a spreading ideotype, to be grown exclusively as a subsistence crop by smallholders in a cereal-based farming system.

The important research priority would be to develop appropriate agronomic and nutritional packages. It appears that, for this purpose, the cream-to-white landraces would serve as a genebank for the commercial production of bambara groundnut, while the red and black landraces could provide a genebank for the ideotype required for the rain-fed, cereal-based subsistence farming system. Researchers at the Botswana College of Agriculture are currently working towards achieving these objectives.



## Burkina Faso

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### Introduction

Given the rapid rate at which the world's population is currently increasing in relation to agricultural production, the goal of agronomic research must be to improve the productivity not only of our main crops, but also of certain crops that have hitherto been neglected. Among the latter group of crops, particular attention should be focused on the bambara groundnut, *Vigna subterranea* (L.) Verdc., which flourished before the introduction of the peanut, *Arachis hypogaea* (Goli *et al.* 1991).

Between 1982 and 1985, an attempt was made to improve bambara groundnut in Burkina Faso. This initiative followed the collection of local cultivars in 1981, and involved the participation of plant breeders in the Grain Legumes Programme. In the adaptation trials we conducted, bambara groundnut was severely affected by leaf spot and viral diseases (Sérémé 1989), and the preliminary work undertaken led us to decide that it would be necessary to include a plant pathologist in the research team, before continuing our bambara groundnut research (Drabo 1987). With the arrival of two plant geneticists, the research work was carried out in 1986, and a number of significant results have been obtained to date.

Since 1989, collections of local varieties of the bambara groundnut have been undertaken several times in Burkina Faso. Local varieties from other countries in the subregion (Mali, Nigeria, Niger, etc.) have also been introduced into our collection. This paper reviews current knowledge of bambara groundnut germplasm and the state of research on this crop in Burkina Faso.

### Production and use

In Africa, the bambara groundnut is generally cultivated by women on small plots. Production is primarily at subsistence level, and only the surplus is sold. In 1982, world bambara groundnut production was around 330 000 t (Linnemann 1994). A total of 150 000-160 000 t, or 45-50% of world production of the crop, came from West Africa (Kiwallo 1991).

The bambara groundnut is grown in all regions of Burkina Faso (Table 1). In 1989, the country produced an estimated 20 000 t, making it the third largest grain legume crop, after peanut (160 000 t) and cowpea (74 000 t) (Kiwallo 1991). Like cowpea, bambara groundnut is produced according to traditional methods, and is intercropped with cereals (sorghum, millet and maize), although in poorer soil, it is mainly grown in monoculture.

The bambara groundnut is primarily consumed by its producers, during the period before the cereals are harvested. Along with the cowpea (*Vigna unguiculata* (L.) Walp.), it constitutes the main source of vegetable protein for the rural populations of Burkina Faso. Its leaves, which are rich in protein and phosphorus, are used as fodder for livestock.

**Table 1. Distribution of production (t) of bambara groundnut, cowpea and peanut, by crop and by CRPA<sup>†</sup> (Kiwallo 1991).**

| CRPA          | Bambara groundnut | Cowpea | Peanut  |
|---------------|-------------------|--------|---------|
| Central       | 360               | 1411   | 8741    |
| East-Central  | 265               | 16 103 | 43 826  |
| Comoé         | 714               | 559    | 20 863  |
| North         | 3990              | 5054   | 8234    |
| Mouhoun       | 3742              | 1645   | 10 857  |
| West-Central  | 2422              | 11 280 | 9067    |
| Sahel         | 231               | 10 570 | 1154    |
| Upper Valleys | 3490              | 3517   | 8879    |
| Southwest     | 528               | 899    | 8483    |
| North-Central | 1201              | 12 695 | 9336    |
| South-Central | 627               | 1853   | 11 108  |
| East          | 2541              | 8793   | 12 625  |
| Total         | 20 111            | 74 379 | 160 075 |

<sup>†</sup> Centre Régional de Promotion Agro-Pastoral (Regional Centre for Agropastoral Promotion).

### Genetic resources

In 1981, local cultivars were collected in Burkina Faso by IBPGR (now IPGRI), in collaboration with the former Institut Voltaïque de Recherches Agronomiques et Zootechniques (IVRAZ), now called the Institut d'Etudes et de Recherches Agricoles (INERA), with the aim of increasing the world bambara groundnut collection established at IITA. This made it possible to launch an improvement programme. The collection in Burkina was almost entirely lost, following very severe attacks of leaf diseases and viruses, which occurred from one year to the next. Twice the number of samples collected in 1981 (a total of 90 ecotypes from southwest Burkina Faso) was submitted to IITA.

In addition to this collection, there were approximately 10 samples from the central and other regions of Burkina Faso, 15 from Nigeria, 1 from Niger and 1 from Ghana. Following this initial collection, a second one was conducted by a plant pathologist from the Protein Plants Programme. This collection comprised 110 ecotypes, with the following distribution:

- 17 from southwest Burkina Faso, collected in 1990
- 57 from central, north, east and west Burkina Faso, collected in 1990
- 14 from central, east and north Burkina Faso, collected in 1989
- 17 from Mali
- 5 from Nigeria.

The collecting sites of the ecotypes in Burkina Faso are shown in Figure 1; the overall distribution is presented in Annex A. In 1993, a collecting programme was carried out in the southeastern, eastern and northern regions of Burkina Faso. A total of 33 samples was obtained (see Annex B). Currently, 143 local varieties of bambara groundnut are available in Burkina Faso, at the Kamboinse Research and Training Station. The seeds of each accession are preserved in polyethylene containers with a capacity of 300 g of seed. All the containers are stored in a climate-controlled room. To maintain the viability of accessions, they are planted every 2 or 3 years.

The collection of local ecotypes in Burkina Faso is incomplete because the sampling has been very irregular. A more intensive project needs to be undertaken,

to collect all existing genetic variation. In our programme, the germplasm of the bambara groundnut was not described as such, but there are some preliminary data on yield, 50% flowering (30-36 days) and the reaction to leaf and viral disease of many accessions (Kiwallo 1991; Sérémé 1992, 1993).



**Fig. 1.** Geographic distribution of the varieties of bambara groundnut collected in Burkina Faso between 1989 and 1991 (Source: Direction de la Vulgarisation Agricole (Agricultural Extension Directorate)).

## Research

Research on the cultivation of the bambara groundnut in Burkina Faso has been very limited, compared with that on the cowpea, and did not really begin until 1986. The following results have been obtained.

### Plant pathology

#### *Leaf spot diseases*

The seeds of 110 bambara groundnut cultivars (88 indigenous and 22 exotic varieties) were analyzed according to the ISTA method, and planted in fields at the Kamboinse and Farakoba research stations. This made it possible to identify the presence of several major pathogens responsible for the leaf diseases of bambara groundnut that

are known in Burkina Faso, such as *Phoma sorghina*, *Macrophomina phaseolina*, *Phomopsis sojae*, *Fusarium oxysporum* and *Rhizoctonia solani*. The role of *P. sorghina* and *P. sojae* in the etiology of leaf spot disease was established by testing for pathogenesis. Tests showed that 4-week-old plants, and doses of  $10^5$  or  $10^6$  spores/ml of water, constituted ideal conditions when screening for resistant varieties (Séréme *et al.* 1991).

The influence of planting date on the development of leaf diseases was examined for 20 varieties of bambara groundnut in the central region of Burkina Faso, in a multilocation (Kamboinse, Gampéla) and 2-year trial (1991, 1992). In the first year, results showed a low level of grain production (23-369 kg/ha) of these varieties, and a decrease in the severity of the disease, with early planting. This did not affect the yield, however (Séréme *et al.* 1991).

In 1992, using a wider range of planting dates, seven relatively productive varieties were identified for at least one planting date, from 24 June to 9 July in Kamboinse or Gampéla, with yields from 552 to 1027 kg/ha. The Benlate T20 used to treat the seeds totally eliminated all the bambara groundnut seed pathogens. Field treatments made it possible to gain a better understanding of the low productivity of bambara groundnut plants resulting from leaf diseases, and to estimate the yield loss at 83% (Séréme 1993).

#### ***Viral diseases***

The use of current technologies made it possible to identify several viruses transmitted by seeds of 17 bambara groundnut samples (Séréme 1989). Viruses associated with cowpea aphid-borne mosaic (CAMV), blackeye cowpea mosaic virus (BLCMV) and peanut mottle virus (PMV) were observed. We were not able to identify all the viruses, even if all the ones we observed were potyviruses. These results suggest that there may be a complex of several bambara groundnut viruses in Burkina Faso, transmitted by seed. The effect on the biomass of virus-infected bambara groundnut plants caused was measured. In some cases, the biomass was reduced by 63%; this demonstrates the significant extent to which these parasites contribute to reducing the productivity of the bambara groundnut.

#### **Entomology**

The traditional method of preserving the bambara groundnut in Burkina Faso consists of putting small quantities of seed in terracotta pots and mixing them with ashes. Although bambara groundnut has been described as a healthy crop, resistant to insects (Duke *et al.* 1977) in Burkina Faso, the most severe damage to this crop has been chiefly in storage by the bruchid *Callosobruchus subinotatus*. The cowpea bruchid, *Callosobruchus maculatus*, causes less damage. These two species of bruchids are the main insects which attack stored bambara groundnut in West Africa (Begemann 1986b). However, the bambara groundnut is much less susceptible than the cowpea to bruchids. The first collections in the southwestern area of the country carried out in 1981 were all screened for resistance to bruchids, and no resistant variety was identified (Dabire, unpublished).

#### **Selection**

Since 1994, the plant breeders in the Grain Legume Programme have conducted adaptation trials, in order to identify the varieties of bambara groundnut with high yield potential. Seeds are planted on flat-topped ridges, following a treatment of NPK (14-24-14) at the rate of 100 kg/ha. Rows are planted 40 cm apart, with 15 cm between seed holes. The 1994 and 1995 trial results are given below.

**1994**

This trial in Kamboinse consisted of 20 entries, originating from national germplasm. Differences in yield between the entries were significant. The difference between the varieties was not significant for leafspot diseases or flowering. With respect to yield, the varieties to be retained were: CVS/BF 066 (799 kg/ha), CVS/BF 065 (697 kg/ha), CVS/BF 003 (600 kg/ha), CVS BF 038 (592 kg/ha) Yalgo local-1 (532 kg/ha), CVS/BF 004 (517 kg/ha), Douna-3 (515 kg/ha) and Dassanga (497 kg/ha).

**1995**

This trial, which comprised the nine best ecotypes for 1994, was conducted in Kamboinse on two dates (26 June and 9 July) recommended for planting in the Central region of Burkina Faso. The average yield obtained is presented in Table 2. Statistical analysis shows no significant difference between the planting dates and the ecotypes. Given the high coefficient of variation (33.2%), the trial is inconclusive. However, the low yields obtained may be explained by periods of drought during plant growth, and the high incidence of leaf diseases and viruses. The varieties CVS/BF 066, CVS/BF 065 and CVS/BF 003, which ranked first in 1994, reconfirmed their superior performance in 1995.

**Table 2. Average yield for two planting dates of the bambara groundnut landraces examined in 1995 (Programme Protéagineux 1995).**

| Variety                   | Yield (kg/ha) |
|---------------------------|---------------|
| CVS/BF 066                | 757.5         |
| CVS/BF 065                | 800           |
| CVS/BF 003                | 722.2         |
| CVS/BF 038                | 661.3         |
| Yalgo local               | 660.7         |
| CVS/BF 004                | 654.2         |
| Douna-3                   | 527.8         |
| Dassanga                  | 632.9         |
| Kamboinsé local (control) | 658.8         |
| CV (%)                    | 33.2          |

Source: Rapport annuel 1995 (unpub.), Ouagadougou, Burkina Faso.

### Conclusions

The various collecting missions for local varieties of bambara groundnut conducted in Burkina Faso have made it possible to gather 143 ecotypes. Collecting was not exhaustive, and projects to collect bambara groundnut in all regions of the country must be planned in the short term in order to preserve the genetic variability of this crop. Research on the resistance of the bambara groundnut revealed a complex of pathogens that severely affect its productivity, particularly *Phoma* spp., *Phomopsis sojae* and viruses. Methods of resisting leaf spot disease were developed by combining the best planting dates (late June/early July) with treatments of Benlate T20. Considering the weak purchasing power of Burkina Faso's producers, our research programme on the bambara groundnut aims at the genetic enhancement of the most productive local varieties, by introducing genes resistant to *Phoma* spp., *P. sojae*, to viruses and, if possible, to bruchids. This requires the availability of a wide range of appropriate scientific equipment and of local varieties (indigenous and exotic), which will be screened by plant pathologists and entomologists to identify resistant components.

## Annex A. List of the varieties collected, 1989-93.

| Accession no.†          | Origin (CRPA‡ or country) | Locality (or village of origin) |
|-------------------------|---------------------------|---------------------------------|
| CVS BF 001              | North-Central             | Banguessom                      |
| CVS BF 002              | North-Central             | Bobo                            |
| CVS BF 003              | North-Central             | - <sup>s</sup>                  |
| CVS BF 004              | North-Central             | Pissila                         |
| CVS BF 005              | North-Central             | Pissila                         |
| CVS BF 006              | North-Central             | Kongoussi                       |
| CVS BF 007              | North-Central             | Barsalogo                       |
| CVS BF 008              | North-Central             | Barsalogo                       |
| CVS BF 009              | North-Central             | Kongoussi                       |
| CVS BF 010              | North-Central             | Zeguedeguin                     |
| CVS BF 011              | North-Central             | Zeguedeguin                     |
| CVS BF 012              | North-Central             | Zeguedeguin                     |
| CVS BF 013              | North-Central             | Samtaba                         |
| CVS BF 014              | North-Central             | Samtaba                         |
| CVS BF 015              | North-Central             | Zambanga                        |
| CVS BF 016              | North-Central             | Boulsa                          |
| CVS BF 017              | North-Central             | Toaga                           |
| CVS BF 018              | East                      | Fada <sub>2</sub>               |
| CVS BF 019              | East                      | Fada <sub>1</sub>               |
| CVS BF 020 <sub>1</sub> | East                      | Komyanga <sub>1</sub>           |
| CVS BF 020 <sub>2</sub> | East                      | Komyanga <sub>1</sub>           |
| CVS BF 020 <sub>3</sub> | East                      | Komyanga <sub>1</sub>           |
| CVS BF 020 <sub>4</sub> | East                      | Komyanga <sub>1</sub>           |
| CVS BF 021              | East                      | Komyanga <sub>2</sub>           |
| CVS BF 022              | Central                   | Tingandogo                      |
| CVS BF 023              | Central                   | Zouma                           |
| CVS BF 024              | Central                   | Samtenga                        |
| CVS BF 025              | -                         | Gnintaya                        |
| CVS BF 026              | South-Central             | Goulagon                        |
| CVS BF 027              | -                         | -                               |
| CVS BF 028 <sub>1</sub> | -                         | -                               |
| CVS BF 028 <sub>2</sub> | -                         | -                               |
| CVS BF 028 <sub>3</sub> | -                         | -                               |
| CVS BF 029              | -                         | -                               |
| CVS BF 030              | Comoé                     | Sidéradougou                    |
| CVS BF 031              | Comoé                     | Kassidé                         |
| CVS BF 032 <sub>1</sub> | South-Central             | Thiougu                         |
| CVS BF 032 <sub>2</sub> | South-Central             | Thiougu                         |
| CVS BF 032 <sub>3</sub> | South-Central             | Thiougu                         |
| CVS BF 033              | Sahel                     | Falagountou                     |
| CVS BF 035              | West-Central              | Didyr                           |
| CVS BF 036              | West-Central              | Kikiyi                          |
| CVS BF 037              | West-Central              | Konkourou                       |
| CVS BF 038              | West-Central              | -                               |
| CVS BF 039              | West-Central              | Tenado                          |
| CVS BF 040              | West-Central              | Kouyouani                       |
| CVS BF 041              | West-Central              | -                               |
| CVS BF 042              | West-Central              | -                               |
| CVS BF 043              | East-Central              | Tenkodogo                       |
| CVS BF 044              | West-Central              | Ténado                          |
| CVS BF 046              | West-Central              | Ténado                          |
| CVS BF 047              | Black Volta River Loop    | Ténado                          |
| CVS BF 048              | East                      | Nienna (Djibasso)               |
| CVS BF 049 <sub>1</sub> | East                      | Bogandé (1)                     |

| Accession no.†          | Origin (CRPA‡ or country) | Locality (or village of origin) |
|-------------------------|---------------------------|---------------------------------|
| CVS BF 049 <sub>2</sub> | East                      | Bogandé (2)                     |
| CVS BF 049 <sub>3</sub> | East                      | Bogandé (2)                     |
| CVS BF 049 <sub>4</sub> | East                      | Bogandé (2)                     |
| CVS BF 050              | Upper Valleys             | Satiri (1) (salla)              |
| CVS BF 051              | Upper Valleys             | Satiri (2) (ramatoulaye)        |
| CVS BF 052              | Upper Valleys             | Satiri (3) (niefiélaye)         |
| CVS BF 053              | Upper Valleys             | Dandé (1)                       |
| CVS BF 054              | Upper Valleys             | Dandé (2)                       |
| CVS BF 055              | Upper Valleys             | Dandé (3)                       |
| CVS BF 056              | Upper Valleys             | Bekuy (1)                       |
| CVS BF 057              | Upper Valleys             | Bekuy (2)                       |
| CVS BF 058              | Upper Valleys             | Bekuy (3)                       |
| CVS BF 059              | Upper Valleys             | Karangasso vigué (1)            |
| CVS BF 060              | Upper Valleys             | Karangasso vigué (2)            |
| CVS BF 061              | Upper Valleys             | Karangasso vigué (3)            |
| CVS BF 062              | Upper Valleys             | Koumbia (1)                     |
| CVS BF 063              | Upper Valleys             | Koumbia (2)                     |
| CVS BF 064              | Upper Valleys             | Koumbia (3)                     |
| CVS BF 065              | Mouhoun                   | Diouroum                        |
| CMV 8-4                 | Mali                      |                                 |
| CMV 7-1                 | Mali                      |                                 |
| CMV 5-3                 | Mali                      |                                 |
| CMV 34                  | Mali                      |                                 |
| CMV 39                  | Mali                      |                                 |
| CMV 1-15                | Mali                      |                                 |
| CMV 6-1                 | Mali                      |                                 |
| CMV 1-2                 | Mali                      |                                 |
| CMV 2-2                 | Mali                      |                                 |
| CMV 28                  | Mali                      |                                 |
| CMV 20                  | Mali                      |                                 |
| CMV 52                  | Mali                      |                                 |
| CMV 21                  | Mali                      |                                 |
| CMV 9-1                 | Mali                      |                                 |
| CMV 36                  | Mali                      |                                 |
| CMV 40                  | Mali                      |                                 |
| CMV 8-2                 | Mali                      |                                 |
| TVSU 32                 | Nigeria                   |                                 |
| TVSU 33                 | Nigeria                   |                                 |
| TVSU 609                | Nigeria                   |                                 |
| TVSU 649                | Nigeria                   |                                 |
| TVSU 1140               | Nigeria                   |                                 |
| 06 K                    | Sahel                     | Silgué (Pobé)                   |
| 16 K                    | Sahel                     | Gargaboulé                      |
| 19 K                    | North                     | Zamsé                           |
| 20 K                    | North                     | Zonon                           |
| 29 K                    | Sahel                     | Silgué (Pobé)                   |
| 31 K                    | -                         | Sabraoghin                      |
| 32 K                    | -                         | Kagbilin                        |
| 34 K                    | Sahel                     | Bougué                          |
| 43 K                    | North                     | Bogoya                          |
| 48 K                    | East-Central              | Cella                           |
| 49 K                    | North                     | Soula                           |
| 78 K                    | -                         | Tassagha                        |
| 87 K                    | -                         | Galbogo                         |
| 92 K                    | North                     | Bogoya                          |

† Subscripts denote different colours recorded in the same accession.

‡ Centre Régional de Promotion Agro-Pastorale (Regional Centre for Agropastoral Promotion).

§ – = no information available.

#### Annex B. List of ecotypes collected, 1993-95.

| Name of collection | Origin (CRPA or country) | Locality (or village) |
|--------------------|--------------------------|-----------------------|
| Kamboinsé local-1  | Central                  | Kamboinsé             |
| Kamboinsé local-2  | Central                  | Kamboinsé             |
| Pobé local         | Sahel                    | Pobé-Mengao           |
| Titao-1            | Yatenga                  | Titao                 |
| Titao-2            | Yatenga                  | Titao                 |
| Titao-3            | Yatenga                  | Titao                 |
| Titao-4            | Yatenga                  | Titao                 |
| Pouytenga local-1  | North-Central            | Pouytenga             |
| Pouytenga local-2  | North-Central            | Pouytenga             |
| Pouytenga local-3  | North-Central            | Pouytenga             |
| Pouytenga local-4  | North-Central            | Pouytenga             |
| Pouytenga local-5  | North-Central            | Pouytenga             |
| Pouytenga local-6  | North-Central            | Pouytenga             |
| Pouytenga local-7  | North-Central            | Pouytenga             |
| Dassanga local     | South-Central            | Dassanga              |
| Kambo local-1      | South-Central            | Kambo                 |
| Kambo local-2      | South-Central            | Kambo                 |
| Kambo local-3      | South-Central            | Kambo                 |
| Kambo local-4      | South-Central            | Kambo                 |
| Kambo local-5      | South-Central            | Kambo                 |
| Nyaogo local-1     | East-Central             | Nyaogo                |
| Nyaogo local-2     | East-Central             | Nyaogo                |
| Youngo local-1     | East-Central             | Youngo                |
| Youngo local-2     | East-Central             | Youngo                |
| Youngo local-3     | East-Central             | Youngo                |
| Youngo local-4     | East-Central             | Youngo                |
| Gombousgou local-1 | East-Central             | Gombousgou            |
| Gombousgou local-2 | East-Central             | Gombousgou            |
| Sanga local        | East-Central             | Sanga                 |
| Bagré local-1      | East                     | Bagré                 |
| Bagré local-2      | East                     | Bagré                 |
| Douna local        | Comoé                    | Douna                 |
| Kayao local        | Southwest                | Kayao                 |



## Cameroon

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### Introduction

Cameroon covers an area of 474 442 km<sup>2</sup>, and contains exceptionally diverse physical environments. The country extends from latitudes 2° to 13°N, its altitudinal range from sea level to over 4000 m, and spreads from coastal mangrove swamp to the remote continental interior. Above latitude 6°N, rainfall varies from 800 to 1700 mm annually, and the mean temperature is 28°C, with an annual amplitude of 10-15°C depending on latitude, and a daily amplitude of 20°C. Below latitude 6°N, annual rainfall ranges even more widely, from 1900 to 4000 mm, and the mean temperature is around 25°C, with an annual amplitude of 3°C and a daily amplitude of 5-10°C.

Bambara groundnut is successfully grown above and below latitude 6°N, which reveals its great adaptability to a wide range of environmental conditions. It is a staple food for the population of part of the central, littoral and the most northern provinces.

### Research

Predictably, bambara groundnut is one of the crops that is most neglected by researchers in the Cameroon, and as far as is known, it has not yet been studied by any of the country's agricultural research institutes. The crop's advantages have been reported (National Academy of Sciences 1979), and dishes prepared with bambara groundnut are highly valued in the author's tribe. She began her research on the crop mainly in the littoral and western provinces in March 1989, and divided it into a number of phases, described below. So far, phases 1 and 2 have been carried out.

1. Survey, collecting and characterization of local cultivars.
2. Tests for yield potential and yield variability among the cultivars collected.
3. Biochemical analysis, and screening for superior cultivars, on the basis of yielding ability and nutritional value.
4. Investigation of the physiological parameters that could account for yield variability.
5. Improvement of the crop's management in the traditional farming systems of Cameroon.

### Survey

In the areas surveyed, bambara groundnut is mainly cultivated by women, on small farms, and is primarily destined for home consumption. Part of the harvest, however, is given away as presents to relatives and friends living in urban areas. Some may also be sold to obtain cash. As is mentioned elsewhere in this book, statistics on bambara groundnut production do not exist. The crop is mainly consumed fresh. The whole pods are boiled, and the seeds are eaten as a snack. Fresh testa-free seeds are cooked with seasoning and eaten as a complete meal, or they are ground to make a pudding (traditional cake), to which taro leaves are sometimes added.

Bambara groundnut is often mixed with the other crops, including peanut, maize, cassava, cocoyam, common bean and yams. It is sown on ridges or mounds. Ridges are 30-40 cm apart and 2-3 seeds are sown per hole, 20-25 cm apart. Mounds vary greatly in size, depending on the farmer. The average mound is 40 cm wide (diameter) and 30 cm high. They are approximately 50 cm apart. Each mound contains one hole, which receives 2-4 seeds at sowing.

previous harvest for sowing. In some areas, bambara groundnut can be sown twice a year, in February-April and in August. Harvesting is done by hand, 3-5 months after

Large and hole-free seeds (which should be undamaged) are chosen from the sowing. No fertilizer or any other chemical treatment is applied. Weeding and earthing-up are carried out simultaneously, 2-3 times before harvesting. Whole pods are sun-dried and kept in bags for the next cropping season. Occasionally, the pods are shelled, and the dry seeds are carefully wrapped in calabashes, with or without wood ashes.

No major diseases of bambara groundnut have been identified to date, owing to the lack of research carried out on the crop. Although no farmer has complained of a serious reduction in production caused by diseases or pest attacks, it was obvious from the author's survey that all parts of the plant (leaves, roots and pods) were attacked.

In the rare instances where bambara groundnut is grown by men, the crop is cultivated in pure stand, and is usually destined for commercialization. Cultivation is carried out on ridges or beds, with an average plant spacing of 30 x 25 cm.

### Collecting and characterization

Cultivars were collected from farmers and local markets. The following testa colours have been identified: black, cream, dark brown, light brown, dark red, light red, brownish red, dotted brown and dotted cream. In the environmental conditions prevailing in Dschang (West Province), plants emerged 7-10 days after planting (DAP). Flowering occurred 57-69 DAP, with an average of 64 DAP. Cultivars exhibited different growth habits: spreading, bunch and semi-bunch type. Seed weight varied from 380 to 470 mg/seed, with an average of 430 mg/seed.

### Yield variability and physiological traits

A mathematical equation relating the estimated leaf area (ELA, length x width of leaflets) to the actual leaf area (ALA) was found:

$$ALA = 0.71 ELA + 0.23$$

This equation is useful to researchers who lack adequate tools for determining leaf area. The leaf area index, the ratio of the leaf area of a group of plants to the area occupied by those plants, is an important parameter in growth analysis, and appears to be a useful criterion in the search for high yielding ability (as are other physiological features in crop selection). Total crop growth rate ranged from 0.44 to 1.27 g·plant<sup>-1</sup>·day<sup>-1</sup>, and averaged 0.72 g·plant<sup>-1</sup>·day<sup>-1</sup>, while pod growth rate varied from 0.52 to 0.72 g, with an average of 0.61 g. Partitioning coefficients ranged from 104 to 130% for most cultivars (only brown cultivars had partitioning coefficients of less than 50%, approximately 48%).

Harvest index, expressed as the ratio of pods to the whole plant, ranged from 0.42 to 0.49 and averaged 0.45. Shelling percentage was highly variable, ranging from about 17 to 55%, with an average of 35%. Yield on a plant basis varied from 13.40 to 47.16 g/plant and averaged 28.89 g/plant. Considering the plant spacing used in the trial (40 x 25 cm), this would give a yield range of 130-470 kg/ha, with an average of 290 kg/ha. These values fall into the range indicated in bambara groundnut literature for African yields.

### Prospects

Subject to the availability of funds, the author intends to:

- extend the survey in the northern regions of the country, where bambara groundnut seems to be important, as it is grown in pure stand and apparently receives fertilizers
- continue collecting accessions (having found cultivars with different testa colours)
- continue investigations of the crop through the implementation of phases 3, 4 and 5 of the research programme described above, leading to:
  - (i) evaluation of the nutritional value of different cultivars
  - (ii) assessment of the nature and extent of the relationships between leaf area index, harvest index, partitioning coefficient, grain/pod-filling period and yields
  - (iii) determination of the optimal harvest period, in order to minimize losses due to overmaturity (where pods will rot), or immaturity, as harvesting cannot be done gradually, owing to underground fruiting
  - (iv) improvement of cropping techniques (optimal plant density in sole and multiple cropping; the best species in the association; plant arrangement in intercropping; the use of fertilizers, including type, dose and application period; type of sowing beds, i.e. ridges, mounds or flat).

In collaboration with colleagues in the Plant Protection Department, pathological and entomological aspects will be addressed, as the author has noticed leaf, root and pod damage in the field. The author hopes to publish her research on bambara groundnut in a PhD thesis, and wishes to exchange information on the crop, through the Bambara Groundnut Research Network.

## Ghana

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### Introduction

According to the 1970 Ghana Agricultural census, there were 28 700 ha of bambara groundnut under cultivation in the Upper Region, and only 2800 ha in the rest of the country. In recent years, a number of factors have contributed to a decline in the importance of the crop in Ghana. These include inadequate research and funding to improve existing varieties and cropping systems, and, most significantly, the introduction of soybean. Although it is not as drought-tolerant as bambara groundnut, soybean appears to be much easier to cultivate, and the yields of improved varieties are much higher. Soybean has also received such considerable material and financial support that in about 5-10 years, it is likely to be the leading food legume crop in Ghana. Statistics are not available on the area under cultivation, the average yield, and total national production of bambara groundnut, all of which have decreased. Nonetheless, bambara groundnut still remains the third most important food legume crop in Ghana, after cowpea (*Vigna unguiculata*) and peanut (*Arachis hypogaea*).

Although the crop has not received government or international support in Ghana, work on bambara groundnut in the late 1960s and early 1970s gained international recognition. The University of Ghana believed that IITA had been mandated to work on the crop, and passed our germplasm collection to it, in the hope that our research workers and students would have the opportunity of working on the crop at IITA. As is well known, IITA's mandate for the crop was very short-lived. In the interim our germplasm collection disappeared, so we are now having to build it up from scratch.

### Cropping system

Bambara groundnut is cultivated in the drier Sudan, Guinea and coastal savanna zones of Ghana, where the annual rainfall ranges from 800 to 1200 mm. In the Guinea savanna zone, the crop is usually grown during the minor season (September-November), when the rainfall is reliable. In the Sudan savanna zone, it is usually cultivated towards the end of the single long rainy season.

There are very few bambara groundnut cropping systems, and these have changed little. In southeastern Ghana (the eastern Greater Accra and southern Volta regions), and also in northern Ghana, the crop is always grown at high densities, in pure stand and in rotation with cereals, etc. Recently, however, some farmers in the southern regions have started growing mixed stands of bambara and peanuts, the seeds being mixed before broadcasting. In the other growing areas of northern Ghana, it is usually grown as a mixed crop, with sorghum and millet. There is also a trend towards mixed cropping with yams, the bambara groundnut being planted on yam mounds that would otherwise have remained bare (except for the straw cap or mulch) for a long period. The bambara crop protects the mounds from erosion, conserves moisture and creates fewer temperature fluctuations in the mound. There are no yield or crop performance data for the various cropping systems. However, farmers' yields are believed to be very low, ranging from 0.5 to 0.8 t/ha. In the absence of improved varieties and cropping systems, yields are likely to decline.

## Uses

The high carbohydrate (65%) and relatively high protein (18%) content of bambara groundnut make it a complete food. In northern Ghana, the fresh immature beans are boiled and consumed after adding a little salt. The dry beans are also boiled, crushed and made into cakes or balls, which are then fried and used to prepare stews. In southern Ghana, the beans are usually soaked overnight, after which they are boiled until soft, to produce a kind of porridge/blancmange. Capsicum pepper and salt may be added during the boiling process. This preparation, called 'aboboi', is served with 'gari' (roasted, grated cassava) or with mashed, fried, ripe plantain. In the early 1960s, bambara groundnut was canned in Ghana, in tomato sauce with pieces of meat, in brine, or as 'aboboi'. Canned bambara groundnut was very popular, and competed favourably with Heinz baked beans, but the state-owned cannery has now collapsed.

## Genetic resources

Local germplasm collecting and foreign introductions began in the early 1960s. The local materials were from the principal growing areas, and the foreign introductions came from northern Nigeria, East Africa and Zimbabwe. Accessions are normally kept in cold storage in bottles or polythene bags. Institutions holding germplasm collections in Ghana are: the Crop Science Department, University of Ghana (80 accessions); the Savanna Agricultural Research Institute (SARI) (formerly Nyankpala Agricultural Experimental Station) (NAES, 90 accessions) and the Plant Genetic Resources Centre (PGRC, 166 accessions). Both SARI and PGRC are institutions under the aegis of the Council for Scientific and Industrial Research (CSIR).

Primary evaluation of collections is carried out for yield, maturity period, pest and disease resistance, and characters by which they can be readily identified. These include seed coat and eye colour, growth habit (bunch or spreading), colour of stem, petiole length and leaflet size. The findings of research completed at the Crop Science Department, University of Ghana, on some 70 local and exotic accessions, indicated a three-fold categorization of characters with respect to their variation:

- (i) plant base spread and petiole length (the most variable)
- (ii) number of branches/plant (moderately variable)
- (iii) canopy spread, leaflet length and width (the least variable).

It was suggested that the characters in category (i) could be most usefully employed in a primary grouping, and those in categories (ii) and (iii), in secondary and tertiary groupings, respectively. However, preliminary visual grouping into open, bunch and intermediate types indicated quite clearly that, taken by themselves, the numerical values representing the character did not match the observed form. For example, some visually observed open types had similar values to the intermediate and bunch types for canopy and plant base spread, as well as for petiole length. Further examination of the data revealed that the ratio of plant canopy spread to base spread was the only parameter that could accurately represent the observed forms, without any overlap between the groups. Group A cultivars (open type) had canopy: base ratios of from 1:1-1.4:1, Group B cultivars (intermediate), from 1.9:1-3.5:1, and Group C cultivars (bunch), of 4:1 and above.

## Research

Very little work is being done on the bambara groundnut crop at present, and the main research efforts are concentrated on variety characterization, and testing to assess yield potential, components and yield-related characters. Some work is in progress on *Bradyrhizobium* relationships and nitrogen fixation (Samasegaram *et al.* 1993; Kumaga *et al.* 1994). Research is also being carried out to ascertain the relationships between growth habit and breeding system, and to confirm an earlier finding (Doku 1969a) that open and semi-bunch cultivars depended more on the help of ants for effective pollination, fertilization and pod formation than the bunch types.

The flower stalk is very brittle (and there appear to be no varietal differences in this character), and so flower handling for emasculation is not possible, as flowers drop very readily. Boric acid ( $H_3BO_4$ ) application to the flower buds (0.1 ml of 200 ppm) prevented pollen sac dehiscence and pollen tube germination with subsequent flower dropping. The task now facing researchers is to find boric acid concentrations (150-180 ppm) that will induce male sterility, without immediate flower dropping, to permit pollination and fertilization by nearby plants with the aid of ants. This information is needed before any meaningful hybridization work can start.

The crop is relatively pest- and disease-free. Apart from weevil attack during storage, there are no serious field pests. Diseases affecting bambara groundnut include leaf spot (*Sclerotium rolfsii*, *Phyllosticta* spp.) and late blight (*Corticium solani*). Cowpea mild mottle virus has recently been confirmed on bambara groundnut (P. Lamptey, pers. comm.).

## Kenya

**G.W. Ngugi**

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### Introduction

The Republic of Kenya covers an area of 587 900 km<sup>2</sup>, of which 576 700 km<sup>2</sup> (about 98% of the total area) is land surface, while the remaining area of 11 200 km<sup>2</sup> is inland waters, mostly Lake Turkana and part of Lake Victoria (about 2% of the total area). About 80% of the land surface (461 400 km<sup>2</sup>) is arid and semi-arid land (ASAL). The remaining 20% (115 300 km<sup>2</sup>) of the total area (which includes inland water) is of medium to high agricultural potential.

### Land use and population distribution

About 80% of Kenya's population, which stands at around 24 million people, lives on land of high agricultural potential (20%). Land is considered the most valuable resource in Kenya, where a recent report described the situation as follows:

"The demands on the available land for various uses are many, and often create tremendous pressures and conflicts. Sustainable land-use planning becomes crucial, as it enables the available land to be used in such a way that it brings optimal benefits to the users, while having minimal negative impact on the environment."

(Page 116 in Kenya National Environment Action Plan (NEAP) Report, June, 1994, Ministry of Environment and Natural Resources, Nairobi.)

The ASALs are thinly populated, and mainly support pastoral communities. Kenya's population is made of about 60 ethnic groups and subgroups, and the majority of Kenyans live in the medium- to high-potential areas, where crop growing is the main economic activity. Population pressure in these higher-potential areas has resulted in migrations to the ASAL areas, which are suitable for livestock keeping. Mixed farming is predominant in most of the areas that can support agriculture. Diverse farming systems have been developed by the various ethnic groups, who possess a high level of indigenous agricultural knowledge.

An average of 6.5% of the rural population migrates to urban centres annually. This has resulted in a large city-dwelling population, which presently stands at over 5 million (5.2 million in 1992, 22% of the country's population). The production, marketing and use of traditional crops have been affected by the urban population's tendency to adopt exotic feeding habits, leading to loss of traditional knowledge on food preparation.

### Climate

Kenya can be divided into seven climatic zones, based on rainfall and potential evaporation, and nine temperature zones, ranging from the cold highlands of the interior to the hot coastal and desert regions (Tables 1 and 2, Fig. 1). Reliable rainfall, adequate for cultivation, can only be expected over 15% of Kenya. Rainfall is greatest at the coast, in the west of the country, near Lake Victoria and in the

highlands. The extensive plains below 1200 m asl are arid or semi-arid, however. In the region of Lake Victoria, and in the highlands west of the Rift Valley, rain falls in one long rainy season. East of the Rift Valley, there are two distinct seasons: the long rains (March-May) and the short rains (September-October).

The Kenyan soils can be divided into 10 groups, on the basis of various properties related to crop production and soil management (Table 3).

**Table 1. Agroclimatic zones of Kenya.**

| Zone | Average annual      |                             | Classification<br>r/ E° (%)    | Typical vegetation            |
|------|---------------------|-----------------------------|--------------------------------|-------------------------------|
|      | Rainfall,<br>mm (r) | Potential<br>evap., mm (E°) |                                |                               |
| I    | 1100-1700           | 1200-2000                   | 80 humid                       | moist forest                  |
| II   | 1000-1600           | 1300-2100                   | 65-80 sub-humid                | moist to dry forest           |
| III  | 800-1400            | 1450-2200                   | 50-65 semi-humid               | dry forest and moist woodland |
| IV   | 600-1100            | 1550-2200                   | 49-50 semi-humid/<br>semi-arid | dry woodland and bushland     |
| V    | 450-900             | 1650-2300                   | 25-40 semi-arid                | bushland                      |
| VI   | 300-550             | 1900/2400                   | 15-25 arid                     | bushland and scrubland        |
| VII  | 150-350             | 2100-2500                   | 15 very arid                   | desert scrub                  |

Source: Braun, H.M.H *et al.* 1980. Agro-climatic zone map of Kenya, scale 1:1,000,000. Ministry of Agriculture, Kenya Soil Survey. Nairobi, Kenya.

**Table 2. Temperature zones of Kenya.**

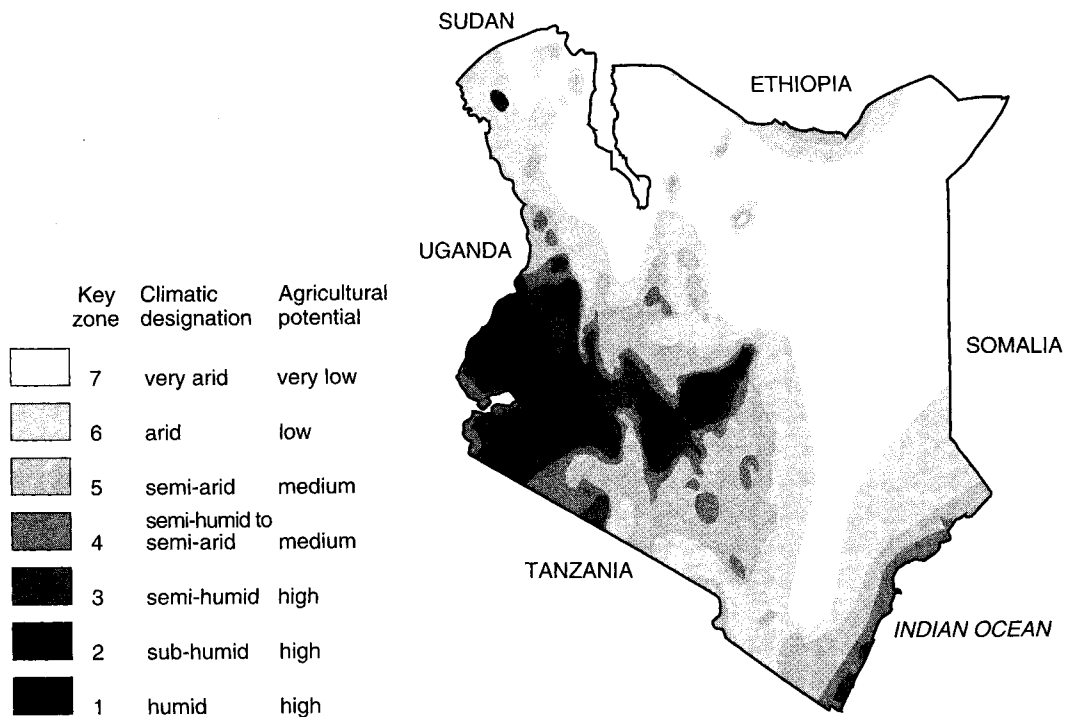
| Zone | Mean annual<br>temp. (°C) | Classification      | Night frost | Altitude<br>(m) | General<br>description |
|------|---------------------------|---------------------|-------------|-----------------|------------------------|
| 9    | <10                       | very cold           | very common | >3050           | Afro-Alpine highlands  |
| 8    | 10-12                     | cold/very cold      | common      | 2750-3050       | Upper highlands        |
| 7    | 12-14                     | cool                | occasional  | 2450-2750       |                        |
| 6    | 14-16                     | fairly cool         | rare        | 2150-2450       | Lower highlands        |
| 5    | 16-18                     | cool temperate      | very rare   | 1850-2150       |                        |
| 4    | 18-20                     | warm temperate      | none        | 1500-1850       | Midlands               |
| 3    | 20-22                     | fairly warm         | none        | 1200-1800       |                        |
| 2    | 22-24                     | warm                | none        | 900-1200        |                        |
| 1    | 24-30                     | fairly hot/very hot | none        | 0-900           | lowlands               |

Source: Braun, H.M.H *et al.* 1980. Agro-climatic zone map of Kenya, scale 1:1,000,000. Ministry of Agriculture, Kenya Soil Survey. Nairobi, Kenya.

## Crops

Maize is the most important cereal cultivated, followed by sorghum. Other cereals grown include rice, wheat (in the highlands), pearl millet and finger millet. Beans are the most important pulses, followed by cowpea, lablab, green gram and pigeon peas (in the eastern lowlands). Crop distribution is influenced not only by climate and soil type, but also by cultural factors. Different communities tend to grow and eat specific foods, and adaptation to other foods has been slow or non-existent.





**Fig. 1.** Agroclimatic zone map of Kenya (source: Braun, H.M.H *et al.* 1980. Agroclimatic zone map of Kenya, scale 1:1,000,000. Ministry of Agriculture, Kenya Soil Survey. Nairobi, Kenya).



**Fig. 2.** Distribution of *Bambusa groundnut*.

### Bambara groundnut

Bambara groundnut (*Vigna subterranea* (L.) Verdc.) is a minor crop in Kenya. It is used as a traditional food by the Luhya, by the Giriama and Kambe at the coast, and to a lesser extent by the Luos (who probably borrowed bambara groundnut's name and its culinary and other uses from the Luhya). The crop can usually be grown in relatively poor soils, and is found in hot, low-lying regions, often with sandy to loam soils. It can be intercropped with maize, sorghum or millet, and is mainly grown at altitudes ranging from 0 to 1550 m. Ethnobotanical surveys have shown that bambara groundnut used to be produced in abundant quantities. Although it is still considered a delicacy by the communities who use it in Kenya, current levels of production are lower than those of the past.

Considering that bambara groundnut has its origin in West Africa, and taking into account that the Bantu (within which larger group the Luhya, the Kambe and the Giriama fall) originated from West Africa, it is the author's opinion that the crop migrated with them. The Bantu peoples migrated into Kenya via two routes:

1. Through Uganda (as in the case of the Luhya). According to an Elder that the author interviewed, when the Luhya encountered those migrating southwards from Sudan (e.g. the Luo, who are not Bantu), conflicts would usually take place between them, with the victorious tribe appropriating the possessions of the defeated tribe, including its seeds. It seems probable that bambara groundnut passed into the Luo culture in this way. That the Luo name for bambara groundnut appears to be borrowed from the Luhya would support this hypothesis, as would the fact that the crop is not as widespread among the Luo as it is among the Luhya culture. It is also interesting to note that those Luo who settled at greater distances from the Luhya recall that although bambara groundnut is no longer grown in their areas, it was in the past.
2. To the coast and interior, via Tanzania (the migratory route of the coastal and central Bantu, for the most part). This group may have brought seeds with them, including those of the bambara groundnut, but the crop's distribution was probably affected by the environment in the places the various groups settled in. This may explain the fact that bambara groundnut is only found among a few Bantu peoples of the coast, notably the Giriama and the Kambe. There is also a possibility that the crop was introduced there from the western parts of Kenya, owing to their vicinity to the coastal towns of Mombasa and Malindi. The majority of people interviewed by the author who came from the central regions of Kenya claimed not to know bambara groundnut. The few who did know the crop recognized it from the Swahili name, and some said they had only seen it at the coast. The Kambe the author talked to said that they only eat bambara groundnut when other vegetables are scarce. These reports would seem to support the crop's introduction to the coast from the western areas of Kenya.

According to one Luo man the author interviewed, his tribe brought bambara groundnut with them when they migrated to Kenya from Sudan (that such a migration occurred is supported by research findings). The same man emphasized, however, that different tribes followed the same migratory routes, and cultural interchange and exchange of seeds may well have occurred in the process. According to Christopher Ehret (1985), the introduction of crops that were often of

considerable economic importance, represented one aspect of the gradual changes that occurred in Kenya in the 19th century. He observes that:

“...if naming data, for instance, imply an introduction from a plant earlier from one direction and oral evidence, its introduction from a second direction at a later period, the normal inference would be that linguistic data reflect first bare knowledge of the plant, and oral data, the beginning of cultivation of the crop in significant quantities”.

Ehret (1985) also observes that terms used to name the American peanut (*Arachis hypogaea* L.) raise additional historical inferences from word distribution. Several different names are applied in different areas of East Africa to bambara groundnut, in keeping with expectations that things develop a variety of names in different languages, having been around through many years of language change. But contrary to this, only two terms for the peanut, both probably being of Swahili provenance and adopted from names of indigenous plants, developed, i.e. ‘njugu karanga’. ‘Njugu’ is probably the early Coastal Bantu name for bambara groundnut (but in Upland Bantu the name of pigeon pea instead), and ‘karanga’ was probably the name for the wild plant *Desmodium abscondans*, which today is called ‘karanga mwitu’ to distinguish it from the peanut. It is thus possible that the Swahili name for bambara groundnut was later changed to describe its characteristics (‘njugu mawe’: ‘njugu’ meaning hard, ‘mawe’ meaning stone), and to distinguish it from the now adopted plant of similar characteristics – peanut (‘njugu karanga’).

### Distribution

Bambara groundnut is chiefly grown in the western parts of Kenya, and to a limited extent, in the coastal provinces. In western Kenya, it is mainly found throughout the Western Province, i.e. the Bungoma, Kakamega, Busia and Vihiga districts. It is also found in parts of the Siaya district, especially in Gem, in Masiro in East Ugenya and in Usonga in Alego. In South Nyanza, it is found in Nthiwa, Kologi, Homabay, Migori, Macalder and Miuru. At the coast, it is mainly found in the Kilifi district, especially in Bahari, Kaloleni and Malindi (Fig. 2).

Bambara groundnut is generally found in agroclimatic-temperature zones I-3, I-4, II-3, II-4, III-1, III-3 and IV-3, and in IV-1, VI-1, V-1 and VII-1 at the coast (Tables 1 and 2, Fig. 1), and in areas where rainfall pattern is bimodal. Rainfall at the coast is generally low, but there is high humidity from the ocean, which probably favours the growth of bambara groundnut. The soils in which it is found are generally well-drained, deep to moderately deep, and reddish to brown, sandy clay loam to clay. At the coast, however, it is found in well-drained, deep fine to very fine, sandy to sandy loamy soils, ranging in colour from yellow brown to reddish brown (Table 3). The natural fertility status is high, moderate and low in the western parts of Kenya, and moderate at the coast.

#### Local (vernacular) names for bambara groundnut in Kenya

|                             |                        |
|-----------------------------|------------------------|
| Swahili                     | ‘njugu mawe’           |
| Luo                         | ‘bande’                |
| Luhya (Wanga/Kisa/Maragoli) | ‘tsimbande’            |
| Luhya (Bukusu)              | ‘chimbande’            |
| Luhya (Tiriki)              | ‘simbande’, ‘zimbande’ |
| Giriama                     | ‘nzugu mawe’           |
| Kambe                       | ‘tendegwa’             |

**Table 3. Summary of the broad soil groups in Kenya (Kenya Soil Survey).**

| Group                                   | Area (ha)  | Natural fertility |  | FAO 1974 classification  |
|---|------------|-------------------|--|--|
|   |            | status            |  |  |
| weakly developed soils                  | 3 638 235  | low               |  | xerosols; yermosols  |
| shallow/juvenile soils                  | 6 697 809  | moderate/high     |  | lithosols; regosols, rankers and rendzinas                                       |
| sodic and/or saline soils               | 13 489 985 | low               |  | solonetz; solonchaks; solodic planosols  |
| alluvial soils                          | 1 936 582  | high              |  | fluvisols  |
| deep/very deep soils                    | 3 796 669  | moderate          |  | nitosols; andosols   |
| sandy soils                             | 436 683    | very low          |  | arenosols  |
| poorly drained soils                    | 5 604 302  | moderate          |  | vertisols; gleysols; other planosols; greyzems; chermozems; vertoluvic phaeozems |
| moderately deep/deep soils              | 7 408 426  | high              |  | luvisols; cambisols; phaeozems; chernozems                                       |
| deep red, strongly weathered acid soils | 6 839 464  | low               |  | ferralols, acrisols; ironstone soils   |
| shallow to moderately deep soils        | 7 688 796  | high              |  | shallow cambisols; luvisols; phaeozems   |

Source: Ministry of Environment and Natural Resources. 1994. Kenya National Environment Action Plan (NEAP). Nairobi, Kenya.

## Uses

### General culinary uses

Each community has its own way of preparing bambara groundnut. Among communities from western Kenya, for example, seeds are cooked with maize (occasionally after overnight soaking), or on their own, then mashed, fried and made into a stew. Stomach ache can result from eating this stew in large quantities, although it is reported to be less upsetting to the digestion than beans. It is claimed by some that bambara groundnut requires careful preparation, as it has a rather bitter taste.

### Culinary uses by the Kambe/Giriama

Among the Kambe and Giriama peoples of the Coast Province, bambara groundnut is normally cooked or used when vegetables are in short supply.

- When the seeds are dry, they are pounded in a 'kinu' (mortar) to remove the seed coat (they do not break), winnowed and boiled until they are cooked. They are then pounded using a 'kipawa' (serving spoon made from the coconut shell) or 'mwiko' (wooden spoon), and 'tui' (coconut juice) is added. The mixture is boiled until cooked, and stirred with a wooden stirrer ('lufidzo') until smooth. It is then served with rice or 'ugali' (a stiff maize meal porridge).
- When the seeds are still green, the seed coat is peeled off by hand and the seeds are then prepared in the same way as the dry ones (described above).

### Culinary uses by the Luhya

The Luhya consume bambara groundnut in the following ways:

- Cooked fresh in its pods (green pods are washed and boiled in salted water, which is said to penetrate the pods). This is reported to be the tastiest snack among the many that are made from bambara groundnut, and is rated even more highly than the peanut.
- The dry seeds are salted while roasting (the seeds may be washed before roasting). Owing to the hardness of the seeds, this dish is not a favourite, especially with children. Sometimes, a small number of seeds is reportedly roasted with a greater proportion of peanuts, to reduce the hardness effect.
- Dry seeds can either be pounded or ground and the resultant meal made into some stew (or sauce). The stew/sauce is then added to the traditionally prepared leafy vegetables, particularly 'sikhubi'/'elikhubi' (cowpea) and cooked. This may be served with 'ugali' or potatoes.
- Boiled with maize and beans and served as a snack, especially with tea.
- Fried (like peanuts), usually with sesame seeds.
- Boiled, then mixed with boiled sweet potatoes and mashed (a popular children's dish). It is also consumed plain, after being boiled and mashed.
- Unshelled pods are boiled, fried and served with potatoes, bananas or 'ugali'.

### Culinary uses by the Luo

Bambara groundnut is also prepared in a number of ways by the Luo:

- Used in the same way as kidney beans, to make 'nyoyo' (a mixture of beans and maize boiled together), or plain boiled. This is served with tea, 'nyuka' (porridge), or on its own.
- Dried, ground using a 'pong' (grinding stone), or pounded in a 'pany' (mortar), then cooked in the same way as greengrams, in a sauce traditionally known as 'ogira'. This is served with other foods, such as potatoes. Traditionally it was eaten using a 'sare' (bivalve shell from lake Victoria).
- Roasted like the peanut. This is not common, because the seeds remain hard after roasting. Peanuts are normally added, probably to reduce the effect of hardness.

### Medical uses by the Luo (according to one informant)

- Water from the boiled maize and pulse mixture is drunk to treat diarrhoea.
- The leaves are pounded with those of *Lantana trifolia* L. ('nyabend winyo', 'nyamrithi'), then water is added to make a solution used to wash livestock as a preventative against ticks. This solution is used as a pesticide on vegetables too.
- The leaves can be combined with those of 'nyajagra' (mexican marigold) and *L. trifolia*, pounded, and water added. This mixture can also be used as an insecticide. When applying the solution to vegetables, care needs to be taken to apply it to the ground, and not to pour it on the leaves, as it is reported to burn them.
- When dry, the leaves are pounded with traditional salt ('mbala', harvested at Sindo and Homalime), and fed to cattle infected with 'tuolao' (a type of mouth disease). The leaves cauterize and heal the animals' wounds.

### Miscellaneous uses

Among the Luhya, bambara groundnut is said to be mainly cooked for consumption at ceremonies such as weddings, or by dignitaries. The leaves are used for animal fodder. Also of interest are some studies undertaken by the Kenya Energy and Environment Non Governmental Organisation (KENGO) of the bambara groundnut as a substitute ingredient for peanut in weaning foods. Researchers worked on traditional recipes provided by several collaborating women's groups, and developed four new recipes. Nutritional analysis of the new recipes was carried out, but no palatability tests were done (Table 4).

**Table 4. Weaning food recipes (KENGO<sup>†</sup> unpublished).**

|   | <b>Ingredients</b>                  | <b>Proportion (%)</b>    |
|---|-------------------------------------|--------------------------|
| 1 | Finger millet                       | 70 (the most nutritious) |
|   | Bambara nut                         | 25                       |
|   | <i>Amaranthus</i> (dry leaf powder) | 5                        |
| 2 | Finger millet                       | 70                       |
|   | Bambara nut                         | 30                       |
| 3 | Sorghum                             | 70                       |
|   | Bambara nut                         | 25                       |
|   | <i>Amaranthus</i> (dry leaf powder) | 5                        |
| 4 | Sorghum                             | 70                       |
|   | Bambara nut                         | 30                       |

<sup>†</sup> Kenya Energy and Environment Non Governmental Organization.

### Agronomy

Bambara groundnut is planted in rows, or randomly. In western Kenya, the crop is normally planted in March and harvested in August. If intercropped, it does not do well unless the other crop (usually maize) is quite scattered (i.e. there are few plants). It takes 5-6 months to mature, at which stage the leaves turn brown and fall off. Harvesting is usually done by uprooting or digging out the entire plant and picking the individual pods. The yield is said to be low during the short rains. Unlike the peanut, however, the plants are said not to be destroyed by hailstorms.

### Pests and diseases

It has been reported that if the seeds remain underground for a long period, they are eaten by termites, but that, unlike peanuts, insects do not attack them during the growth period. If stored when shelled, they are said to be attacked by the common bean weevil. Some of the seeds brought to the National Museums of Kenya were infested with insects which were identified as the cowpea bruchid (*Callosobruchus* sp. probably *maculatus*; identification by P. Kamau of the Department of Invertebrate Zoology, National Museums of Kenya). Some pigeon pea (*Cajanus cajan* (L.) Huth) seeds, which were also affected by this pest, were mixed with the bambara groundnut seeds and may have infested them. This corroborates an earlier report by Hepper

(1963) on bambara seeds found to be infested with bruchid beetle, which were identified as *Callosobruchus subinnotatus* Pic.

### Harvesting and storage

The pods, which are produced underground, are pressed by hand, or more often sun-dried, threshed and winnowed to obtain the seeds. These are then sun-dried and stored. Traditionally, the seeds were left in the pods, which would then be stored in a pot, and would only be shelled when they were needed for cooking. This storage method is still used by some people, especially in Bungoma district.

### Production and markets

Table 5 gives production figures per district for bambara groundnut. Surveys undertaken in Nairobi indicated that bambara groundnut is more expensive than other pulses in the city. It is mainly found in three markets in Nairobi: Gikomba, on the outskirts of the city, Nyamakima, near the city centre, and at Kawangware, in the suburbs. In the Nyamakima market, the crop is sold at Ksh. 80/kg, and for Ksh. 120/kg at Kawangware (the average price of beans in most parts of Nairobi is Ksh. 28/kg.) The demand for bambara groundnut in Nairobi is quite low, and for this reason, few stallholders stock it. At Gikomba market, which is the largest of these, only one woman (from the Kakamega district) sells the crop. At the Kawangware market, it is only sold by one stallholder (also from Kakamega), who seemingly buys his stock from the stallholder at the Gikomba market. Bambara groundnut is also sold in other urban centres, such as Kakamega, Bungoma, Kisumu (at the Mbero and Kibuya markets), Homabay, Nthiwa, Mirogi, Ratang'a, Aorachuotho, Macalder and Migori.

### Genetic resources

Most of the germplasm found in Kenya can be classified as traditional landraces or local cultivars. No major work has been done on bambara groundnut in Kenya, and for this reason, no modern varieties have been developed. The country's germplasm-holding institutions and their accessions are described in Table 6. The germplasm held at the National Genebank of Kenya has not been characterized. There are 6 accessions at the Genebank, 1 from Nigeria, 1 from England, 1 from Australia and 3 from Kenya. The Kenyan accessions are the following:

- (i) a primitive cultivar/landrace from Busia (South Teso Kwangamor), collected at 1290 m asl
- (ii) a wild landrace from Siaya (South Sakwa bar Kowino sublocation)
- (iii) a primitive cultivar/landrace from Kilifi (Chasimba sublocation).

According to G.O. Rachier (pers. comm.), however, at the Kakamega Regional Research Centre of the Kenya Agricultural Research Institute (KARI), under whose aegis groundnut research falls, local farmers hold seeds belonging to traditional landraces/local cultivars, of the following size and colour: medium-sized brown and purple, and large brown tinted.

Table 5. Production of bambara groundnut per district 1992-94 (data compiled from the Ministry of Agriculture annual district reports, subject to availability).

| District | Year | Actual         |                           |                           | Production<br>(t) | Value<br>(Ksh. 000)  | Status of crop/cultivation constraints |
|----------|------|----------------|---------------------------|---------------------------|-------------------|--|--|
|          |      | Actual<br>(ha) | Actual<br>yield<br>(t/ha) | Actual<br>yield<br>(t/ha) |                   |  |  |
| Bungoma  | 1993 | 1.4            | 0.6                       | 0.84                      | 1.68              | Production of the crop is still very low in the district. The seed is expensive and not readily available. The crop is also labour-intensive and farmers give it low priority. The 1995 targets are 2 ha for long and short rains.   |  |
|          | 1994 | 2              | 0.6                       | 1.2                       | 5.1               |  |  |
| Kakamega | 1992 | 105            | 0.53                      | 56                        | 28                | This is still a minor oil/protein crop, mainly grown in the Butere, Mumias, Lurambi and Khwisero divisions. The crop has considerable potential in the district; demand is high and market prices are good.  |  |
|          | 1993 | 224            | 0.56                      | 126                       | 76                |  |  |
| Vihiga   | 1992 | 3              | 0.5                       | 1.5                       | 3.03              | Hectarage of the crop has stagnated due to:<br><ul style="list-style-type: none"> <li>• small land holdings.</li> <li>• lack of promotion of the crop locally.</li> <li>• farmers' lack of interest in the wider economic importance of the crop.</li> <li>• bambara groundnut's principal use as a snack rather than as a main food.</li> </ul> |  |
|          | 1993 | 3              | 0.4                       | 1.2                       | 3.2               |  |  |
|          | 1994 | 6              | 0.56                      | 3.4                       | 6.8               |  |  |
| Kilifi   | 1992 | 6              | 0.5                       | 3                         | n.a. <sup>†</sup> | Lack of planting material is a major drawback, but there is great potential for expansion.   |  |

<sup>†</sup> n.a. = not available.



A number of seeds held at the National Museums of Kenya were purchased from the Kawangware and Nyamakima markets, while others were personal donations to the institution. The lot from Kawangware is a mixture of more than 10 varieties, differentiated on the basis of size and colour, which ranges from cream/white, through orange, brown, red, dark red/maroon and black, to cream-, brown- and red-speckled. The lot from Nyamakima is homogenous, containing dark brown/red large seeds. The seeds of one sample given to the museum are black (some very tiny, and others medium sized). The range of diversity in the collections is not presently known, as no survey has been carried out. Both Dr J.K. Kimei of the National Genebank and G.O. Rachier of Kakamega RRC admit that the existing collections are highly incomplete, both in terms of genetic diversity and geographic representation. At the NMK, ethnobotanical information on bambara groundnut is inadequate.

**Table 6. Germplasm-holding institutions and the state of their collections.**

| <b>Institution</b>                             | <b>Accessions/storage conditions</b>  |
|--|---|
| National Genebank of Kenya                     | Seeds viable, but the amount held was not specified   |
| KARI - Kakamega Regional Research Centre (RRC) | 2 kg of a mixture of brown and purple medium-sized seeds, which have not been sorted out or characterized   |
| National Museums of Kenya (NMK)                | Seeds sorted according to colour and size (14 groups) and stored under long-term storage conditions at The Plant Conservation and Propagation Programme |

#### **Conservation methods used**

The bambara groundnut accessions at the National Genebank are placed in long-term cold storage at  $-20^{\circ}\text{C}$ . Seeds for the base collection are dried until their moisture content is 3-7%. This is done with a cool-drying system, using a dehumidifier running at  $-20^{\circ}\text{C}$  and 15% relative humidity, until the correct moisture content is achieved. The seeds are then hermetically sealed in aluminium foil containers. Seed viability testing is carried out after drying, just before storage, to determine the viability of the seeds before final storage. The recommended viability standard is 85% and above. Subsamples for regeneration/multiplication, distribution, characterization and monitoring viability are kept at  $5^{\circ}\text{C}$  and/or  $-20^{\circ}\text{C}$ . At Kakamega RRC, short-term conservation at  $5^{\circ}\text{C}$  is used. Materials are stored in the form of seeds and unshelled pods.

#### **Major limitations and constraints**

The following problems have been reported in bambara groundnut (G.O. Rachier, pers. comm.):

1. Agronomic
  - individual cultivars are not very adaptable, although the crop is found in vastly different environments
  - careful cultivation is needed, as the flower stalks are much weaker in comparison to those of groundnuts, and cannot penetrate hard soil crusts.

## 2. Pathological and entomological

- *Fusarium* with leaf spot, root rot nematodes and virus are known to attack bambara groundnuts.

No information exists on the use of germplasm in research/breeding/crop improvement and selection procedures, because no work has been undertaken on bambara groundnut by the Kenyan research centres in particular. Nor are any individual research findings available.

## Conclusions

Ethnobotanical research indicated that bambara groundnut production is declining. One of the reasons for the decline to which attention was drawn, is the cost of purchasing the seeds, which farmers find a strain on their finances. The price of seeds is determined by the level of production of the crop: the lower the quantity produced, the higher the cost. This also affects utilization of the crop, as consumers buy what they can afford. In the rural areas, the cost of a glass (about 200 ml) of bambara groundnut is Ksh. 20, while that of beans is Ksh. 10-15/kg (most people indicated that beans were quite affordable, and preferred to buy them). Despite its prohibitive cost, bambara groundnut is still considered a delicacy by the communities which eat it and they would like something to be done to promote its production and use.

One clear cause for concern is the high level of genetic as well as cultural erosion occurring in bambara groundnut, a situation that requires swift action to be taken. Cultural erosion of a crop increases genetic erosion, as it promotes non-usage, which causes production to decrease. It also contributes to non-utilization of the crop by other communities, owing to its unavailability, and a lack of indigenous knowledge pertaining to its use, and thus to its various methods of preparation. Over the last 30 years, bambara groundnut has declined significantly in importance. The majority of those who confirmed that production of the crop is falling are young people, who said that while it was grown abundantly in their youth, it is now cultivated in few areas. One clear cause for concern is the high level of genetic as well as cultural erosion occurring in bambara groundnut, a situation that requires swift action to be taken. There is an urgent need for:

- collecting bambara groundnut germplasm to fill the gaps in the existing collections described above
- intensification of ethnobotanical research, to help fill these gaps
- the use of newly collected germplasm in research, breeding and crop improvement, to help increase bambara groundnut production
- collecting and documenting the indigenous knowledge (IK) pertaining to bambara groundnut before it disappears, and incorporating this into selection and breeding procedures
- research to determine which of the various varieties of bambara groundnut is nutritionally superior
- encouragement of germplasm exchange, to help improve the local varieties, and to make the improved varieties available to farmers.

## Northern Nigeria

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### Introduction

Bambara groundnut (*Vigna subterranea* (L.) Verdc.) is believed to originate in several areas of Nigeria, notably that between Jos and Yola (Hepper 1970). The crop is presently grown throughout the country, with the exception of the riverine and swampy areas. It is grown by subsistence farmers, on small patches of land, and is frequently intercropped with cowpea, sorghum and cotton, among other crops.

The research activities of the Institute for Agricultural Research (IAR), Ahmadu Bello University cover the savanna ecological zone of Nigeria (latitudes 7-13°N) (Fig. 1). Rainfall there varies from less than 500 mm in the Sahel and Sudan zones to 1200 mm in the southern Guinea zone, and is spread over periods that range from 3 to 7 months. The climate during the remaining months of the year is characterized by dry weather, with Harmattan winds lowering night temperatures to 18-20°C between October and February.

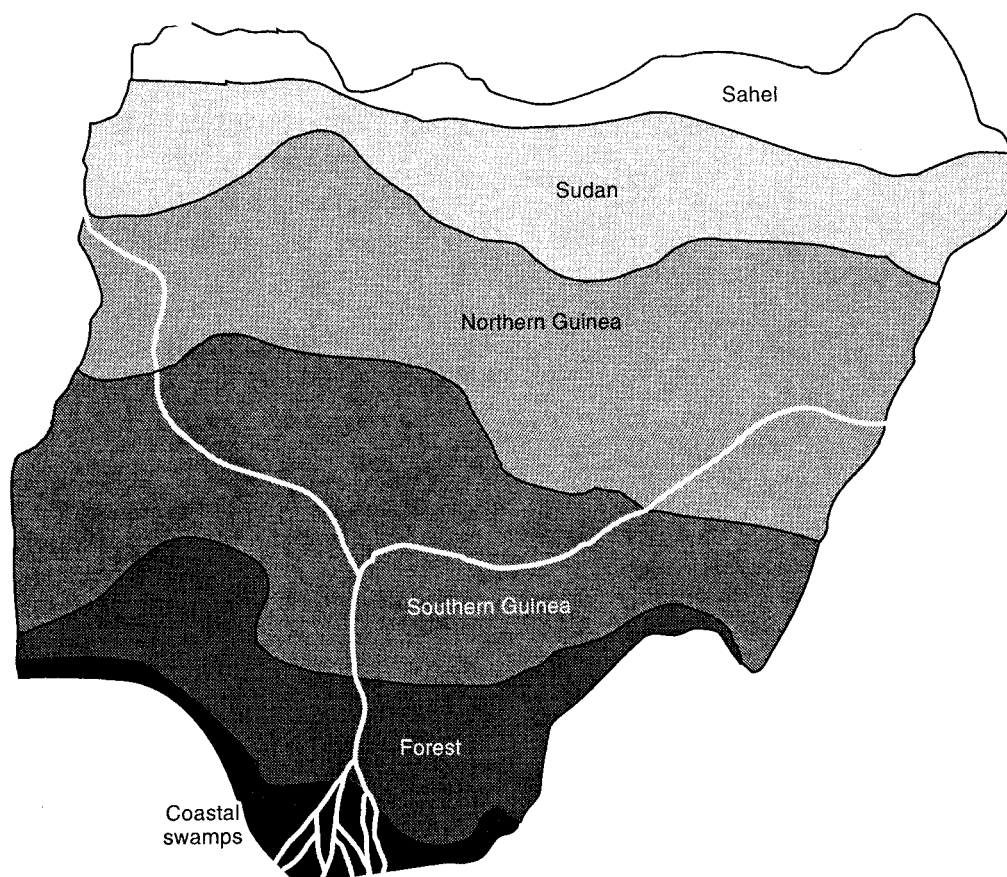
### Production

It is difficult to obtain accurate production and yield figures for the bambara groundnut crop in Nigeria. However, Rachie and Roberts (1974) estimated that the country produces about 100 000 t of the crop annually. The area under bambara groundnut cultivation in the Sahel and Sudan savanna zones of Nigeria has declined over the past two decades. Farmers in these areas estimated that the present area is about 5-20% of that of 20 years ago. They attributed this decline to drought. On the other hand, the area under bambara groundnut cultivation has increased during the same period in the southern Guinea and forest zones of Nigeria. The increase in the amount of the crop produced in these areas is thought to be due to the fact that the crop fetches higher prices now than it did previously.

The majority of the farmers cultivate the crop primarily for food; however, they may sell part of it when they produce a surplus, or when they need money to pay taxes, loans or school fees (Linnemann 1988). The shift in cultivation of bambara groundnut from the drier to the wetter parts of the country has reduced overall production of the crop, for the following reasons: (i) there are fewer farmers producing the crop in the wetter areas; (ii) land clearing is difficult and costly; (iii) the soils in the wetter areas are more difficult to cultivate, as they are heavier and more prone to weeds, and (iv) more disease problems are encountered in the wetter areas because of the prevalent high humidity.

### Uses

In Nigeria, most of the bambara groundnut produced is consumed locally. No industrial use of the crop has been reported. The haulm is used for livestock feed, while the fresh pods are boiled and eaten as a snack. Seeds are often crushed into flour, to prepare the following dishes: 'alele', 'alelen ganye', 'danwake', 'gauda', 'kosai', 'kunu', 'tuwo' and 'waina' (Linnemann 1988). The fresh immature seeds are also eaten raw.



**Fig. 1.** Major vegetation/agro-ecological zones of Nigeria.

### Genetic resources

Nigeria is believed to be one of the centres of origin of this crop, and possesses extensive bambara groundnut genetic resources. This can be observed from the wide range of differences in the seed coat colour, seed sizes, pigmentation around the eye, pod shape, growth habit and other characters. In April 1984, a collecting mission was organized by the Institute to various parts of the country. About 80 accessions were collected, multiplied and maintained, and the most promising ones were subjected to yield evaluation trials. Foreign accessions have not yet been received, although requests for seeds have been sent to various researchers outside Nigeria. Some seeds were collected from northern Namibia, but were lost in transit. Because of inadequate modern storage facilities at the Institute of Agricultural Research, Samaru (IAR, see below), collections were sent to Dr A.R. Linnemann, and some to IITA for conservation.

### Breeding

Bambara groundnut is self-pollinating. The small, yellowish flowers are borne on the plant's short, creeping stems, and are fertilized before opening. After fertilization, a peduncle grows positively geotropic, and the fruits develop and ripen underground (Sands 1931). The breeder's aim is to combine desirable traits from all available genetic resources into a single new variety. The starting point for any breeding programme is therefore to establish a germplasm collection containing the widest

possible range of the genetic variability available within the species. Such a genetic resource will play a key role in crop improvement and its protection against drought, pests and disease, etc.

A bambara groundnut breeding programme was begun in 1984 at IAR, with the aim of collecting and preserving local germplasm, and developing superior varieties through selection and hybridization. Evaluation trials were carried out to establish the potential of local germplasm as source material for future crop improvement. A number of different bambara groundnut accessions collected from various parts of the northern states of Nigeria were evaluated at Samaru. The phenotypic and genotypic performance of these accessions is presented in Tables 1 and 2, respectively. A wide range of genotypic and phenotypic variation was observed in a number of characters, such as seed yield, 100-seed weight and shelling percentage (Tanimu *et al.* 1990). The variation observed, especially for seed yield and 100 seed-weight, was then used as the basis for selection and genetic improvement of the crop.

As a self-pollinating crop, any population of bambara groundnut may consist of numerous homozygous pure lines. For this reason, the selection method used was single plant selection, where individual plants manifesting desirable traits were selected and grown separately, to produce several parallel pure lines. Roguing is also used to maintain the standard of any chosen line; plants showing undesirable characteristics are generally removed from the selected population, leaving the more typical plants to grow and produce seed.

### Major problems/constraints

#### Agronomic

Most of the varieties are local, and are thus limited in their genetic potential. Both haulm and seed yields are therefore invariably low. Until very recently, there were no recommended sowing dates, optimum plant density values, or fertilizer rates. There is also inadequate information on the type and intensity of mixture with other crop types in the farming systems practised by local farmers. Pod-shedding is also a problem with certain varieties, or the crop may fail to set pods, owing either to the wrong timing of agronomic practices, or to crop injury during weed removal.

#### Pathological

Because bambara groundnut is grown during the rainy season, a period of high temperatures and humidity, it is highly susceptible to fungal diseases, which are common during this period. Attacks of rust and leaf blight, caused by *Puccinia* sp. and *Colletotrichum* sp., respectively, have been reported in the crop when grown on station. Isolated cases of rosette disease also have been reported in bambara groundnut.

#### Entomological

Bambara groundnut is relatively free of the insect pests that plague other legumes, such as the cowpea and peanut. On the whole, pesticides are hardly used by farmers when cultivating bambara groundnut. However, the presence of some viral diseases transmitted by insects suggests simultaneous infestation of the crop by hemipterans, such as aphids, mealy bugs and scale insects. Local farmers store the bambara groundnut seeds with various substances, including tobacco, peppers and sand (Linnemann 1988), to protect them from storage pests (which represent a major problem). At the Institute for Agricultural Research in Samaru, seeds are packed with phostoxin tablets in sealed drums, to control *Callosobruchus* sp.

**Table 1. Phenotypic performance of bambara groundnut accessions at Samaru in 1986 (Tanimu *et al.* 1990).**

| Accession | Source     | Seed yield <sup>†</sup><br>(kg/ha) | 100-seed<br>wt. (g) | Shelling<br>percentage | Plant          |                | Days to<br>flowering |
|-----------|------------|------------------------------------|---------------------|------------------------|----------------|----------------|----------------------|
|           |            |                                    |                     |                        | Height<br>(cm) | Spread<br>(cm) |                      |
| 005       | Rigachikun | 1417.22 a                          | 135.5               | 49.0                   | 16.5           | 40.7           | 42                   |
| 7007      | Pategi     | 1348.33 ab                         | 68.1                | 57.8                   | 15.9           | 40.4           | 42                   |
| 9009      | Pategi     | 1308.11 ab                         | 62.5                | 56.2                   | 16.5           | 40.8           | 42                   |
| 006       | Pategi     | 1302.56 ab                         | 67.5                | 54.0                   | 16.5           | 40.4           | 41                   |
| 001       | Zaria      | 1263.11 ab                         | 77.3                | 53.8                   | 17.0           | 39.5           | 41                   |
| 011       | Pategi     | 1217.89 ab                         | 95.2                | 57.4                   | 16.2           | 40.7           | 42                   |
| 010       | Giwa       | 849.56 abc                         | 80.7                | 59.2                   | 16.5           | 40.4           | 42                   |
| 008       | Zaria      | 804.11 abc                         | 77.2                | 59.3                   | 16.5           | 40.2           | 43                   |
| 004       | Pategi     | 634.67 bc                          | 50.7                | 51.6                   | 16.5           | 40.8           | 42                   |
| 003       | Makarfi    | 408.11 c                           | 90.2                | 54.1                   | 16.2           | 40.2           | 42                   |
| 002       | Zaria      | 390.11 c                           | 64.9                | 50.8                   | 16.2           | 38.7           | 42                   |
| Mean      |            | 994.89                             | 79.1                | 54.7                   | 16.4           | 40.3           | 42                   |
| SE $\pm$  |            | 160.14                             | 4.06                | 4.50                   | 0.69           | 0.03           | 0.59                 |

<sup>†</sup> Means followed by the same letters in a column are not significantly different using Duncan's Multiple Range Test (DMRT) at 5% levels.

**Table 2. Estimates of heritability ( $h^2$ ), environmental variance ( $\delta^2e$ ), genotypic variance ( $\delta^2g$ ) and phenotypic variance ( $\delta^2ph$ ), with their respective standard errors (SE) in bambara groundnut (Tanimu *et al.* 1990).**

| Character                   | $\delta^2e$                | $\delta^2g$                 | $\delta^2ph$                | $h^2$                 |
|-----------------------------|----------------------------|-----------------------------|-----------------------------|-----------------------|
| Seed yield                  | 62298.10<br>$\pm$ 18783.58 | 101956.30<br>$\pm$ 6252.454 | 164254.40<br>$\pm$ 82.46238 | 62.07<br>$\pm$ 75.870 |
| 100-seed weight             | 24.72 $\pm$ 7.453          | 502.54 $\pm$ 68.343         | 1.26 $\pm$ 5.3199           | 95.31 $\pm$ 12.8467   |
| Shelling percentage         | 30.41 $\pm$ 9.169          | 12.04 $\pm$ 3.463           | 4.45 $\pm$ 1.1084           | 28.37 $\pm$ 3.1243    |
| Plant height                | 0.706 $\pm$ 0.2129         | 0.155 $\pm$ 0.07255         | 0.551 $\pm$ 0.06671         | 20.87 $\pm$ 1.0875    |
| Plant spread                | 1.041 $\pm$ 0.3139         | 0.05 $\pm$ 0.147            | 1.091 $\pm$ 0.1483          | 0.946 $\pm$ 0.7060    |
| No. of days to<br>flowering | 0.530 $\pm$ 0.1598         | 0.015 $\pm$ 0.05323         | 0.514 $\pm$ 0.946           | 2.91 $\pm$ 0.5627     |

### Nutrient deficiencies

The alternating wet and dry seasons (the latter characterized by intense heat) cause a rapid decomposition of soil organic matter in the savanna, which is the major bambara groundnut production area (Owonubi and Yayock 1987). Indiscriminate burning of fallow and crop residues by farmers also reduces the accumulation of soil organic matter. Thus, under continuous cultivation, the soils rapidly lose their fertility and productivity (Jones 1971). Because soil organic matter is low, native soil nitrogen and phosphorus are also very low (Jones 1971). Phosphorus and sulphur deficiencies are thus widespread (Goldsworthy and Heathcote 1963).

### Funding/storage facilities/equipment

Bambara groundnut has a low priority on the agenda of the Ahmadu Bello University's Institute for Agricultural Research, and is therefore receiving less attention than many crops whose research is funded externally. The poor viability of bambara seeds, especially when they are stored for a long period of time, is a frequent complaint of farmers. Storage is normally at room temperature, without the application of any techniques to enhance the shelf-life and longevity of the seed.

Research may be needed to determine optimum storage conditions/structures and methods of enhancing seed viability, but our Institute lacks the cold-storage facilities which the seeds require. Research is also hampered by the scant availability and high cost of equipment for tissue and soil analysis.<sup>2</sup> These and other constraints make it impossible to conduct adequate research on this crop.

### **Drought**

Prolonged dry spells during the wet season, and the abrupt cessation of the rains prior to full crop maturity, are perennial problems in the savanna ecological zone. Either the crop fails, or growth is retarded, resulting in low yields. The solution to this problem may require the development of a day-neutral crop that could be grown under irrigation during the dry season.

### **Industrial uses**

Presently, bambara groundnut is not being utilized for industrial purposes, hence the degree of neglect it suffers, compared with other legumes such as the peanut. Biochemical analysis of the crop may yield useful information on its industrial potential.

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<sup>2</sup> Post-graduate agronomic researchers have only been able to perform tissue analysis of bambara groundnut thanks to the assistance of Dr A.R. Linnemann.

## South Africa

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### Introduction

Despite possessing considerable commercial (including export) potential, bambara groundnut or 'njugo' is a neglected crop in South Africa. It was brought to the country by the migrating peoples from Central Africa, and is chiefly grown in the northern and eastern regions of the country, where it is most popular. The crop is mostly cultivated by small farmers in an intercropped system, or in family gardens, although a lack of statistics makes overall production of bambara groundnut in South Africa difficult to estimate. Owing to the crop's labour-intensive harvesting process, farmers have shown little interest in the crop and its commercial production, although this situation is now changing. Because it is cultivated on a small scale, there is a constant shortage of the fresh vegetable for consumption. Expansion of bambara groundnut production in South Africa is hampered by these shortages, and also by a lack of good varieties of the species.

### Production

In the Northern and Eastern Transvaal, bambara groundnut is grown extensively in the Letaba and Louis Trichardt districts, and fairly extensively in the Baberton, Pietersburg, Pilgrims Rest and Potgietersrust districts. In KwaZulu-Natal, it is grown in the Greytown, Msinga, Nkadla, Nguthu, Makhatini and Kosibaaai areas. It is also grown on a minor scale in the Tugela Ferry, Izopo and Maphumulo areas. Somewhat unsuccessful attempts have been made by agricultural cooperatives to grow bambara groundnut for local consumption and for export.

### Uses

The following culinary uses of the crop have been reported.

- 'Sekome' (Sesutho), 'tihove' (Shangaan) or 'tshidzimba' (Venda) is prepared by adding 'njugo' beans and peanuts, or just one of the two, to maize or millet-meal and boiling the mixture until it forms a stiff dough. This is salted and pounded into a ball, and will often keep fresh for several days.
- Bambara groundnuts are boiled and then stirred, to make a thin porridge, which is known as 'tshipupu' (Venda). Like maize, they may also be added to 'lupida', a porridge made from peanuts.
- 'Njugo' beans are often eaten when still immature, simply boiled until soft, and shelled. When quite dry and hard, they are generally shelled, and then boiled to make a stiff porridge.
- Bambara groundnut can be cooked with maize and pounded into a thick, sticky dough known as 'dithaku' (in Sesutho).

The only use of bambara groundnut observed among the local white population was of the dried beans, to make a soup.



## Folklore

In the past, a number of superstitions and taboos existed regarding the bambara groundnut, which probably extended to other crops whose fruits develop and ripen underground. For example, when a chieftain died, or when drought was predicted, planting of the crop was prohibited for periods varying from one to five seasons. Bambara groundnut might not be planted before the maize crop had germinated, and was pulled up if the rains were late. Males were forbidden to walk through 'njugo' fields, as it was believed that bad yields would result.

Furthermore, land belonging to males was only planted with bambara groundnut every other year, for fear that the male landowners might otherwise die, or some evil come to them or their families. Land belonging to women, however, was allowed to be planted annually with the crop. Young people were not permitted to eat the fruit of unrounded bambara groundnut, as it was believed that permanent or temporary sterility would result if this rule was not observed. Planting of the crop in virgin soil was also forbidden.

It is not known to what extent these traditional beliefs persist, but the Venda still consider that bambara groundnut should not be planted before the maize crop. It is likely that many of these beliefs have a practical explanation. For example, the taboo against young people crossing bambara groundnut fields probably had the useful function of protecting the small, intensively cultivated plots. It seems likely, on the other hand, that the taboo against eating unrounded bambara groundnut fruit served to ensure that women cultivated the crop properly.

Chewing and swallowing raw bambara groundnut beans is alleged to check nausea and vomiting (also for years afterwards), a remedy that is often used to treat morning sickness in pregnant women.

## Genetic resources

The three bambara groundnut collections in South Africa (see Appendix D for their addresses), are all frequently regenerated. They are situated at the following locations:

1. Potchefstroom (Oil and Protein Seed Centre of the Institute for Grain Crops). Most of the accessions are landraces, which have been acquired over the past 10 years, from the Seed Control division of the Department of Agriculture, local markets, seed firms and local farmers. No specific South African cultivar is available, and seeds of mixed colours and sizes are usually planted. The collection contains a total of 198 lines, but it is believed that duplicates exist. It is being regenerated in 1995-96. The whole collection will be planted out, and the major features described, to eliminate most of the obvious duplicates. The seed colour and hilums are recorded, but no other features.
2. White River (Department of Agriculture, Mpumalanga). This recent collection (with 20 accessions in total) contains a number of landraces, and also material obtained from Potchefstroom.
3. Roodeplat (Institute for Veld and Forage Utilization). This holds 117 lines, a number of which have been fully or partly described.

These collections possess a wide range of variation in leaf colour and shape, growth habit, pod colour and shape, seed size, seed colour, eye colour and testa pattern. Photoperiodical requirements have not been determined. Accessions in the three collections are in the process of being described, and information on all of these should be available in the next few seasons. It is not currently possible to specify gaps in the existing collections.

### Germplasm exchange

Potchefstroom has supplied germplasm to Roodeplaat and White River, and also to researchers in Zambia, Swaziland, Zimbabwe, Malawi, Botswana, Namibia, the United Kingdom and the Netherlands.

### Research

Research on bambara groundnut is carried out at the research institutions described below.

| Institution   | Activities  |
|---|---|
| Potchefstroom   | <ul style="list-style-type: none"> <li>germplasm collecting and evaluation</li> <li>cultivar development and evaluation for small-scale and commercial farmers</li> <li>development of a mechanical harvesting process for bambara groundnut</li> </ul>                             |
| Roodeplaat  | <ul style="list-style-type: none"> <li>research and development of indigenous edible leaves and seed vegetable crops</li> <li>genetic description of legumes</li> <li>agronomic evaluation of legumes</li> </ul>  |
| University of Natal   | <ul style="list-style-type: none"> <li>seed storage conditions</li> <li>tissue-culture protocols</li> </ul>   |
| University of Pretoria  | <ul style="list-style-type: none"> <li>calcium requirements for flower formation and pollination</li> <li>tolerance and organic admentment as integrated pest management components for the control of root knot nematode (<i>Meloidogyne</i> spp.) on bambara groundnut</li> </ul> |
| University of Cape Town<br>Department of Agriculture,<br>Mpumalanga | <ul style="list-style-type: none"> <li>nitrogen fixation</li> <li>cultivar evaluation</li> <li>planting dates x earthing-up</li> <li>planting depth x spacing x earthing-up</li> <li>cultivar x earthing-up</li> </ul>  |

## Tanzania

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### Introduction

Tanzania is a tropical country occupying an area of 943 000 km<sup>2</sup>, with a population of about 28.5 million. It comprises 20 administrative regions on the mainland, and five in Zanzibar and Pemba. The country extends from about latitudes 1°30' to 11°45'S and from about longitudes 29°21' to 40°45'E. Elevation starts from sea level on the eastern coast, rising to 5895 m above Mount Kilimanjaro. Tanzania's natural vegetation comprises coastal forests, open woodlands, dense mountain forests, wetland vegetation, and scrub and bushland.

### Climate

Tanzania has various climatic conditions, ranging from very hot and humid at the coast, to very hot and dry in central regions, and very humid and cool in highland areas. Mean annual rainfall varies widely, from 320 to 2400 mm. Most of the country has a unimodal rainfall distribution, which is generally restricted to the period between November and May. A bimodal rainfall distribution pattern is characteristic of the area around Lake Victoria, and of the northeast part of the country. Mean monthly temperatures are generally above 10°C and rarely exceed 30°C, and temperature is closely correlated with altitude. This diverse climate allows a range of crops to be grown. Food crops include maize, paddy, wheat, sorghum, millet, beans, sweet potatoes, cassava, Irish potatoes, bananas, cucurbits, pigeon peas, cowpeas, bambara groundnut, cocoyams, yams and various vegetables. Cash crops include coffee, cotton, sisal, cashew, tea, tobacco, pyrethrum, sugarcane and coconuts. Bambara groundnut (among other crops) is not one of the research priorities of the National Agricultural Research System (NARS) (see Table 1). It can therefore be categorized as a neglected crop in Tanzania.

### Production and distribution

A study by the International Trade Centre (Coudert 1982) estimates annual global production of bambara groundnut at 330 000 t, of which about half is produced in West Africa. The exact date of bambara groundnut's introduction into East Africa is unknown. The production of bambara groundnut in Tanzania is associated with traditional peasant farming systems, in which it is mixed with other crops, and grown in small patches in monoculture (Smyth 1968). The crop is mainly intercropped with cereals such as millet, sorghum or maize, root and tuber crops, and other legumes.

Bambara groundnut production areas are indicated in Figure 1. Yields per plant are fairly high, but since bambara groundnut is mostly grown as a mixed crop at wide spacing, yields per unit area are usually low. It is difficult to obtain accurate production figures for Tanzania, as the crop is cultivated and consumed by families, and very little finds its way to urban markets.

**Table 1. Commodity Research Programmes under the National Agricultural Research System (NARS).**

| Programme           | Crops  |
|---------------------|--|
| Maize               | Maize ( <i>Zea mays</i> )  |
| Rice                | Rice ( <i>Oryza sativa</i> )   |
| Sorghum and millet  | Sorghum ( <i>Sorghum bicolor</i> ), pearl millet ( <i>Pennisetum americanum</i> ), finger millet ( <i>Eleusine coracana</i> )                |
| Wheat and barley    | Wheat ( <i>Triticum aestivum</i> ), barley ( <i>Hordeum vulgare</i> )  |
| Grain legumes       | Cowpea ( <i>Vigna unguiculata</i> ), black gram ( <i>Vigna mungo</i> ), pigeon pea ( <i>Cajanus cajan</i> ), soyabean ( <i>Glycine max</i> ) |
| Common bean         | Common bean ( <i>Phaseolus vulgaris</i> )  |
| Oil seeds           | Sesame ( <i>Sesamum indicum</i> ), sunflower ( <i>Helianthus annuus</i> ), groundnut ( <i>Arachis hypogaea</i> )                             |
| Root and tubers     | Cassava ( <i>Manihot esculenta</i> ), sweet potato ( <i>Ipomoea batatas</i> ), potato ( <i>Solanum tuberosum</i> )                           |
| Coffee              | Coffee ( <i>Coffea arabica</i> and <i>C. robusta</i> )   |
| Cotton              | Cotton ( <i>Gossypium hirsutum</i> )   |
| Tea                 | Tea ( <i>Camellia sinensis</i> )   |
| Sisal               | Sisal ( <i>Agave sisalana</i> )  |
| Coconut             | Coconut ( <i>Cocos nucifera</i> )  |
| Cashew              | Cashew ( <i>Anacardium occidentale</i> )   |
| Sugarcane           | Sugarcane ( <i>Saccharum officinale</i> )  |
| Tobacco             | Tobacco ( <i>Nicotiana tabacum</i> )   |
| Horticultural crops | Fruits, vegetables and ornamentals   |
| Viticulture         | Grapes ( <i>Vitis</i> spp.)  |
| Pyrethrum           | Pyrethrum ( <i>Chrysanthemum cinerariifolium</i> )   |

Results from Ukiriguru Agricultural Research Institute indicate that under good management, yields of up to 2.6 t/ha have been achieved (Akonaay and Mazige 1982). Recently, Sibuga *et al.* (1994) reported that Dodoma Red (DodR94), a local cultivar from Dodoma can produce pods yielding up to 3 t/ha. The crop yield reported in Tanzania also compares well with that reported by Johnson (1968) in Central Africa, which was 2 t/ha of shelled seeds. Smyth (1968) reported that in the Western Lake regions in Tanzania, bambara groundnut is grown on highly infertile Rweya grassland soils every 7 years, in rotation with the grass.

### Uses

In semi-arid parts of the country, bambara groundnut is considered as an insurance or a security crop. It is therefore eaten in a variety of ways, ranging from the freshly cooked pods to the cooked dry grains. The crop is incorporated into main dishes, such as cooked plantains and cereals. Kinyawa (1969) indicated that Ukiriguru bambara groundnut cultivars constitute a well-balanced food source; he found that the composition of 100 g of bambara groundnut contains water, protein, fat, carbohydrates and minerals, in the proportions given in Table 2. The vegetative parts of the plant, and sometimes the haulms, are used to feed livestock. The crop is also useful in crop rotations, as it contributes nitrogen to the soils, which benefits subsequent crops.



**Fig. 1.** Shaded areas indicate the general distribution of Bambara groundnut growing areas in Tanzania. (Source: Atlas of Tanzania, Survey and Mapping Division, Dar es Salaam, 1976)

**Table 2. Composition of bambara groundnut (Platt 1965)<sup>†</sup>.**

| Components              |               | Platt (1965) | Kinyawa (1969)    |
|-------------------------|---------------|--------------|-------------------|
| <b>Major (%)</b>        | Water         | 10           | 11                |
|                         | Protein       | 18           | 15.6-21.9         |
|                         | Fat           | 6            | 5-7.5             |
|                         | Carbohydrates | 60           | 64                |
|                         | Fibre         | 3.3          | n.a. <sup>‡</sup> |
| <b>Minor (mg/100 g)</b> | Calcium       | 65           | 30-100            |
|                         | Phosphates    | n.a.         | 100-200           |
|                         | Iron          | 6            | 7                 |
|                         | Magnesium     | n.a.         | 100               |
|                         | Potassium     | n.a.         | 1.2               |
|                         | Thiamin       | 0.3          | n.a.              |
|                         | Riboflavin    | 0.1          | n.a.              |
|                         | Nicotinamide  | 2            | n.a.              |
|                         | Ascorbic acid | insufficient | n.a.              |

<sup>†</sup> Analyzed by Kinyawa (1969) at Ukiriguru.

<sup>‡</sup> n.a. = not available.

### Genetic resources

Owing to its broad geographic distribution in Tanzania, a wide range of bambara groundnut cultivars (landraces) exists. Most of the current cultivars have arisen by random selection during the course of cultivation, and during migrations of various peoples, and are very local in their distribution. Farmers distinguish them by the size and shape of the leaves, and also by seed colour. In Tanzania, initial selection of landraces was based on colours of the testa, eye colour and collection site (Smyth 1968). Some of the landraces grown in Tanzania, such as the red-coloured BA/48/1, the cream-coloured, red-eyed Mwanza, the black-coloured Shinyanga, the cream-coloured, speckled or mottled Singida, the black-patched Dodoma, the cream-coloured, brown-patched Tabora, the cream non-eyed BA/2 and the cream, black-eyed Mpwapwa, were identified at Ukiriguru in the 1968/69 season. Very little research work has been done in the past to improve the crop's yield performance (Smyth 1968).

A collection of over 400 accessions was held at Ukiriguru between 1967 and 1971, but because of priority and staff changes, coupled with a lack of proper storage facilities, these accessions have since been lost (Marandu and Ntundu 1995). Recent multi-crop collecting missions by the National Plant Genetic Resources Centre (NPGRC) have gathered 22 accessions of bambara groundnut. These are stored according to genebank standards. Bambara groundnut is also threatened by competition from other legumes such as beans, which are available in almost all markets in the country.

Changing farming systems have gradually resulted in individual farmers cultivating fewer crops, which has contributed to bambara groundnut's further marginalization. Furthermore, in southern Tanzania, the crop is being threatened by the recent use of elemental sulphur to save the cashew crop from powdery mildew devastation. The consequence of this chemical treatment seems to be an increase in soil acidity, which may reduce production of most legumes in the affected areas.

### Research

Although the Bambara groundnut is an important food crop in Tanzania, very little research has been done on it to improve the crop. Neither improved varieties nor agronomic recommendations exist for Tanzania. Research on the production of bambara groundnut was initiated at Ukiriguru in 1967-68, when a total of 62 cultivars, some local (from Tabora, Mwanza, Musoma, Singida, Rungwe and Kagera), and others foreign (from Nigeria, Malawi, Zambia, Uganda, Sudan and Dahomey), were evaluated for yield and other important characteristics, including insect pest and disease resistance. Preliminary results indicated that there was scope for selection for high yield within local cultivars. The main results of breeding work carried out between 1967 and 1971 at Ukiriguru are summarized below.

- Varieties collected both from within and outside the country differed greatly in terms of yield and other important characteristics.
- Selection within the varieties themselves showed that many of the local cultivars and several of the introductions were genetically variable.
- Three purple-coloured cultivars – 70/1, BA 48/1 and BA/48/2 – showed good resistance to *Fusarium* wilt disease caused by *Fusarium oxysporum*.

Bambara groundnut appears to be quite adaptable to different environments, except that cultivars from wetter areas such as Bukoba were less promising under drier conditions. Of the 23 cultivars which were evaluated for yield, 9 were identified as the best yielders. Their yields ranged from 888 to 2600 kg/ha.

Agronomic research was done at Ukiriguru on the time of planting and on spacing, and comparisons were made between planting on ridges and on flat land. It was reported that bambara groundnut sown after December suffered more heavily from early attack by *Cercospora* leaf spot, virus rosette diseases and powdery mildew, which reduced yield significantly. Research results indicated that there was no significant difference in yield from bambara groundnut grown on ridges and flat land.

Local and exotic collections were assessed for resistance to the most common diseases, such as *Cercospora* leaf spot, virus rosette disease and powdery mildew. Leaf spot caused by *Cercospora canescens*, producing severe premature defoliation, was the most serious disease affecting bambara groundnut. Two races of virus which had been found to be latent in peanuts (*Arachis hypogaea*) were shown to have a rosetting effect on bambara nuts. One variety from Bukoba (BA/30) and another from Mwanza (BA/25) had high resistance to both *Cercospora* leaf spot and virus rosette diseases. Kindale, a local variety from Ukiriguru, was among the most resistant to rosetting. Powdery mildew, although widespread, was reported to be a late-season disease and was found to be economically unimportant. This initial interest in bambara groundnut research in Tanzania decreased during the 1970s, but the crop has remained an important food for the rural poor, especially in semi-arid areas.

In 1992, the Sokoine University of Agriculture at Morogoro, and Nottingham University, UK, initiated a multilateral project on bambara groundnut improvement. Other collaborating institutions in the project include Njala University College, Sierra Leone, Wageningen Agricultural University, The Netherlands, and Botswana College of Agriculture, Botswana. The project's objectives are to:

- evaluate local genotypes (landraces) grown under rain-fed and irrigated conditions
- study the growth and development of these genotypes
- identify suitable agronomic practices for the cultivation of bambara groundnut in Tanzania and other collaborating countries.

Two local cultivars, Dodoma Red (DodR94) and Dodoma Cream (DodC94), purchased from a farmer in Dodoma, are being used in this study. The cultivars are being evaluated both in Dodoma and at Sokoine University of Agriculture in Morogoro.

Generally, the project's findings, as reported by Sibuga *et al.* (1994), indicated severe leaf damage caused by mildew and *Cercospora* leaf spot at Morogoro, under irrigated sowings. However, the results at both sites revealed a general decline in leaf and flower number and dry weights with later sowing. This was reflected in pod yields, with a decline from approximately 6 g per plant, when sown in January, to less than 1 g per plant, when sown after May. Furthermore, DodR94 was reported to produce 3 t/ha of pods under rain-fed conditions in Dodoma.

### Future crop improvement programme strategies

- Systematic country-wide collecting of bambara groundnut germplasm has been planned for April-May 1996, initially in southern Tanzania, and subsequently in other parts of the country, as the initial phase in an improvement programme.
- Characterization of all collected accessions of bambara groundnuts, to provide necessary information for breeding purposes.
- Evaluation for yield and other important characteristics, including insect pest and disease resistance in multilocational trials.
- Studies of antinutritional factors, to promote utilization of the crop, and collaborative studies on various aspects of bambara groundnut improvement.

### Conclusions

Although bambara groundnut is an important crop in Tanzania, especially in parts which are more arid and marginal for other legumes, little work has been done to improve its yield and utilization. The species could be developed into a major crop, and research efforts made to improve existing germplasm in the country, for:

- high yield
- agronomic purposes
- improved disease and pest resistance
- utilization as a food crop
- possible use as a rotation crop in areas which are marginal for other legume crops.

### Acknowledgements

The author of this report thanks the Director of the Tropical Pesticides Research Institute and the curator of the National Plant Genetic Resources Centre of Tanzania, for facilitating this publication. Grateful thanks is also extended to the International Plant Genetic Resources Institute, Rome, Italy and the Department of Research and Specialist Services, Harare, Zimbabwe, for inviting Tanzania to participate in the bambara groundnut workshop.



## Togo

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### Introduction

In Togo, two different types of climate prevail: a Guinean climate in the southern part of the country, with two rainy and two dry seasons; in the northern half of the country, one rainy and one very dry season. Togo is a predominantly agricultural country where all the tropical and subtropical crops of the subregion can be grown. Bambara groundnut (*Vigna subterranea* (L.) Verdc.) is a grain legume that is rich in protein. The crop is known and cultivated in Togo, but to a much lesser extent than other vegetables such as cowpea, peanut and soyabean.

Despite its high protein content, bambara groundnut has yet to become an integral part of the diet of the Togolese populations. It is considered a 'poor man's crop', and is traditionally cultivated in home gardens and in farmers' fields, which may explain its marginal status. Bambara groundnut is cultivated sporadically throughout Togo, and produces low yields of 0.25-0.6 t/ha. The crop is mainly found in the Savannah, Kara and Central regions of the country, and in small quantities in the Plateaux and Maritime regions.

Togo's Grain Legume Programme does not contain a programme of specific activities relating to bambara groundnut, but collecting has been done, and preliminary characterization was initiated in 1985 by the National Food Crops Institute (NFCI).

### Production

The crop is usually grown on ploughed ridges 20 cm high and on mounds. It has been observed that planting density varies from area to area, as do the soil preparation techniques and the tools farmers use. Planting density is either 80 x 20 cm, 75 x 10 cm, or 75 x 20 cm. Bambara groundnut is planted in July, one grain being planted per hole, and has a vegetative cycle of 4 months. Farmers use local varieties and the preceding crop may be maize, sorghum millet, or other vegetables, if they are not affected by the same pests or diseases. Farming techniques are traditional: the use of fertilizers and pesticides is almost nonexistent. Average yields are usually about 0.5 t/ha, and throughout Togo, the crop is largely cultivated by women.

Figures from the Direction des Enquêtes et Statistiques Agricoles of Togo (Office of Agricultural Investigations and Statistics) between 1982 and 1994 (Table 1) show that acreages as well as production fluctuate, owing to the socioeconomic conditions peculiar to this crop. Total acreages can be seen to have risen from 6800 ha in 1982 to 10 400 ha in 1985. From 1986 until 1988, a downward trend is apparent. From 1988 to 1993, total acreage averaged 3728 ha. As can also be seen from Table 1, the highest production of bambara groundnut of 6527 t was recorded in 1986, while between 1988 and 1993, production averaged 2059 t.

Table 2 lists local varieties of bambara groundnut.

Table 1. Total acreage (ha), yields (t/ha) and production (t) of bambara groundnut, 1982-94.

| Regions              | 1982  | 1983  | 1984  | 1985   | 1986  | 1987  | 1988  | 1989  | 1990  | 1991  | 1992  | 1993  | 1994  |
|----------------------|-------|-------|-------|--------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| <b>Maritime</b>      | n.a.  | n.a.  | n.a.  | n.a.   | n.a.  | n.a.  | n.a.  | n.a.  | n.a.  | n.a.  | n.a.  | n.a.  | n.a.  |
| <b>Plateaux</b>      |       |       |       |        |       |       |       |       |       |       |       |       |       |
| Total acreage        | n.a.  | n.a.  | 2500  | n.a.   | 300   | 800   | n.a.  | n.a.  | n.a.  | n.a.  | n.a.  | n.a.  | n.a.  |
| Yield 1 <sup>†</sup> |       |       | 0.436 |        | 0.825 | 0.870 |       |       |       |       |       |       |       |
| Yield 2 <sup>†</sup> |       |       | 0.320 |        | n.a.  | n.a.  |       |       |       |       |       |       |       |
| Production           |       |       | 812   |        | 259   | 656   |       |       |       |       |       |       |       |
| <b>Central</b>       |       |       |       |        |       |       |       |       |       |       |       |       |       |
| Total acreage        | n.a.  | 200   | 400   | 500    | 700   | 1000  | 400   | 700   | 750   | 290   | 289   | 327   | 685   |
| Yield 1              |       | n.a.  | 0.324 | 0.526  | 0.363 | 0.340 | 0.322 | 0.351 | 0.350 | 0.478 | 0.478 | 0.452 | 0.322 |
| Yield 2              |       | 0.339 | 0.324 | 0.310  | 0.345 | 0.412 | 0.255 | 0.251 | 0.256 | 0.338 | 0.338 | 0.277 | 0.273 |
| Production           |       | 68    | 130   | 190    | 258   | 361   | 93    | 246   | 246   | 107   | 107   | 98    | 202   |
| <b>Kara</b>          |       |       |       |        |       |       |       |       |       |       |       |       |       |
| Total acreage        | 3400  | 2200  | 400   | n.a.   | 1500  | 900   | 1100  | 700   | 1300  | 1650  | 1648  | 1375  | 3332  |
| Yield 1              | 0.530 | 0.471 | 1.293 |        | 0.774 | 0.657 | 0.552 | 0.574 | 0.672 | 0.792 | 0.797 | 0.703 | 0.731 |
| Yield 2              | 0.213 | 0.290 | 0.510 |        | 0.307 | 0.351 | 0.720 | 0.200 | 0.298 | 0.595 | 0.595 | 0.689 | 0.712 |
| Production           | 1371  | 856   | 442   |        | 951   | 449   | 646   | 307   | 775   | 1305  | 1305  | 955   | 2424  |
| <b>Savanna</b>       |       |       |       |        |       |       |       |       |       |       |       |       |       |
| Total acreage        | 3400  | 4100  | 5000  | 9900   | 6500  | 4100  | 1300  | 1500  | 3250  | 2230  | 2238  | 1422  | 4493  |
| Yield 1              | 0.681 | 0.565 | 0.613 | 0.609  | 1015  | 0.669 | 0.392 | 1162  | 0.335 | 0.440 | 0.400 | 0.756 | 0.396 |
| Yield 2              | 0.217 | 0.153 | 0.329 | 0.418  | 0.511 | 0.460 | n.a.  | 0.824 | n.a.  | 0.250 | 0.250 | 0.430 | 0.392 |
| Production           | 1718  | 916   | 2384  | 5764   | 5059  | 2112  | 517   | 1680  | 1087  | 925   | 925   | 1030  | 1776  |
| <b>TOGO</b>          |       |       |       |        |       |       |       |       |       |       |       |       |       |
| Total acreage        | 6800  | 6500  | 8300  | 10 400 | 9000  | 6800  | 2800  | 2900  | 5300  | 4170  | 4175  | 3124  | 8510  |
| Yield 1              | 0.611 | 0.506 | 0.653 | 0.604  | 0.885 | 0.639 | 0.444 | 0.844 | 0.409 | 0.600 | 0.600 | 0.734 | 0.531 |
| Yield 2              | 0.239 | 0.191 | 0.329 | 0.395  | 0.482 | 0.444 | 0.507 | 0.431 | 0.282 | 0.309 | 0.309 | 0.567 | 0.469 |
| Production           | 3089  | 1840  | 3768  | 5954   | 6527  | 3578  | 1255  | 2233  | 2108  | 2337  | 2337  | 2083  | 4403  |

<sup>†</sup> Totals of pure cultivation (culture en pur) and main cultivation (culture en principal).

+ Secondary crop (culture en secondaire).

n.a. = not available.

Source: data from Direction des Enquêtes et Statistiques Agricoles, 1994, Production des principales cultures vivrières.

**Table 2. Location of bambara groundnut accessions in Togo.**

| <b>Location</b> | <b>Accession no.</b> |
|-----------------|----------------------|
| Tchitchao       | 4 NVS - 56           |
| Tchitchao       | 2 NVS - 56           |
| Tchitchao       | 11 NVS - 63          |
| Koumonde        | 2 NVS - 118          |
| Sarakawa        | 3 NVS - 45           |
| Lassa           | 2 NVS - 118          |
| Awandjaleo      | 2 NVS - 67           |
| Ketao local     | n.a.                 |
| Sarakawa        | 4 NVS 54             |
| Aleheride       | n.a.                 |

n.a. = not available.

### Use

Despite its status as a marginal crop, bambara groundnut is much appreciated by Togolese consumers throughout the national territory, and sells briskly at local markets and those in urban centres, usually at a higher price than beans. The greater part of the crop produced (80%) is consumed by the local producers themselves, and markets are generally undersupplied

Consumers prefer the ivory-cream coloured grains, of 6-8 mm diameter; small grains and black-coloured varieties are not particularly popular. Bambara groundnut is a complete food, which is more palatable when fresh, semi-dry, or not fully mature, as it becomes tough when dry. It can be consumed boiled or fried, and fried or boiled puddings may be prepared with a dough/paste made from bambara groundnut flour, which may also be used as a base for many other dishes.

### Plant genetic resources

Since 1977, 12 collaborative collecting missions have been undertaken by Togolese and foreign institutions, with the financial support of such institutions as the University of Maryland, USA, and the International Board for Plant Genetic Resources (IBPGR). These missions, which each involved different crops, aimed to meet the objectives of the Plant Genetic Resources Programme of the National Food Crops Institute. Between 1983 and 1985, 326 different accessions of bambara groundnut were collected on missions participated in by the University of Maryland and NFCI (the former Office of Agronomic Research). These collecting missions were undertaken across the whole of Togo. By 1992, introductions from other countries (Cameroon and Ghana) had increased the number of different bambara groundnut accessions to 420.

### Characterization and preliminary evaluation

Since 1988, many working descriptors have been recorded for a total of 249 bambara groundnut accessions. These have been used to describe plants during their vegetative state, and their fruits and grain crops 2 months after harvesting.

**Number of days to 50% germination**

For 15 sampled plants, the number of days from planting to germination was observed to vary from 8 to 9 days.

**Initial leaf colour at germination**

It has been observed that the young shoots of bambara groundnut are of a green or violet colour, depending on the dominant colour of the seeds. Often, the deep red-violet colour of the seeds gives the leaves a violet colour at germination, while the young leaves of white, grey or white-grey seeds are green. It is observed that 77% of the plants sampled have green leaves, and 23% have violet leaves at germination.

**Shape of the apical leaflet and growth habit**

Observations 10 weeks after planting show that 0.43% of leaflets are round, 93.8% are oval and 5.75% are lanceolated. A total of 38% of plants sampled have a bushy, 18.1% have a semi-bushy and 43%, a creeping growth habit.

**Number of days from planting to 50% flowering**

The number varies from 37 to 45 days, with the first flowers appearing 1 week earlier.

**Shape of the pod**

The shape of the pod is characterized by the existence or absence of a beak: 66% of the samples are beak-free and 34% are beak-shaped. None of the samples described has two beaks.

**Grain colour**

At 2 months after harvesting, 25% of grains are observed to be brown to yellowish, while 75% are mid-brown.

**Pod texture, thickness, length and width, and percentage of grains at threshing**

At 2 months after harvesting, 57.2% of pods are observed to be wrinkled, 20.3% to be folded, 6.3% to be smooth and 15.3% to have small wrinkles. The average thickness of 10 pods is observed to vary from 0.2 to 0.59 mm. Pod length varies from 14.4 to 19.5 mm, and width from 10.2 to 16.5 mm. Percentage of grains at threshing varies from 60.5 to 85.8%.

**Grains**

All the characters are recorded 2 months after harvesting. Colours are specified according to the Munsell Colour Charts. The texture of the testa, as well as its underlying and secondary colours, and the eye type, main colours and pigmentation have been described

**Exchange of germplasm for research purposes**

Exchanges of germplasm have taken place between NFCI and the University of Maryland, and with Cameroon and Ghana.

**Conservation technique**

Treated grains are stored in sealed polythene bags, which are placed in sealed plastified aluminium bags. Bags are stored in a drawer of a 24 m<sup>3</sup> cold room, at a

temperature of 9-10°C. For each variety, three bags are packaged, of which two are put in the cold room and one into a 650-L capacity freezer at -18°C.

#### **Use of germplasm in research**

Because of the lack of a programme for improvement of varieties of bambara groundnut, not all of the samples characterized morphologically have been used in research.

#### **Selection**

Selection work has not taken place, owing to the lack of an improvement programme for bambara groundnut.

### **Main problems**

Generally speaking, the bambara groundnut plant withstands drought and diseases, with the exception of *Fusarium*, which hardens pods and grains. *Cercospora* disease is also sometimes observed on bambara groundnut leaves.

### **Conclusions**

It is the hope of the National Food Crops Institute (NFCI) that this workshop will lead to the creation of a solid programme for the improvement of bambara groundnut varieties in this country. New collecting and characterization work is anticipated, which will replace material lost as a consequence of the social and political unrest in Togo over the past 3 years. It is to be expected, however, that monitoring and improvement of plant genetic resources conservation will be required for the success of any bambara groundnut programme.

## Zambia

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### Introduction

Bambara groundnut (*Vigna subterranea* (L.) Verdc.) is one of the minor grain legumes in Zambia, together with cowpea, pigeon pea, chickpea, mungbean, lentils and adzuki beans. Its advantages include a balanced nutritional composition, adaptability to marginal land, and relatively high tolerance to diseases and pests. The crop is cultivated on a small scale, and is concentrated in the western, southern and eastern provinces, where the greatest diversity is exhibited. Average yields reported are 300-400 kg/ha. The dietary and soil amelioration potential of the crop in farming systems is yet to be fully exploited. The crop fares rather poorly in terms of research interest, although this is increasing. Numerous studies have been carried out on various aspects of the crop, but most of these have been exploratory in nature, with few conclusions being drawn.

Although it is rated as a minor legume crop, the need to conserve bambara groundnut germplasm was recognized in the 1980s, and collecting missions were carried out (see below). Unfortunately, characterization and evaluation of the collections has been slow. There is a need to exploit the diversity and potential of the crop, through focused plant genetic management, breeding, plant protection and agronomic strategies. This paper outlines the status of the crop in Zambia, with respect to its genetic resources and breeding, and the major agronomic, pathological and entomological problems that have been experienced.

### Production

Bambara groundnut is grown in all provinces of Zambia, cutting across a wide range of agro-ecological zones<sup>3</sup> and farming systems. The crop is most important in the farming systems of marginal areas, from the point of view of moisture availability and soil conditions. As it is grown by farmers on a small scale, the crop does not enter the formal marketing system, and aggregate production figures are not available. However, given that there are estimated to be approximately 600 000 smallholders in the country, each cultivating less than 0.25 ha of bambara groundnut, total production can be estimated to be very low. Bambara groundnut is usually intercropped, with a small proportion grown as a sole crop. Planting is done flat, or on ridges, between November and December in agro-ecological region III, and in January, in regions I and II. Fertilizer and manure are never applied.

No detailed studies have been carried out to estimate the yields obtained at farm level, but empirical evidence and exploratory studies involving a wide range of landraces in the country have shown that yields rarely exceed 500 kg/ha. This is a

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<sup>3</sup> Agro-ecological zone I is located in the southern part of the country, which includes the valley area; the semi-arid area with rainfall of less than 800 mm. Agro-ecological zone II covers the broad central belt, which includes the soils of highest potential, and is the main area of commercial farming. The annual rainfall is 800-1000 mm. Agro-ecological zone III covers the northern and northwest parts of the country. It is a high-rainfall area, with annual precipitation of more than 1000 mm.

problem that researchers face when multiplying seed. All seed for planting is from local landraces, and differs in size and colour. Farmers usually keep their seed for planting. There is no commercial variety of bambara groundnut in Zambia.

### Uses

Bambara groundnut is mainly used as a relish for food. The fresh or dry legume is a very common snack, although in some parts of the country it is eaten as a main meal.<sup>4</sup>

### Genetic resources

#### Collections and their diversity

Almost all the material grown by the farmers are traditional landraces that have been selected and maintained by local communities over a long period. A number of these landraces are maintained as uniform lines with distinct characteristics, e.g. seed colour. Others, however, are kept as mixtures. Farmers are not in possession of modern and improved varieties suitable for the climatic conditions in Zambia.

There appears to be significant genetic variation across the country in the bambara groundnut germplasm collected. Purseglove (1968) indicated that Zambia and Togo had the greatest variety of cultivars. In Zambia, the western and southern provinces have the most varied landraces. Recent collections, however, have revealed substantial variation in some parts of Northern province.

Much of the variation found in local landraces is in seed colour, eye pattern and seed size. Variation in growth habit and yield is also found. Although a number of seed colours exist, the most dominant and common is white or cream ground colour with black and white eye. Seed size does not show much variation, with most seeds being medium sized.

Bambara groundnut germplasm held in the local collections has been obtained from within Zambia and from other countries. Accessions of traditional landraces occurring in different parts of the country have been collected through internationally and locally organized missions. Quite a number of accessions were collected through IBPGR/FAO sponsored missions, which began in the early 1980s. Locally organized missions, such as the University of Zambia's SACCAR<sup>5</sup>-funded mission, and that funded by the National Plant Genetic Resources Centre (NPGRC) at Mount Makulu Research Centre, have also contributed to the collections. Their foreign accessions came mainly from West Africa, as IITA collections, and from Zimbabwe.

Bambara groundnut germplasm is being held at two institutions. The major collection, with 463 accessions, of which 146 are locally collected and the rest are foreign, is held by the University of Zambia. The other collections are held at the National Plant Genetic Resource Centre (NPGRC)<sup>6</sup> at Mount Makulu Research Centre. A total of 152 accessions from the collections held at the Crop Science Department has been characterized, and some preliminary evaluation has been done on these. The characterization of material held at the NPGRC is planned for the 1995/96 season. Some germplasm from outside the country continues to come in through the Food

<sup>4</sup> United Nations University (UNU). 1993. Field Survey of Indigenous Food Crops and Useful Plants, and their Food Preparation in Zambia (unpublished).

<sup>5</sup> Southern African Centre for Co-operation in Agricultural & Natural Resources, Research & Training.

<sup>6</sup> The total number of accessions held by the NPGRC in Zambia is 4619.

Legume Improvement Programme, mainly for the purposes of screening for possible adaptation and yield assessment studies.

The diversity of the Zambian collections was found to be less than in other West African collections (Begemann 1990a). In particular, the collection at the University of Zambia was the least diverse with respect to quantitative characters. For a more accurate picture of Zambia's current collections, however, diversity studies need to be carried out.

### Gaps in existing collections

Characterization of the Zambian collections is in progress, but needs to be accelerated, as its slowness has delayed the utilization of germplasm in breeding and crop improvement programmes. Accessions are lacking from certain parts of the country, such as the Central and Copperbelt provinces. The collections seem to include much of the existing variation, however.

### Storage techniques

Both at the University of Zambia and the NPGRC, bambara groundnut germplasm is being conserved through seed storage in deep freezers operating at  $-20^{\circ}\text{C}$ . The seed samples are dried to below 10% moisture content, and are then packed in aluminium foil packets, which are hermetically sealed before being placed into the deep freezers.

### Germplasm use

The use of the current collections in crop breeding and improvement activities has been limited, due to the slow characterization and evaluation of the germplasm. However, important information, on which use could be based, is gradually being accumulated. At the University of Zambia, efforts to develop selection protocols are underway.

### Breeding

No full-scale breeding work has been done on bambara groundnut in Zambia. Some preliminary work has nonetheless been done by the Food Legumes Programme of the Ministry of Agriculture, Food and Fisheries. Scarce funding and staff (time) are the main constraints to more breeding work being done on the crop. At the University of Zambia, genetic studies have been carried out to get a deep understanding of the heritability of important bambara groundnut characters. Analysis of the components' genetic variance has revealed a large environmental influence. The highest estimate of heritability was for 100-seed weight (0.22-0.25). Table 1 shows the range of heritability estimates for traits found to be important for seed yield in bambara groundnut. Other studies that looked at the associations among the important characters for yield have confirmed the importance of 100-seed weight and pods per plant. It is planned to initiate a single plant selection in some of the accessions characterized and evaluated at the University of Zambia in the 1995/96 season.

**Table 1. Heritability estimates of traits of bambara groundnut grown in the 1992/93 and 1994/95 season in Zambia (Nkumba 1993).**

| Trait              | 1992 estimate | 1993 estimate |
|--------------------|---------------|---------------|
| No. branches/plant | 0.07          | 0.11          |
| No. pods/plant     | 0.01          | 0.21          |
| 100-seed weight    | 0.22          | 0.35          |
| Plant height       | 0.09          | 0.13          |



### Problems and constraints

- Adaptation (poor yields)
- Cultivation practices
- Planting methods
- Planting dates
- Planting density
- Nutrient requirements
- Weeding
- Pathogens: notably *Cercospora* leaf blight, scab and *Fusarium* wilt. There have been no crop loss assessment studies to confirm the importance of these and other diseases
- Insect pests: several important ones have been identified, from sucking pests (jassids and aphids) to chewing insects (leaf beetles, termites and grasshoppers).

### Conclusions

The little research being carried out at present on bambara groundnut is attributable to:

- a lower allocation of resources to the crop, compared with other (major) legumes
- a lack of economic and nutritional information on the crop, at both producer and consumer levels.

Bambara groundnut is unfortunately considered a smallholder's crop, of marginal importance. This is a misguided perception, and promotion of the crop is needed to change it.

The current state of bambara groundnut is encouraging, and attempts have been made to address various aspects of the crop. These now need to focus on producing concrete results in exploiting the potential of the crop. The realization of the Bambara Improvement Programme, which was conceived in 1990, would be an important first step towards this goal. Undoubtedly, the formation of a local, regional and international network will be necessary if all the objectives for the crop are to be met.

## Zimbabwe

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### Introduction

The bambara groundnut is one of the most important local crops in Zimbabwe, where it is known as 'nyimo' (Shona) or 'indlubu' (Ndebele). It is used both as a food and a fodder crop. The plant is an indeterminate, annual herb, growing to a height of up to 30 cm, with prostrate, highly branched, leafy lateral stems just above ground level (Linneman and Azam-Ali 1993). In 1981, the area under bambara groundnut cultivation on resettlement farms was estimated to be around 4000 ha, with an annual production of 2200 t, while the area under bambara groundnut cultivation by small farmers was estimated to be 1300 ha, with annual production of about 750 t of unshelled nuts (Central Statistical Office 1993, unpublished data). Although the 1993 figures are not yet available for the rural sector, it is widely believed that more than 50% of bambara groundnut annual production comes from the sector. A total of 91% of the rural areas are situated in Natural Regions III, IV and V, which receive low rainfall (800 mm or less) in relatively short seasons, making them unfavourable for intensive dryland cropping (Vincent and Thomas 1961). In addition, the rural area soils are generally coarse-textured sands derived from granite, largely deficient in organic matter. Commercial farmers produce very little of the crop.

The aim of this survey was to increase the amount of information available on production, agronomic practices, utilization of the crop and the limitations upon it.

### Materials and methods

The survey was conducted during the growing season of 1989. It covered all aspects of bambara groundnut production in rural areas, agronomic practices and constraints, marketing, and socioeconomic factors affecting production of the crop. The survey involved interviews with farmers, using a questionnaire, and also observations. Certain measurements such as row spacings, plant densities and nodule count were conducted in the field. Variables such as the cropped area per farmer, bambara groundnut hectareage and yield were estimated. Between 20 and 23 farmers were interviewed in each province. The survey was conducted in all eight provinces of the country, in the districts shown in Table 1.

**Table 1. Provinces and districts surveyed in the 1989 growing season.**

| Province            | District      |
|---------------------|---------------|
| Masvingo            | Zaka-jerera   |
| Midlands            | Chiundura     |
| Matabeleland South  | Esgodini      |
| Matabeleland North  | Ntabazinduna  |
| Manicaland          | Marange North |
| Mashonaland West    | Zvimba        |
| Mashonaland Central | Rushinga      |
| Mashonaland East    | Mutoko        |

### Results

### **Total cropped area/area under bambara groundnut cultivation**

The total cropped land per farmer varied considerably from one district to another. Generally, the three districts of Mashonaland province included in the survey (Zvimba, Mutoko and Rushinga) had higher cropped areas than those in the southern provinces. However, the average area under bambara groundnut cultivation was extremely low throughout the country, reaching a maximum of 2400 m<sup>2</sup> in Zaka, and a minimum of 400 m<sup>2</sup> in Zvimba. The average area planted with bambara groundnut was only 0.135 ha per farm. On average, the area cropped with the legume, expressed as a percentage of the total cropped area, was 7%, which is rather low. About 50% of the farmers interviewed indicated that they planned to decrease the area cropped with bambara, owing to land scarcity, shortage of seed and other factors; 7% had no plans to change their hectarage; 43% said they would increase the bambara groundnut cropped area because the crop fetches higher prices now than it did previously.

Farmers identified land shortage as a major contributing factor in their plans to reduce production, and stated that there was not enough land available to allocate to the various crops they would like to grow. As maize is the main staple food crop, and has now become an important cash crop, more and more land is being allocated to maize at the expense of the other crops. Some farmers also leave a sizeable percentage of land fallow each season, for a number of reasons, which include labour and draught power shortages.

### **Soil fertility problems**

A decline in soil fertility was the major reason for the decrease in bambara groundnut yield. Rural area soils are generally coarse-textured sands, derived from granite, and largely deficient in nitrogen, phosphorus and sulphur (Grant 1988). They are low in soil organic matter and have low water-holding capacity. Farmers said they used to grow the crop on virgin land with high nutrient levels (which is no longer available). The practice of leaving some land fallow, to improve fertility, is also fast disappearing, owing to shortages of land. Farmers' inability to buy mineral fertilizer worsens the nutrient status of the soil, and the decline in the number of farm animals per household also resulted in reduced amounts of manure. The decreasing soil fertility represents a major challenge, to farmers and to all those involved in local agriculture.

### **Seed viability and varieties**

Shortage of seed, lack of improved varieties and the planting of seed retained by farmers (which usually has germination and viability problems) are other important factors contributing to low production and yield. It should, however, be noted that there are virtually no improved varieties commercially available, and farmers have little choice in those that they plant. About 24% of the farmers interviewed rated the germination of the crop as fair to poor. Most of the farmers who rated the germination as poor were from the Ntabazinduna and Marange North districts.

There are no varieties of bambara groundnut, *sensu stricto*, but farmers distinguish different seedlots by their appearance (Linneman and Azam-Ali 1993). Seed colours observed during the survey varied from white, black, red and brown, through to cream, with different eye colours. Various combinations of these colours were observed, as well as speckled, mottled and mosaic testa patterns. The distribution of these varieties varied from region to region. For example, in Matabeleland, the black as well as the cream and red-seeded varieties were dominant, and in Mashonaland, the cream and red-seeded varieties. The cream-seeded type of bambara groundnut was the most widely grown in the country.

### Planting methods, dates and plant population

On average, 75% of the farmers interviewed plant the crop in rows. The remainder grow it in a scattered pattern, but they do not broadcast. Planting dates ranged from late October to early January, but more than 80% of farmers plant the crop between mid-November and mid-December. The highest number – 12 plants/m<sup>2</sup> – was obtained in the Zvimba district. The Rushinga district had an average of 11 plants/m<sup>2</sup>; planting densities in the other districts were between 8 and 10 plants/m<sup>2</sup>. The drought occurring over the past few years, especially in Masvingo and Matabeleland, reduced germination and other processes. The consequences of this have been reduced yield and even reduced seed supply.

### Fertilizer application and nodulation

On average, only 18% of the farmers apply fertilizer directly to bambara groundnut, and it is this group who registered yield increases in some years. They apply fertilizer in the form of organic manure, compound D and ammonium nitrate. Most farmers lack knowledge of the appropriate fertilizers, and most of them indicated that even if they knew which fertilizers to apply, they could not afford to buy them. Another group of farmers stated that since they apply fertilizers to maize, the subsequent bambara groundnut crop benefits from the residual fertility. It is important to note, however, that the fertilizer applied to maize is sometimes not adequate. Partly due to a lack of nutrients, about 60% of the bambara groundnut crop had yellowish green leaves. Only 17% of the crop appeared dark green in colour (indicating adequate nutrition) and 23% of the crop was green.

The average number of nodules per plant in Zimbabwe was only 11. This seems to be lower than that recorded in countries such as Ghana, where the number of nodules per plant ranged from 92 to 318 (Thompson and Dennis 1977; Mafongoya 1988). The lowest number of nodules per plant was at Zaka, and the highest at Esgodini. There was no relationship between the number of nodules per plant and the plant density (number of plants/m<sup>2</sup>). One reason for the low nodule number is the fact that most farmers do not inoculate seed with *Bradyrhizobium* at planting.

### Weed control

In only two out of the eight districts is the crop weeded at 2 weeks after planting. In the remaining six districts, weeding takes place at 3 weeks after planting. Farmers expressed concern over the critical labour shortage, especially during weeding, earthing-up and harvesting.

## Pests and diseases

The incidence of pests and diseases in bambara groundnut has increased in recent years, and this causes substantial production losses. Aphids represent 65% of the insect pests on the crop. The aphid problem is encouraged by late planting, and by periods of heavy rainfall, followed by days of sunshine. Extension staff attribute the aphid problem to low plant populations. Ants and termites constitute another 15% of bambara groundnut pests, and the remaining 20% are accounted for by such pests as cutworms, nematodes and weeds. Current bambara groundnut diseases of note are die-back, rosette and a virus disease, spread by aphids. These pests and diseases are not considered very serious problems on the crop, however. Only 5% of the farmers interviewed chemically control the pests and diseases. Others are not familiar with

control methods and cannot afford to buy the chemicals. However, 94-100% of the farmers practise rotation of bambara groundnut with other crops (both legumes and non-legumes), which is one way of controlling some of the pests.

### **Crop yields**

Yield is one of the most important aspects to be considered in efforts to improve the level of production. Current yields are generally low, ranging from 400 kg/ha to just under 1400 kg/ha of unshelled seed. In the survey, the highest yields were obtained in the Esgodini district and the lowest in the Mutoko district. Some of the recorded yields, especially at Mutoko, are inaccurate, however, because farmers harvest a great part of the crop for consumption at immature stages. Farmers expressed different opinions on whether the total production and yield of bambara groundnut are increasing, although more farmers stated that yields were decreasing, due to a number of constraining factors, mentioned above.

### **Use at household level**

The crop has distinct advantage over many other crops, because it is easy to prepare for consumption and has many culinary uses. The beans are prepared in various ways. The seeds can be boiled and eaten as a soft porridge. At maturity, the dry seeds are eaten after being boiled, either on their own or mixed with maize grain. Many farmers also preserve bambara groundnut as a relish, mainly for consumption during the dry season. Alternatively, some farmers eat it roasted as a snack. Other farmers leave the dry leaves in the field so that livestock can feed on them.

### **Research needs**

The survey revealed some areas to be targeted, to increase production and improve the marketing of bambara groundnut.

- Immediate attention must be given to improving production and distribution of seed, to overcome the present seed shortage.
- The extremely low current yields need to be improved through breeding programmes, and also through developing better crop husbandry techniques (these include: identification of the best fertilizers to be used, and appropriate levels and methods of application; economic methods of pest and disease control, and improved plant populations).
- The development of a better marketing strategy to exploit any increased production of the crop.

### **Acknowledgements**

The authors thank Mrs D. Hikwa and Mrs R. Madamba for their comments during the preparation of this paper, and Mr E. Hungwe for helping in the collection and analysis of the data.

## Agronomy

### Nitrogen fixation and nitrogen nutrition in symbiotic bambara groundnut (*Vigna subterranea* (L.) Verdc.) and Kersting's bean (*Macrotyloma geocarpum* (Harms) Maréch. et Baud.)

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#### Introduction

In terms of both production and consumption, bambara groundnut (*Vigna subterranea* (L.) Verdc.) is the most important food legume in Africa after cowpea (Doku and Karikari 1970), and has numerous agronomic and nutritional attributes which make it an excellent legume crop to develop. This legume is adapted to both the poor and the fertile soils of the entire continent, and produces seeds that are high in protein (14-24%) and carbohydrate (60%) content (NAS 1979). Bambara groundnut seed protein is richer in the essential amino acid, methionine, than most other grain legumes. Kersting's bean (*Macrotyloma geocarpum* (Harms) Maréch. et Baud.), a related, similarly geocarpic species, also has a seed protein content of 21.5% and high levels of the sulphur-containing essential amino acids – lysine (6.2%) and methionine (1.4%). Thus, from a nutritional point of view, these two legumes are unique in providing the essential dietary amino acids that are lacking in most food legumes. From an agronomic standpoint, both are disease-free, exhibit considerable tolerance and grow in soils with varied nutrient fertility, including low and high NO<sub>3</sub> levels. They produce yields in poor soils where no other crops can survive.

Despite their nutritional and agronomic attributes, very little work has been done on improving the yields of these legumes. The aim of this paper is to examine the relative physiological improvements of these crops, with respect to the dependence of each on symbiosis vs. soil sources for their N nutrition.

#### Selecting for symbiotic performance

Bambara groundnut and Kersting's bean are both tropical legumes that nodulate with cowpea-type bradyrhizobia. An earlier study by Doku (1969b) demonstrated the ability of bambara groundnut in particular to cross-nodulate with isolates from different tropical legumes, which indicates that the species is less selective in its bacterial requirements. However, because these legumes grow over a wide range of soil factors (low fertility, low moisture, vs. high fertility, high moisture, or low temperature vs. high temperature), their symbioses with root-nodule bacteria are bound to differ from one locality to another within Africa. The bradyrhizobia strains nodulating these legumes will not only differ between dry and well-moistured soils, but also between low and high NO<sub>3</sub> soils, and low and high temperature conditions.

Studies of cowpea (Ahmad *et al.* 1981) have shown that bradyrhizobia nodulating this host plant in the much drier, hotter and infertile Maradi soils of Niger are serologically and morphologically different from those occurring in Ibadan soils, which are wetter, humid and more fertile. Colonies of Maradi strains are 'dry' (colonies

<2 mm, circular and convex, with an entire margin), and serologically very reactive, while those of Ibadan strains are 'wet' (colonies >2 mm, irregular margins, and confluent growth, with abundant extracellular polysaccharide production (EPS) and antigenically less reactive. This wet/dry colony characteristic, together with differences in EPS production, could possibly account for the ability of bradyrhizobia nodulating African legumes such as bambara groundnut, Kersting's bean and cowpea to survive in soils with the highly differing moisture, temperature and pH levels found in Africa.

Whether these features affect bacterial strain survival and persistence in soil as a saprophyte has not been examined. However, the historically marked variation in farm yields (600-3000 kg/ha) of bambara groundnut in Africa (Rachie and Silvestre 1977), and the fact that high-yielding cultivars from one country can perform poorly in another (NAS 1979), suggest considerable differences in the symbiotic efficacy of native bradyrhizobia which nodulate this species. It is therefore not surprising that recent interest in increasing bambara groundnut production in Africa has targeted symbiotic effectiveness as a way to yield improvements.

Although it has been suggested that bambara groundnut does not require inoculation (Johnson 1968), growing evidence indicates the need for inoculation with an effective *Bradyrhizobium*, especially where newly cultivated fields are involved (Stanton *et al.* 1966). It has been demonstrated in Togo that inoculating bambara groundnut with suitable strains of *Bradyrhizobium* can significantly increase yields (Dadson *et al.* 1988). The increase in symbiotic performance and grain yields was higher when cultivars were inoculated with indigenous bradyrhizobia, rather than with foreign strains (Table 1). Similar data have recently been reported in Senegal (Gueye 1990). These findings clearly indicate the potential for increasing yields in bambara groundnut through enhancement of symbiotic N<sub>2</sub> fixation. Thus, programmes which select for effectiveness in *Bradyrhizobium*/bambara groundnut symbioses are indirectly selecting for high grain yields. Programmes initiated in Togo (Dadson *et al.* 1988), Senegal (Gueye and Bordeleau 1988; Gueye 1990) and Nigeria (Mulongoy and Goli 1990) have already started to select for effective symbioses as a way of increasing bambara grain yields. Unlike bambara groundnut, which has started to attract research interest, virtually no data exist on Kersting's bean.

**Table 1. Bradyrhizobial strain effects on grain yield of field-grown bambara groundnut in Africa.**

| Treatment      | Grain yield (kg/ha) |                   |
|----------------|---------------------|-------------------|
| <b>Togo</b>    | <b>cv. Kara</b>     | <b>cv. Ada</b>    |
| Uninoculated   | 742 d               | 396 d             |
| Nitrogen       | 2003 bc             | 1873 a            |
| TAL 169        | 2167 b              | 1318 b            |
| TAL 1380       | 2448 a              | 870 c             |
| TMUN           | 2665 a              | 1931 a            |
| TBAM           | 2084 bc             | 1860 a            |
| MAO 11         | 2482 a              | 1807 a            |
| MAO 26         | 1888 c              | 892 c             |
| <b>Senegal</b> | <b>cv. 79-1</b>     | <b>cv. 83-131</b> |
| Uninoculated   | 2989 b              | 3080 b            |
| Nitrogen       | 2992 b              | 3833 ab           |
| MAO 113        | 3512 ab             | 4661 a            |
| TAL 22         | 4492 aa             | 4864 a            |

Values in a column with the same letter are not significantly different. Adapted from Dadson *et al.* (1988) and Gueye (1990).

### Host-plant dependence on symbiotic N

Although both bambara groundnut and Kersting's bean nodulate freely with bradyrhizobia, little is known about the amounts of N fixed by these symbioses and their relative dependence on fixation for N nutrition. In a recent study by Dakora *et al.* (1992), the separate contributions of  $\text{NO}_3^-$  and fixed N to total plant N were assessed, for both bambara groundnut and Kersting's bean. Our findings showed that nodulated plants of both species depend largely on symbiotic N for their N nutrition, even when free  $\text{NO}_3^-$  is available for uptake by roots (Table 2). In general,  $\text{N}_2$ -fixing legumes require 16 moles of ATP per unit  $\text{NH}_3$  produced, compared with 14 moles of ATP per unit  $\text{NO}_3^-$  absorbed, indicating a greater energy cost, if bambara groundnut and Kersting's bean are to depend on *Bradyrhizobium* for their N requirements. The preference for symbiotic N utilization shown by these species therefore clearly suggests that their symbioses evolved in N-rich soils. This would account for their ability to grow in soils with different N fertility.

**Table 2. Proportional dependence on  $\text{N}_2$  fixation by species grown in the presence of  $\text{NO}_3^-$ .**

| $\text{NO}_3^-$ conc. (mM) | Nitrogen (%) derived from fixation |        |                 |        |
|----------------------------|------------------------------------|--------|-----------------|--------|
|                            | Bambara groundnut                  |        | Kersting's bean |        |
|                            | 28 DAP <sup>†</sup>                | 56 DAP | 25 DAP          | 46 DAP |
| 0                          | 100(0) <sup>‡</sup>                | 100(0) | 100(0)          | 100(0) |
| 2                          | 99(1)                              | 93(8)  | 95(5)           | 91(9)  |
| 5                          | 96(4)                              | 79(21) | 91(9)           | 80(20) |
| 15                         | 95(5)                              | 50(50) | 80(20)          | 52(48) |

<sup>†</sup> Days after planting.

<sup>‡</sup> Proportional dependence by plants on mineral N supplied as  $\text{NO}_3^-$ .

Adapted from Dakora *et al.* (1992).

### Host-plant dependence on mineral N

Some legumes prefer  $\text{NO}_3^-$  to  $\text{NH}_4^+$ , and vice versa. Preference shown for these N types was tested using *Macrotyloma geocarpum* supplied with 2 mM  $\text{NO}_3^-$ , 2 mM  $\text{NH}_4^+$  and 2 mM  $\text{NH}_4\text{NO}_3$ . Nitrogenase activity remained unaltered relative to control within 6 hours after applying treatments (Table 3). However, nodule functioning declined by 39% within 3 days in the 2 mM  $\text{NH}_4^+$  plants, 56% in those at 2 mM  $\text{NH}_4\text{NO}_3$ , and increased by 13% in 2 mM  $\text{NO}_3^-$  plants. By 8 days, nitrogenase activity had decreased to 77% of control for  $\text{NO}_3^-$ -treated plants, 35% for  $\text{NH}_4^+$  and 14% for plants in 2 mM  $\text{NH}_4\text{NO}_3$ . These findings suggest that  $\text{NO}_3^-$  is the likely source of N uptake by nodulated *V. subterranea* and *M. geocarpum* plants grown in soil.

The use of  $^{15}\text{NO}_3^-$  in the study by Dakora *et al.* (1992) permitted a measure of  $\text{NO}_3^-$  uptake by both *V. subterranea* and *M. geocarpum* plants. Except during the first sampling period (up to 28 days after planting), when *V. subterranea* took up considerably less  $\text{NO}_3^-$  than *M. geocarpum*, the amount of plant N derived from  $\text{NO}_3^-$  in the two species was similar (Table 3). In each case, increasing external  $\text{NO}_3^-$  resulted in progressively more  $\text{NO}_3^-$  being translocated in xylem (Table 4). Furthermore, the concentrations of  $\text{NO}_3^-$  in xylem exudate, at comparable levels in the nutrient solution, were similar for the two species (Table 4), indicating that the distribution of assimilation sites between roots and shoots was not likely to be greatly different for the two legumes.



**Table 3.** Nitrogenase activity ( $\mu\text{mol C}_2\text{H}_4$  produced per hour<sup>-1</sup> plant<sup>-1</sup>) of *Macrotyloma geocarpum* plants after supplying combined N.

| N source<br>(mM)                  | No. of days after N supply |         |         |         |         |
|-----------------------------------|----------------------------|---------|---------|---------|---------|
|                                   | 0.25                       | 3       | 6       | 8       | 15      |
| 0                                 | 6.4±0.5 <sup>†</sup>       | 6.4±0.3 | 7.8±0.7 | 9.3±0.9 | 9.0±0.7 |
| 2 NO <sub>3</sub>                 | 6.9±2.0                    | 7.2±0.3 | 8.7±0.5 | 7.2±0.5 | 3.0±0.1 |
| 2 NH <sub>4</sub>                 | 7.9±0.1                    | 3.9±0.6 | 3.2±0.4 | 3.3±0.5 | 2.1±0.1 |
| 2 NH <sub>4</sub> NO <sub>3</sub> | 6.6±1.3                    | 2.8±0.5 | 2.7±0.4 | 1.3±0.6 | 0.5±0.1 |

<sup>†</sup> Values are mean ± SE (n = 4 pots, each with 4 plants) (Dakora, unpublished).

**Table 4.** NO<sub>3</sub>-N and fixed N concentration ( $\mu\text{g N/ml}$ ) in root bleeding xylem exudates. Plants were supplied with NO<sub>3</sub> at 22 DAP<sup>†</sup> (bambara groundnut), 18 DAP (Kersting's bean) and harvested at 35 DAP (bambara groundnut) and 46 DAP (Kersting's bean).

| NO <sub>3</sub> conc. (mM) | Bambara groundnut |                 | Kersting's bean |                 |
|----------------------------|-------------------|-----------------|-----------------|-----------------|
|                            | Ureide-N          | NO <sub>3</sub> | Ureide-N        | NO <sub>3</sub> |
| 0                          | 993 <sup>†</sup>  | 7               | 1171            | 28              |
| 2                          | 698               | 45              | 1003            | 49              |
| 5                          | 279               | 103             | 1161            | 224             |
| 15                         | 303               | 192             | 364             | 525             |

<sup>†</sup> DAP = days after planting. Adapted from Dakora *et al.* (1992).

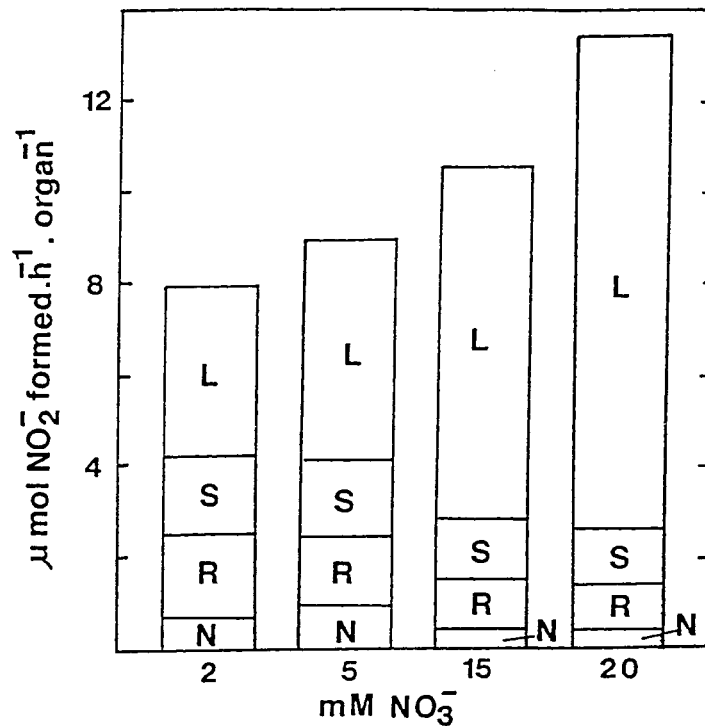
Assays for nitrate reductase activity (NRA) in *M. geocarpum*, made using an *in vivo* method with intact tissue from all component organs of the plant, showed a progressive increase in total activity, as the NO<sub>3</sub> level in the medium was raised (Fig. 1). As has been found for other species belonging to the tribe Phaseoleae (Andrews *et al.* 1990), *M. geocarpum*, and particularly the leaves, contained significant constitutive NRA and it was the activity in leaves which was substrate-induced (Fig. 1). This pattern of induction of NRA is similar to that found previously for cowpea, and is consistent with an increasingly shoot-based reduction of incoming NO<sub>3</sub> (Atkins *et al.* 1980), as the level of NO<sub>3</sub> in the transpiration stream increases (Table 4). In these respects, both legumes were similar to other members of the Phaseoleae (Atkins *et al.* 1980; Pate and Atkins 1983; Andrews *et al.* 1990).

#### Response of symbiotic bambara groundnut and Kersting's bean to NO<sub>3</sub>

Estimates of N<sub>2</sub>-fixing rates in *V. subterranea* and *M. geocarpum* show large differences in symbiotic effectiveness in the presence of NO<sub>3</sub> (Dakora *et al.* 1992). Providing mineral N to nodulated bambara groundnut and Kersting's bean can initially stimulate N<sub>2</sub> fixation in both species. However, with a prolonged supply of external N, fixation in bambara groundnut is severely reduced, a common observation in many legume/*Rhizobium*, or *Bradyrhizobium*, symbioses. With Kersting's bean, on the other hand, continued NO<sub>3</sub> supply for up to 4 weeks did not alter N<sub>2</sub> fixation, compared with purely symbiotic plants. Even at 15 mM NO<sub>3</sub>, plants still showed N<sub>2</sub>-fixing rates higher than plants depending solely on symbiotic N nutrition.

In many ways, the degree of NO<sub>3</sub> tolerance exhibited by Kersting's bean is rather intriguing. In a recent study, we have shown that the difference in inhibition of nitrogenase activity exhibited by these two species is not due to different intensities of NO<sub>3</sub> uptake, or patterns of distribution and assimilation of NO<sub>3</sub>, but rather to some

specific effect of  $\text{NO}_3^-$  on nodule functioning in Kersting's bean. The mechanism involved in  $\text{NO}_3^-$  inhibition of nitrogenase activity has not been clearly defined. Most hypotheses are based either on direct toxicity of  $\text{NO}_2^-$  from NRA on nitrogenase and leghemoglobin (Rigaud and Puppo 1977),  $\text{NO}_2^-$  conversion of leghemoglobin to nitrosylleghemoglobin (Kanayama and Yamamoto 1990), or on an indirect effect of  $\text{NO}_3^-$  assimilation elsewhere in the plant, which results in reduced photosynthate supply to nodules (Harper and Gibson 1984; Oghoghorie and Pate 1971).



**Fig. 1.** Distribution of  $\text{NO}_3^-$  reductase between component organs of nodulated *Macrotyloma geocarpum* plant supplied with  $\text{NO}_3^-$  from 18 to 30 DAP (L = leaves, S = stems, R = roots, N = nodules) (Dakora, unpublished).

Although one or the other of these have been regarded as more relevant in particular symbioses (Wasfi and Prioul 1986), recent studies indicate that  $\text{NO}_3^-$  treatment results in increased resistance of nodules to gaseous diffusion, with consequent limitation of  $\text{O}_2$  supply to bacteroids (Minchin *et al.* 1986; Vessey *et al.* 1988a). Vessey *et al.* (1988b) have further shown that  $\text{NO}_3^-$  treatment reduces phloem supply to nodules which, although possibly restricting the supply of assimilates for nitrogenase, also results in a lowered supply of water for export of the products of  $\text{N}_2$  fixation (Walsh *et al.* 1989). Where and how in such a scenario *M. geocarpum* differs from bambara groundnut, or other nodulated legumes, remains to be determined. However, the degree of tolerance shown by the species to  $\text{NO}_3^-$  provides a useful experimental basis with which to test the components of these hypotheses, and to examine the possibility of exploiting such traits to improve the tolerance of other legumes to combined N. Traditional farming in Africa is based largely on mixed

cropping, a system which does not easily permit N fertilizer application to associated, N-starved cereal and vegetable crops. Identifying naturally occurring  $\text{NO}_3^-$ -tolerant legumes would be an added advantage to mixed cropping systems.

#### **Effects of cotyledon removal and boron nutrition on symbiosis**

Data from another study (Muofhe and Dakora, unpublished) have shown that adequate boron supply is important for effective symbiosis in bambara groundnut. Insufficient boron supply causes a marked decrease in nodule formation in this species. Nodules formed by boron-deficient plants are smaller in size, and paler in colour, with an expected reduced dry weight, compared with those formed under boron-sufficient treatment. As a consequence of the reduced nodulation,  $\text{N}_2$  fixation in such boron-deprived plants decreases by almost 50%.

Removal of cotyledons from seedlings of bambara groundnut resulted in marked reduction in photosynthetic leaf area, an effect likely to decrease photosynthate supply for nodule formation and nodule functioning. This reduction in photosynthetic area was about twice as great when boron was deficient in the rooting medium. Cotyledon removal also inhibited nodulation, particularly in boron-deficient bambara groundnut plants. The physiological response of Kersting's bean to both boron and cotyledon removal has still to be determined.

### **Conclusions**

Inoculating bambara groundnut with suitable strains of *Bradyrhizobium* can markedly increase yields of this crop. So, any programme aimed at promoting bambara groundnut production must consider cultivar selection for effective symbiosis, preferably with native bradyrhizobial strains. A continent-wide programme on collecting germplasm of both bambara groundnut and Kersting's bean, followed by testing of bradyrhizobial strains on various cultivars, needs to be initiated. The relative  $\text{NO}_3^-$  tolerance observed in the symbiosis of both species is also an important trait worth re-evaluating with native strains. No doubt, more research needs to be done, especially on the physiology of  $\text{N}_2$  fixation in these nutritionally important geocarpic species.

## Pests and diseases of bambara groundnut in Zimbabwe

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### Introduction

The bambara groundnut (*Vigna subterranea* (L.) Verdc.) is one of the indigenous African crops currently receiving interest from researchers, owing to its high yield and resistance to diseases (Hepper 1970), as well as its adaptability to poor soils and low rainfall. During a survey carried out by agronomists in 1989 to establish the current bambara groundnut production practices and constraints on the crop in Zimbabwe, the incidence of pests and diseases was found to be high. Since bambara groundnut is not a major crop in Zimbabwe, very little work has been done so far to establish the extent of damage caused by pests and diseases on this crop. The information given in this paper is based solely on advisory records from the Plant Protection Research Institute, and from the findings of the 1989 survey.

### Diseases

Diseases which have been recorded on bambara groundnuts in Zimbabwe include leaf spot (*Cercospora canescens*), powdery mildew (*Erysiphe* sp.), leaf spot (*Phyllosticta voandzeia*), wilt (*Fusarium* sp.), leaf blotch (*Phomopsis* sp.) and *Sclerotium rolfsii* (Pathology advisory notes, unpublished). Leaf spot caused by *C. canescens* was recorded in Zimbabwe by Rothwell in 1983.<sup>7</sup> This disease was also recorded at Gwebi in 1986, and by the Crop Breeding Institute in 1994. Symptoms of isolated brown spots appear on the leaflets, and a severe attack can cause defoliation. Pod size can be reduced significantly if infestation occurs before flowering. Wilting and yellowing of bambara groundnut, caused by *Fusarium* sp., is another disease of bambara groundnut, recorded in Zimbabwe by the Crop Breeding Institute in 1994. Characteristically stunted plants with vascular discolouring appear about 50 days after sowing. Symptomatic yellowing, necrosis and wilting will occur, and the affected plant eventually dies. *Fusarium* wilt has also been reported from Kenya (Cook 1978), and in Tanzania it has been described as *Fusarium oxysporum* (Ebbels and Billington 1972).

Powdery mildew, which is caused by the fungus *Erysiphe pisi*, was also recorded by Rothwell on bambara groundnut in 1983. Symptoms of a whitish powder are visible on both sides of the leaflets, but it is more frequent on the abaxial side. Infected leaves dry out and die prematurely. Powdery mildew is a widespread disease in Madagascar, and has been named *Sphaerotheca voandzeia* (Bouriquet 1946).

*Phyllosticta voandzeia* causes leaf spots on bambara groundnuts. In Zimbabwe, it was recorded at three sites in 1986: Gwebi, Chiduku and Muzarabani. The disease is recognized by the characteristically ill-defined, irregular, circular, brownish purple spots that are visible on the leaves.

Bambara stem rot caused by *S. rolfsii* is another disease of bambara groundnut that was recorded at Kadoma in Zimbabwe, in 1986. The initial symptoms of rot, at

<sup>7</sup> Rothwell, A. 1983. A revised list of plant diseases occurring in Zimbabwe (unpublished).

the base of the stem, are followed by the production of black sclerotia on infected tissue. The rot, which begins below soil level, spreads into the crown of the plant, and in severe cases, to the pods, and downwards into the root system. Sclerotia can survive in the soil between crops.

The bambara groundnut leaf blotch caused by *Phomopsis* sp. has been recorded at only one site in Zimbabwe, and it is not as widespread as the other diseases that have been mentioned.

### Viruses

Bambara groundnuts were found to be susceptible to rosette during the 1989 survey. This is a virus disease, which is spread by aphids. The two main strains of rosette disease are chlorotic rosette and green rosette. The symptoms of chlorotic rosette are a mosaic pattern of dark green banding on light green leaflets, or alternatively, the leaves may be completely necrotic. In the latter case, leaves are slightly reduced in size, and usually have distorted leaflets. The most common symptoms of green rosette are a dark green foliage mottle on a light green background, and a marked reduction in leaflet size.

### Pests

Insect pests which have been recorded on bambara groundnut in Zimbabwe include aphids (*Aphis* sp.), bruchids (*Callosobruchus* sp.), leafhoppers (*Hilda patruelis*) and termites (Entomology advisory notes, PPRI). In the field, pests feed on leaves and sap, thereby disrupting photosynthesis and causing low yields. Other pests feed on the seed, reducing its quality and viability. From the 1989 survey, it was found that aphids (*Aphis* sp.) represented 65% of the insect pest problem on bambara groundnut in Zimbabwe.<sup>8</sup> Aphids feed on young shoots, causing leaves to curl and growth to be stunted. Sap loss from feeding by aphids leads to stress during dry periods. *Aphis* sp. is an important bambara groundnut pest because it transmits the rosette virus.

The sap-sucking leafhopper, *Hilda patruelis*, was recorded on bambara groundnut in Manicaland in 1983. Leafhoppers attack the underground parts of the plant. Plants wilt and collapse, due to sap sucking by the leafhoppers. These insects coexist with black ants, which also protect them.

Termite damage to bambara groundnut in Zimbabwe was recorded during the 1989 survey. Two basic forms of termite damage to bambara groundnuts have been noted, namely scarification of the pods by *Odontotermes*, and penetration and hollowing of the tap root by *Microtermes*. Scarification of the pods weakens them, resulting in shattering or cracking during harvest. Hollowing of the tap root causes wilting of the plants.

The bambara groundnut seed is liable to attack by bruchids, *Callosobruchus* sp. This weevil, which was recorded by the Agronomy Institute in 1987, causes loss of quality, quantity and seed viability. Bruchid infestations start in the field, and in most cases, continue in storage. In a few cases, field infestations soon terminate under storage conditions. Damage to the embryo by the feeding bruchids impairs

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<sup>8</sup> Mafongoya, P. and V. Mabika. 1988. Bambara nut (*Vigna subterranea*) production in communal areas of Zimbabwe (unpublished).

germination. Poor grain quality will also result from reduction in the amount of carbohydrates and proteins.

### **Nematodes**

The root-knot nematode *Meloidogyne javanica* has been found to seriously infect bambara groundnut in Zimbabwe (Martin 1959). These nematodes were also recorded during a survey carried out by the Plant Protection Research Institute in 1989. *Meloidogyne* larvae invade the roots and feed in the vascular system of the bambara groundnut, causing formation of giant cells. In severe cases, the roots of infested plants are completely covered with swellings caused by hypertrophy of the cortical cells. Damage to roots impairs the normal growth of the bambara groundnut, causing stunted growth, yellowing and wilting. Reduced dry matter accumulation, and more frequent flower abortion, has been observed.

### **Current research**

None.

### **Future research**

Since very little work has been done on the pests and diseases of bambara groundnut, there is a need to carry out a country-wide survey, to make an inventory of all the pests and diseases of this crop, and to establish which ones cause serious damage, and hence yield loss. Field research work on yield loss assessment is also important. Since bambara groundnut is said to be resistant to diseases, work needs to be done on screening different varieties for resistance/tolerance to pests and diseases, and this must be collaborative work between breeders and plant protectionists. Bambara groundnut is only grown as a supplementary food crop in Zimbabwe, and it is not economical to chemically control pests and diseases. Therefore, research on cultural and biological control methods also needs to be done.

## Evaluating the potential for bambara groundnut as a food crop in semi-arid Africa: an approach for assessing the yield potential and ecological requirements of an underutilized crop

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### Introduction

In 1992 the European Union initiated funding for a 3-year programme of research to evaluate the yield potential and ecological requirements of bambara groundnut (*Vigna subterranea* (L.) Verdc.). Controlled environment studies have been carried out at Nottingham University in the UK and Wageningen Agricultural University in the Netherlands, and combined with field experiments in Botswana, Tanzania and Sierra Leone. The development of a crop growth simulation model at Nottingham University serves to integrate data from controlled environment work and field studies, and to highlight gaps in understanding in the growth and development of the crop.

The specific objectives of the EU project are to:

1. Identify suitable agro-ecological regions and seasons for the cultivation of bambara groundnut in Tanzania, Botswana and Sierra Leone.
2. Produce a validated model of bambara groundnut for predicting the total biomass and pod yield of different genotypes in contrasting soils and atmospheric environments.
3. Identify the physiological attributes associated with the ability to produce yields under semi-arid conditions.
4. Recommend suitable management practices to stabilize the yields of bambara groundnut under rain-fed conditions.
5. Outline a methodology for applying a similar approach to rapidly assess the potential of other underutilized species in tropical environments.

This project not only assesses the potential for bambara groundnut but also appraises an innovative approach which could be applied to any under-researched species. Research within the International Agricultural Research Centres focuses almost exclusively on the major crop species and agroclimatic regions, and funds are rarely directed towards those crops considered to be of secondary importance. Limited, piecemeal research has been carried out on crops such as bambara groundnut at various African universities and National Research Institutes, but as yet there has been no major funding provided for these minor crop species. It is envisaged that through the integration of controlled environment and field experiments a more comprehensive understanding of the physiology and agronomic requirements of the crop can be established.

### Field experiments

The three African partners within this project are Botswana College of Agriculture, Sokoine University of Agriculture, Tanzania, and Njala University College in Sierra Leone. These three locations encompass much of the rainfall environments and latitudes of the major bambara groundnut growing regions in Africa, and hence are

ideally placed for conducting research on the crop. Within each partner country experiments have been focused on two local landraces usually grown at two field sites. A primary concern has been the effect of sowing date on growth, development and yield, due to the photoperiodic control of pod-filling.

Experiments at Botswana College of Agriculture began in the 1992/93 cropping season when two landraces (Gaborone Cream and Zimbabwe Red) were sown at three dates and under both rain-fed and irrigated conditions at the main site at Sebele (24°33'S, 25°54'E, 994 m). At the secondary site at Tshesebe (21°11'S, 27°32'E, 300 m) three sowings of the same two landraces were carried out under rain-fed conditions. At Sebele five plant populations were sown at the second sowing date, from 5 to 66 plants/m<sup>2</sup>. However, plant population at final harvest varied from only 5 to 22 plants/m<sup>2</sup>, and there were no consistent trends in dry matter production in response to plant population. Delaying sowing at both sites resulted in a reduction in total dry matter and pod yields. However, pod yields were poor across all sowings with a maximum yield of 18 g/m<sup>2</sup>.

During the following season, five sowings were carried out at Sebele and Tshesebe from October 1993 to February 1994. The landraces grown were the progeny of those grown in the previous season. At both sites later sowings resulted in fewer leaves and flowers than the earlier sowings. The last two sowings at Sebele resulted in no pod yields, perhaps due to the lower temperatures experienced during May to July. The maximum pod yield was achieved by Gaborone Cream seed sown at the end of November, resulting in a pod yield of about 120 g/m<sup>2</sup>. A comparison of yields from both seasons indicates that the highest yields would be achieved by sowing before the end of December (e.g. Tshesebe, Fig. 1).

In Tanzania the first experiment was carried out under irrigation in the dry season at the main site, Morogoro (6°49'S, 37°40'E, 300 m), and a secondary site, Miwaleni (3°21'S, 37°19'E, 700 m). Two landraces, one cream-seeded and one red-seeded, were obtained from a farmer in the Dodoma region. Three sowings were carried out between 30 June and 30 August. In general, pod production declined with later sowings. However, pod yields at Morogoro were low (a maximum yield of 10 g/m<sup>2</sup>) compared with those at Miwaleni (up to 80 g/m<sup>2</sup>).

Three irrigated sowings were carried out at Morogoro between February and April 1994, and five rain-fed sowings between January and May 1994. The second site was moved to Dodoma (5°54'S, 35°57'E), which was thought to be more representative of the bambara groundnut growing regions in Tanzania. At this second site three sowings were carried out under rain-fed conditions from January to March 1994. Unfortunately the irrigated treatments at Morogoro had to be abandoned because of leaf damage by mildew and *Cercospora* leaf spot. For the rain-fed treatments, pod yields declined with later sowings: combining pod yields for 1993 and 1994 at Morogoro indicates a clear decline in pod yields per plant with delayed sowings (Fig. 2).

At Dodoma the first sowing produced higher total dry matter and pod yields than the two later sowings (Fig. 3), with DodR94 producing a yield of 300 g/m<sup>2</sup>. The failure of the second two sowings was probably due to the short rainy season at Dodoma as there was little rain from April onwards.

In Sierra Leone two landraces were obtained from farmers in the Kabala (KabC93) and Lunghi (LunT93) regions. These were sown on five occasions from April to August 1993 at two sites: Njala (8°1'N, 12°8'W, 51 m) and Kabala (9°5'N, 11°6'W, 464 m). At both sites later sowings resulted in reduced total dry matter production. Pod production was poor in both landraces, with a maximum yield of 17 g/m<sup>2</sup> produced by LunT94. There were problems with fungal diseases causing



leaf damage, especially at the Njala site where total dry matter production reached a maximum of  $120 \text{ g/m}^2$ , compared with  $340 \text{ g/m}^2$  at Kabala. The trials were sown on flat land at high densities in contrast to the practice of local farmers, who sow on ridged land. Therefore in 1994 an experiment was carried out to investigate the effect of plant population and raised/flat beds on growth and development, at both Njala and Kabala. Increasing plant population (from P1,  $2.8 \text{ plants/m}^2$  to P5,  $44 \text{ plants/m}^2$ ) resulted in fewer leaves and flowers per plant (Fig. 4) at both sites. Dry matter production was much higher at the Kabala site.

At final harvest, plants sown at the highest populations produced higher pod yields per unit area. Pod yields were higher than in the previous year, with a maximum of  $60 \text{ g/m}^2$  produced by LunT93. This may be attributed to a reduced incidence of fungal attack due to a more open canopy, and better drainage from the raised beds.

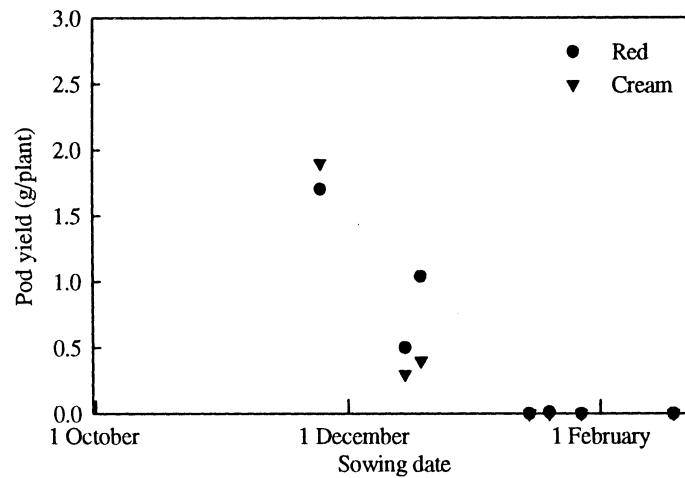


Fig. 1. Pod yields at Tshesebe, in response to sowing date.

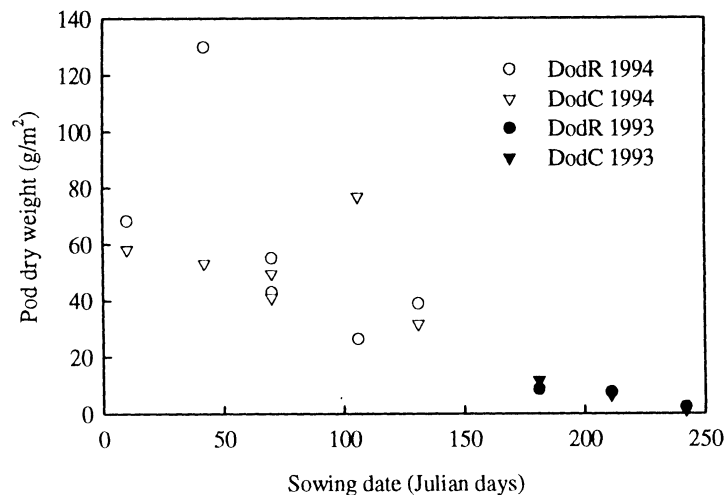
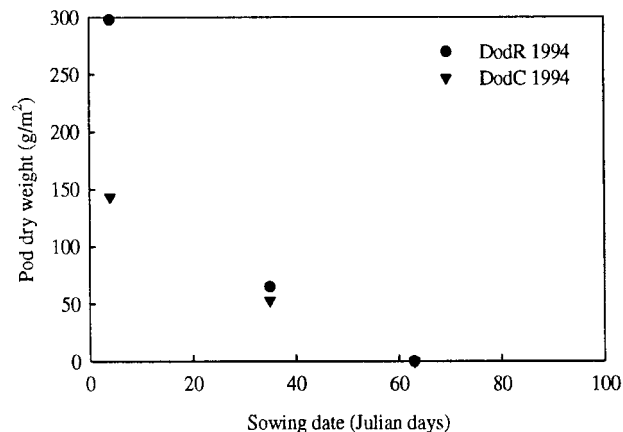
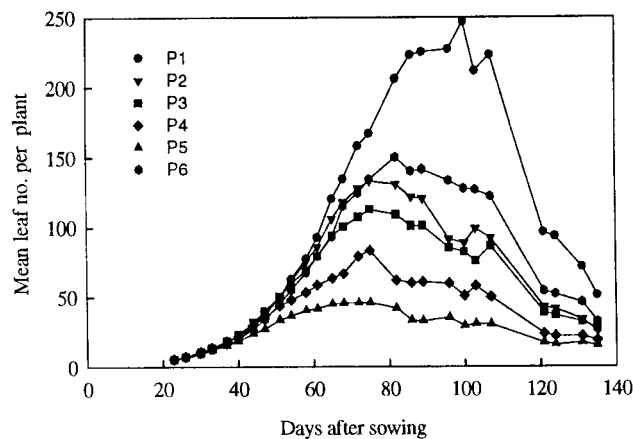


Fig. 2. Pod yields at Morogoro, Tanzania, 1994, in response to sowing date.



**Fig. 3.** Pod yields at Dodoma, Tanzania, 1994, in response to sowing date.

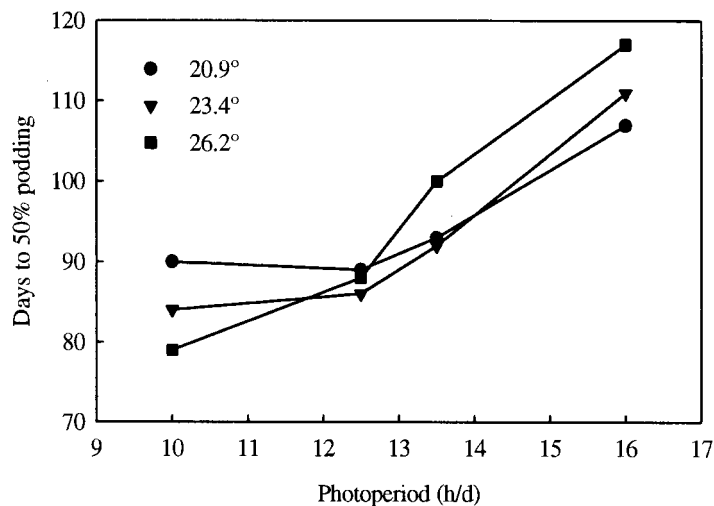


**Fig. 4.** Mean leaf number per plant, for five populations (P1-P5) and one flat-bed treatment (P6) at Kabala, Sierra Leone, 1994.

### Controlled environment experiments

The two European partners in the project have a history of research on bambara groundnut: at Wageningen Agricultural University the focus has been on the effects of daylength and temperature on the rates of phenological development. In 1993, experiments showed that Gaborone Cream was slightly sensitive to daylength with respect to the time to flowering, and both Gaborone Cream and Zimbabwe Red were sensitive to daylength with regards to pod filling. In long daylengths, assimilates continue to be partitioned to the leaves, resulting in a greater leaf area than under short daylengths. In 1994, experiments showed that the rate of progress to flowering could be modelled as a linear function of temperature in three landraces. In two of these landraces (GabC92 and NTSC92) the rate of progress to podding could be modelled as a function of temperature and daylength (Fig. 5). Experiments investigating the timing of photoperiod sensitivity found that the inductive period started around 71 DAS for GabC92, and 43 DAS for NTSC92 and NTSR94.

In 1995 an experiment was carried out in the Tropical Crops Research Unit (TCRU) glasshouses at the University of Nottingham to examine the growth, development and yield of one landrace from each partner country. Two irrigation treatments were imposed: one treatment was irrigated to 90% field capacity on a weekly basis (irrigated); the second treatment was maintained at 50% field capacity until 27 DAS after which there was no further irrigation (stored). Preliminary results indicate that all three landraces produced small pod yields under the stored moisture treatment, and yields in the irrigated treatment ranged from 2.1 to 4.4 t/ha. There were small differences in landraces in terms of resource use, and subtle differences in stomatal number accounting for higher transpiration rates from the landrace from Sierra Leone.



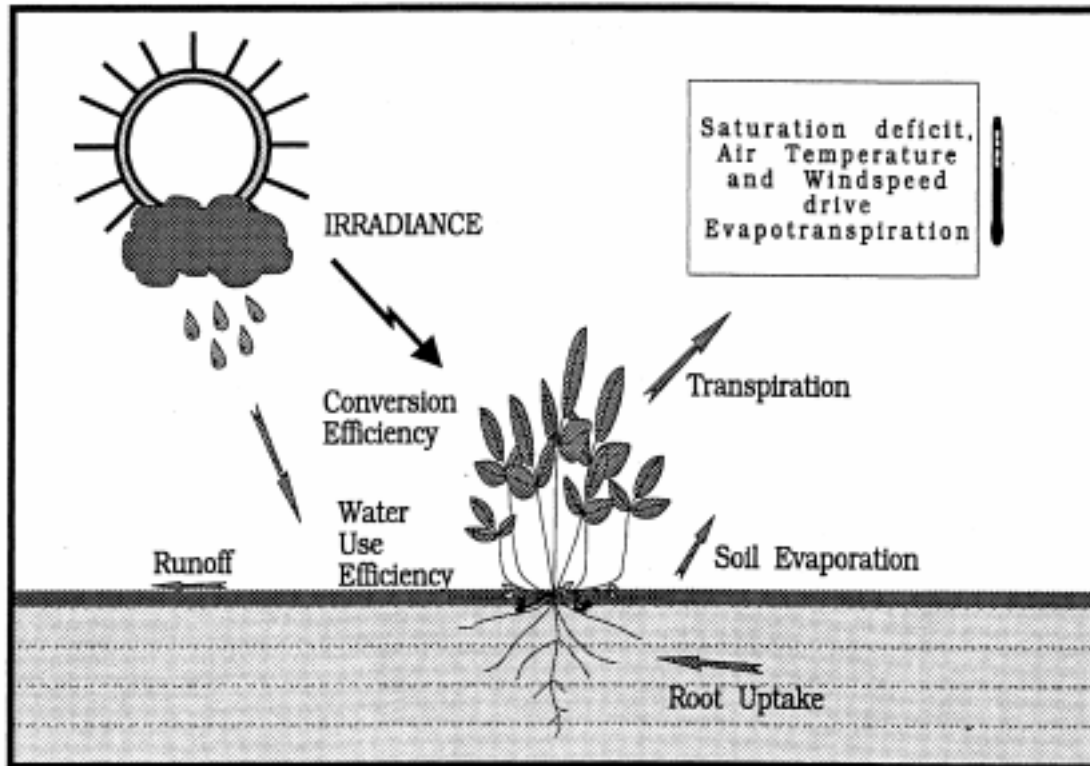
**Fig. 5.** Days to 50% podding in relation to temperature and photoperiod for GabC92.

### Modelling

A preliminary version of the model was based on controlled environment work carried out at Nottingham University prior to the start of the EU project. This has been upgraded using data from Wageningen to simulate the rate of progress to flowering and podding, and data from the TCRU experiment in 1995. The model is based on the PARCH model (Predicting Arable Resource Capture in Hostile Environments) which incorporates a soil profile divided into layers, coupled with a crop growth module (Fig. 6). As this acronym suggests, this model has been developed primarily for harsh environments where water availability is scarce. On each day, light and water are intercepted and converted into dry matter.

If water is non-limiting then growth is equal to the amount of radiation intercepted multiplied by the conversion coefficient for intercepted radiation. If water is limiting, growth equals the amount of water transpired multiplied by the transpiration equivalent (g dry matter produced per kg water transpired). An index of crop stress is derived from the ratio of light-limited to water-limited growth, depending on the availability of these resources and the crop's ability to intercept

them. Partitioning of dry matter between plant organs depends on the developmental stage and the level of stress – increased stress results in increased partitioning to roots and reduced partitioning to pods. Initially most assimilates are partitioned to the leaves, increasing the leaf area and enabling more light to be intercepted. When podding occurs there is a gradual decline in partitioning to leaves and stems as assimilates are preferentially partitioned to pods instead.



**Fig. 6.** Pictorial representation of the PARCH model.

### Progress

The brief summary of field and controlled environment experiments above indicates the immense effort which has been made at each partner institute involved in this project. Data have been collected on leaf and flower numbers, and dry matter production over a wide range of sites, sowing dates and management practices. However, model development has been slow owing to a lack of detailed physiological measurements in the field. For example, Sokoine University has the mandate for crop physiology, and yet until recently there was no equipment in place to carry out detailed physiological measurements. A neutron probe for estimating soil moisture content and an AccuPAR ceptometer for measuring light interception have recently been shipped to Tanzania, and so these measurements will be made in the 1995/96 experimental season. The model is therefore based on data from controlled environments, and will need careful validation against field data if it is to predict field performance accurately.

Although the literature states that bambara groundnut is resistant to pests and diseases, our experience is that in high moisture environments, for example in Sierra Leone, and even in Morogoro, Tanzania, fungal diseases have been a problem. The most prevalent appear to be *Cercospora* leaf spot, *Rhizoctonia solani* and downy mildew. In some cases whole experiments have been wiped out, and in others it is difficult to estimate how much damage was caused by disease, as although leaves were damaged the crop did not fail completely. We must conclude that bambara groundnut is not as resistant to pests and diseases as was previously reported, and future research efforts need to consider this aspect.

Pod yields in many of the field experiments have been poor, with a notable exception being Dodoma where yields up to 3 t/ha were recorded. The reasons behind these poor yields are not known, but possibilities include: management factors, such as earthing-up and growing on ridges; disease problems; nutrient deficiencies, and poor seed quality, although most landraces (from the same seed source) grown in controlled environments have produced high yields. With the benefit of hindsight, it may have been more appropriate to carry out a survey of bambara groundnut growers within each partner country prior to establishing field experiments. This would have highlighted the problems facing bambara groundnut farmers before field experiments were initiated. Ideally, research on minor crop species should be directed by problems identified by those growing the crop, as they are ultimately the targets for any improvements which can be made in managing the crop, or through breeding improved cultivars. A farm survey was carried out in Botswana in February 1995, and some of the findings will be incorporated into the final project report.

One problem in working on an underutilized crop has been the seed supply. Initially, seed was supplied by National Tested Seeds in Zimbabwe, but for the most part seed has been bought from farmers. Hence there is concern over the seed quality due to poor storage conditions and lack of seed treatments available to subsistence farmers. With major crop species a named cultivar can be obtained commercially, and the genetic variability within that cultivar will have been reduced or removed through plant breeding over the years. However, bambara groundnut landraces are an unknown entity, with no local cultivar names and large variation within a so-called landrace. Although seeds can be sorted according to size, colour and eye pattern/colour, this does not eliminate the genetic diversity within a landrace. Therefore across all experiments there has been large variation between plants within the same landrace and under the same treatment, which has sometimes masked treatment differences. The question remains whether the laws which have been learnt from major crop species can be applicable to such non-uniform landraces. For example, can a 'mean' and 'standard error' be applied to a population containing extremely heterogeneous material? As yet there are no alternative ways of describing populations, but a group at the Scottish Crops Research Institute, led by Dr Geoff Squires, is investigating ways of quantifying the variability within bambara groundnut landraces.

An important part of the project is to communicate research findings to other bambara groundnut researchers, through a series of reports and publications in the international literature. A workshop will be held at the University of Nottingham in July 1996, where it is hoped a wider audience will learn in more detail of our findings during this project. During the final year there will be field experiments in Tanzania and Botswana, and further model development based on information from field and controlled environment work and the farm survey. Ideally, information from other sources such as indigenous knowledge, and experience

from other researchers will be incorporated into the model. An essential component will be the development of a strategy, based on the learning experience gained by all project scientists, to identify the potential of any other underutilized crop.

Although this project will end in September 1996 it is hoped that our research on bambara groundnut will be of benefit to those working on the crop in Africa. The bambara groundnut simulation model will be a potentially powerful tool, for example in predicting yield under a set of well-defined conditions, or in defining responses to sowing date at specific locations. At a broader level extrapolation of results from the model could help in setting research priorities, and in agricultural planning for a specific region. It is envisaged that model development will continue after the end of the project, with the development of parameters for other types of bambara groundnut, and further validation across agro-ecological zones. Application of the model could also be made in breeding programmes for improved bambara groundnut types, by defining the most suitable ideotype for a specific environment.

## Towards increased food legume production

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Integrated Crop Management/Food Legume Project, Lusaka, Zambia

### Introduction

During the past 10 years, health, nutrition, education and other key indicators of social development have deteriorated in Zambia, causing hardship for the majority of people. Zambia is facing a severe food security problem, at both household and national levels. Sufficient calories and protein are not provided by traditional starchy foods, and high-protein foods are not available at affordable prices and in sufficient quantities to the majority of the population throughout the year. Zambian agriculture is predominantly rain-fed, and drought has occurred frequently in the past decade. Agricultural activity is dominated by small farmers, who comprise over 90% of the farming population. Crop production is the main agricultural output, even though livestock, wildlife, fisheries and forestry are also important. Zambia's agro-ecology permits a wide variety of farming systems and crops. In spite of this, in the past, little was done to diversify production.

Subsidies and other counterproductive policies contributed to a decline in agricultural yields. Maize production was overemphasized, at the expense of farming systems' productivity and sustainability. Extension activities did not adequately cater for all growers, especially for female farmers. Moreover, the lack of an integrated approach to crop development has contributed to research results not being fully utilized by farmers.

### Food legumes in Zambia

Food legumes are important crops: they possess the highest protein content of all plant foods, and their amino acids complement those of cereals. Peanut is popular with women farmers, and is grown by housewives, mainly to supplement the dietary needs of rural families. Food legumes also enrich the soil, by fixing atmospheric nitrogen and resulting in reduced fertilizer requirements for subsequent crops. Since these crops are adapted to produce some yield, with little input, they are the ideal crops for the multitude of resource-poor smallholder farmers.

Availability of the marketable surplus of peanut, beans, cowpeas and bambara groundnut to small farmers depends on stable and higher yields, which affect national food security. Furthermore, peanut, cowpea, pigeonpea and chickpea have very high export potential, and can contribute to the country's foreign exchange earnings. Principal constraints in the production of food legumes include insect pests, diseases, poor adaptability to abiotic and environmental stresses such as moisture, soil acidity, temperature, poor agronomic practices and the unavailability of improved seed.

The increase in the national production of food legumes requires an increase in the area under these crops and/or the enhancement of productivity in the existing cultivation area. The scope for increasing food legume hectareage is limited by the smallholder farming system, where the families must grow other crops, such as maize, to meet their financial and dietary needs. Competition for land to use for

other purposes or crops also affects the commercial production of food legumes. To increase productivity, the smallholder needs improved technology packages. Most of those currently available are for improving peanut varieties. The extension services will be able to contribute to such increased productivity, only after the research team has developed appropriate technology packages, suitable for the different cropping systems in which food legumes are grown. Continuing research is, therefore, the only real means of achieving increased national production, leading to Zambian self-sufficiency in food legume grains.

#### **The history of food legumes research**

The Food Legumes Research Team (FLRT)<sup>9</sup> is charged with conducting research on all major food legume crops in the country. Most of the research efforts are concentrated on peanut, bean and cowpea. A limited amount of research is also conducted on three minor legume crops: bambara groundnut, pigeonpea and chickpea.

In 1978, with UNDP/FAO assistance (under the NODP), intensive research work was begun on legume improvement for peanut breeding. In 1982, such agronomic research was begun on beans and cowpea, as well as peanut, with IBRD/IFAD loan assistance, as an integral part of the Eastern Province Agricultural Development Project (EPADP), based at Msekera Regional Research Station. In 1986, the peanut breeding component was also taken up by the EPAD Project, whose funding terminated in June 1988.

### **The Integrated Crop Management/Food Legume Project**

#### **Introduction**

The Integrated Crop Management/Food Legume Project (ICP/FL) was formulated to address the problem of food security, and to improve the process of transferring to farmers the food legume technologies that have been developed hitherto. Unlike the previous UNDP-funded Maize and Food Legume Project, which confined itself to funding food legume crop research, the ICP/FL was designed to support research, extension and training, seed multiplication and the utilization of food legumes.

The project, which became operational in March 1993, is funded by the Government of the Republic of Zambia and the United Nations Development Programme (UNDP). The Ministry of Agriculture, Food and Fisheries (MAFF) is responsible for its implementation, assisted by the Food and Agriculture Organization (FAO). The aim of the project is to improve the productivity and sustainability of the smallholder farming systems in the three agro-ecological zones of Zambia. This is to be done through emphasis on increased production, on-farm storage, home utilization, and when possible, the export of food legume crops.

The project strategy involves working through the GRZ extension services, non-governmental organizations (NGOs) and the private sector, and concentrates on smallholder farmers in 30 (out of 57) districts in the three agro-ecological zones.

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<sup>9</sup> Funded by the UNDP/FAO since July 1988.



### Objectives

The development objectives of the project are to improve the agricultural productivity and sustainability of the smallholder farming systems, and to improve the country's nutritional status by increasing the production and utilization of food legume crops. The immediate objectives of the project are to:

- increase national food legume improvement capabilities, with farmers and extension agents playing leading participatory and diagnostic roles in the formulation of production packages
- increase national food legume production capabilities, by disseminating environmentally sound production packages among smallholder farmers, focusing on the needs of female farmers
- contribute to the enhancement of food security in the country and to improved health, especially among the children and mothers, by promoting home utilization of food legumes, and methods of preventing HIV/AIDS.

### Activities

The major activities to achieve the project's objectives are:

- the establishment of an economic database on food legume crops
- variety development tests in the three agro-ecological zones
- participation by farmers in diagnosing research needs and assessing research recommendations
- agronomic studies, on-farm tests and economic analysis of crop production packages for productive and sustainable farming systems
- training of farmers and trainers from government, NGOs and the private sector, on seed production and storage techniques
- seed multiplication of food legume crops, and their distribution to farmers through NGOs
- training programmes and demonstration plots for female farmers in crop production techniques, utilization of food legume crops, health science, and the prevention of malaria and HIV/AIDS.

### Project strategies

The project encourages farmers to participate and play a leading role in the development of crop production packages, where an integrated crop development approach has been adopted. The project focuses on the needs of the small/medium-scale farmers. The agro-ecological region approach to development has been followed for all the project activities.

All the field work is production-oriented. The project collaborates with the government agencies, NGOs and the interested cooperatives, as well as with the private sector. The project activities are directed by a steering committee, whose members are drawn from these and from gender and development groups. Cooperative activities with other groups involved in similar work are also designed to enhance the effectiveness of the project. Gender-sensitive personnel are involved in developing its extension activities, to ensure that equal attention is given to the needs of female and male farmers. Mobile training courses held in the villages, and demonstration plots, form part of the strategy to achieve the project's objective of reaching more women farmers.

### The status of bambara groundnut research and development

Research in bambara groundnut began in 1971, when a series of agronomic trials were conducted in the Western and Southern Provinces. The results showed considerable variation in yield within varieties, with an extremely high coefficient of variation. The mean yields of some varieties were unexpectedly high, and the local varieties outyielded introductions so convincingly that the latter were excluded from future work. More agronomic trials on fertilizer use, ridging and spacing were conducted from 1972 to 1975. No significant results could be obtained from this series of trials, as the variation was too great.

The most significant activity undertaken by the Food Legume Research Team on this crop was the collection of a large number of local landraces in a collecting mission undertaken with FAO/IBPGR. The germplasm was evaluated for yield potential and tolerance to disease and insect pests. Results from the few variety trials have been too varied to be useful.

Responsibility for bambara groundnut research in the country currently lies with the University of Zambia, which has continued with germplasm augmentation. Other research activities undertaken include germplasm conservation, multiplication, characterization and evaluation. In 1989/90, a start was made in establishing a breeding programme, with the first single-plant selections. Multiplication and adaptability trials have also been conducted. From the multilocal trials, three local landraces (ZVS 544, ZVS 545 and ZVS 546) have been found to be promising. Efforts are now being made to multiply these three lines for testing in on-farm trials.

In the 1994/95 season, 43 accessions obtained from South Africa were tested in an observation trial in Msekera. A total of 21 accessions recorded higher grain yields than the three local landraces. The seed of the promising accessions will be multiplied for testing in adaptation and yield trials.

In addition to the research efforts, the project has identified and contracted three farmers to multiply popular local landraces of bambara groundnut. Once multiplied, the seed will be distributed to other farmers, through NGOs.

## Preliminary studies on the germinability and vigour of Zimbabwean bambara groundnut genotypes

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### Introduction

Bambara groundnut (*Vigna subterranea* (L.) Verdc.) is an indigenous African leguminous crop. Its common English name is derived from the Bambara, a tribe of agriculturists who now live mainly in Mali. The crop is called 'nyimo' in the Shona language and 'indlubu' in Ndebele. Bambara groundnut has been cultivated in the tropical regions of Sub-Saharan Africa and in Madagascar for many centuries (Linnemann and Azam-Ali 1992). In Zimbabwe, small-scale communal farmers grow the crop mainly on a subsistence level, although surpluses are often sold in urban centres. Bambara groundnut is traditionally grown as an intercrop, with millet, sorghum, maize, or even vegetables such as okra or pumpkin (Doku 1967; Doku and Karikari 1971a; Ezueh 1977; Haque 1980; Linnemann 1990). The crop may also be grown as a sole crop (Stanton *et al.* 1966). Bambara groundnut is useful in crop rotations, because it can improve the nitrogen status of the soil (Mukurumbira 1985). In many dry, hostile environments, bambara groundnut is able to produce some yield, where groundnut and other drought-tolerant legumes may fail completely (Nyamudedza 1989; Lewitt 1990).

Bambara groundnut is predominantly grown for human consumption, although it also has the potential for use as an animal feed. The seeds of bambara groundnut are often described as a complete food, as they contain protein, carbohydrate and fat in sufficient proportions to provide a nutritious food (Poulter and Caygill 1980). Seeds can be boiled in the immature, green state, either shelled or unshelled, until quite soft. Dry shelled nuts can be pounded to flour and then boiled to a stiff porridge. An alternative is to roast, boil, crush and eat the seeds as a relish with the maize-meal porridge, 'sadza'.

The empirical evidence, and limited research, indicate that bambara groundnut is a promising crop, which has been largely neglected by national and international agricultural researchers. Previous research work on the physiology and agronomy of bambara groundnut has been carried out on a short-term, trial-and-error basis, mainly owing to the limited funds available for research on underutilized crop species (Linnemann and Azam-Ali 1992). The development of improved genetic material should be pursued in conjunction with the search for optimal management practices for commercial and subsistence production.

There is a dearth of reported data on bambara groundnut seed quality tests. In 1992, The International Seed Testing Association (ISTA) stipulated the optimum conditions for the germination of bambara groundnut.<sup>10</sup> In Zimbabwe, the minimum gazetted germination for a bambara groundnut seed crop is 75%. Sowing seed that does not have the capacity to produce an abundant crop of the required cultivar is one of the greatest hazards in crop production (Mupamba, pers. comm.). Large bambara

<sup>10</sup> Section 5.9 of the ISTA rule states that when reporting the result of a germination test, the following items should be entered in the analysis certificate: (i) duration of test; (ii) percentage of normal seedlings, abnormal seedlings, hard seeds and dead seeds. If the result for any of these categories is found to be nil, it is entered as '0'.

groundnut seeds reportedly produce more vigorous seedlings (Karikari 1969). Zulu (1989) reported that small seeds emerge at a faster rate. Maximum fractional germination, i.e. an emerged radicle of 10 mm length, occurs at 22-36°C in contrasting genotypes (Zulu 1989). The highest levels of final germination of two bambara groundnut landraces from Zimbabwe were obtained at 30-35°C (Mabika 1991).

Assessing the germination of different genotypes under controlled environments and seedling emergence in the field is a useful rapid screening technique, which can facilitate the selection of germplasm with good early vigour for moisture-stressed edaphic conditions (Perry 1981). Indeed, seeds of high germination and vigour are highly desirable in the establishment of most crops.

Concomitantly, the effect of the duration of storage on germination is an important determinant of the physiological quality of a seedlot. Prolonged storage for 18 months of bambara groundnut seeds reportedly reduced germinability, delayed germination, reduced root and epicotyl growth, and increased the number of stunted seedlings (Sreeramula 1983).

This paper examines the germination of three contrasting bambara groundnut genotypes, from different seedlots, grown on two inert media or substrates (sand and between paper (BP)), and seed vigour under field conditions.

## Materials and methods

Germination tests were conducted on six seedlots from three bambara groundnut genotypes. The test media used for the controlled environment evaluation were sand and paper. A field test to record seedling emergence/early vigour was also done at The National Tested Seeds Research Station, Sigaro. The seeds of the bambara groundnut genotypes were originally from seed grown and bulked at Sigaro during the 1991/92 season. After each harvest, the seed was hand-shelled, treated with Natsan (a.i. – Captan, 76%; Pirimiphos-methyl, 1.60%), bagged and stored under ambient temperature and humidity. This process was repeated for subsequent crops. Because there are no local improved bambara groundnut varieties, *sensu strictu*, we used three genotypes or landraces, distinguished by their testa colour: red, cream and black were used. The final number of test entries was 6, randomly drawn from pure seedlots harvested from the 1992/93 and 1994/95 crops. Thus the test entries were: Black 92, Cream 92, Red 92, and Black 94, Cream 94 and Red 94, respectively. The genotypes with a 92 suffix had been stored for 20 months.

### Experiment 1

River sand was sieved through a 0.08 cm diameter sieve and then washed and sterilized before use. Fifty seeds per entry, arranged in eight replicates, were planted on a level layer of moist sand, in plastic trays measuring 24.5 x 20 x 3.5 cm. The seeds were then covered with 2.5 cm of uncompressed sand. The sand was kept moistened to about field capacity for the duration of the test. Trays were placed in an air-conditioned germination laboratory, at a constant temperature of 20°C. After 10 days, the germination evaluation was done according to the ISTA rule, section 5.9. The result of the germination test was calculated as the average of eight 50-seed replicates, and expressed as a percentage by number of normal seedlings. Normal seedlings were those which showed the potential for continued development into satisfactory plants when grown in good quality soil, and under favourable moisture, temperature and light conditions.

### Experiment 2

The number of seeds per test entry and the number of replicates were as described above. The seeds were placed with three papers below and one paper on top. The newsprints were 50 x 25 cm. The papers were carefully rolled, and then put into a transparent polythene bag. Each bag was secured with an elastic band and placed in an upright position in a cabinet germinator, where relative humidity was maintained near saturation. Day and night temperatures were kept at 30 and 25°C, respectively. At 10 days after sowing, the germination percentage was determined, as in Experiment 1.

### Experiment 3

As the optimum conditions provided in the germination test rarely, if ever, occur in the field, a simplified vigour test was conducted to identify genotypes/seedlots with rapid synchronous emergence, or those which produce large robust seedlings under field conditions (Perry 1981). Randomly selected pure seed samples of the same six entries as in Experiment 1 and 2 were planted in a complete randomized block design, four replicates, with 50 seeds per replicate. Seeds were sown to a depth of 2.5 cm.

The soil at the trial site is a reddish brown, medium-grained, sandy-clay with a pH of 6.2. The soil was analyzed, and had the following nutrients, prior to sowing: nitrogen, initial and after incubation, 26 and 50 parts per million (ppm), respectively; available phosphorus, 47 ppm; potassium, 0.25 mg/100 g. The trial was irrigated daily, to field capacity, for 10 days. At the end of the test period, replicates were examined, and actual counts were made of emerged seedlings and converted to percentage seedling emergence. Results from the three experiments were subjected to analysis of variance (ANOVA), using a software database for plant breeders.

## Results and discussion

Results of the three germination experiments and vigour tests are summarized in Table 1. The highest mean germination, 83.13%, was obtained between paper, followed by in sand (77.17%). Only 45% of the bambara groundnut seeds germinated and produced robust seedlings in the field. The low emergence could have been due to low temperatures; more time (>14 days) would have been needed to assess emergence. This trend was observed across genotypes and seedlots, which were stored for varying periods. The genotype with the black seed coat consistently performed well across the three media.

Results from Experiment 1 show that there are significant differences between the bambara groundnut genotypes regarding germinability ( $P=0.05$ ). The germination percentage for the three genotypes was over and above the 75% minimum germination stipulated by the Seed Certifying Authority of Zimbabwe, for a bambara groundnut seedlot to be fit for commercial sale. However, for reasons which are unknown, the red-seeded genotype from the 94 seedlot gave a low germination (only 54.5%). Statistically, the results show that sand gives a more precise indication of the germinability of the different genotypes, as shown by the low coefficient of variation and the lowest %E among the three media. The germination on sand suggests that seed storage did not adversely influence viability and germinability, as reported by Sreeramulu (1983). Brook *et al.* (1977) reported that shelled seeds deteriorate at ambient temperature, and seeds should be shelled as near to their planting as possible, in order to maximize their viability. Our findings did not confirm this observation, but our experimental data agree with observations made at the

University of Nottingham. These showed that there was no loss of germinability in red seeds stored at ambient temperatures for 2 years (Mabika, pers. comm.).

**Table 1. Germination and field emergence of bambara groundnut genotypes tested at Sigaro in 1995.**

| Genotype              | Germination (%) |               | Field emergence (%) |
|-----------------------|-----------------|---------------|---------------------|
|                       | Sand            | Between paper |                     |
| Cream 92 <sup>†</sup> | 79.3            | 84.5          | 19.0                |
| Cream 94              | 82.5            | 81.0          | 55.6                |
| Black 92 <sup>†</sup> | 80.3            | 93.0          | 51.6                |
| Black 94              | 88.0            | 72.5          | 64.0                |
| Red 92 <sup>†</sup>   | 78.5            | 84.3          | 51.6                |
| Red 94                | 54.5            | 83.5          | 33.0                |
| Trial means           | 77.17           | 83.13         | 45.8                |
| SD                    | 2.42            | 3.41          | 2.36                |
| CV (%)                | 6.27            | 8.21          | 20.67               |
| %V <sup>‡</sup>       | 95.67           | 73.30         | 91.85               |
| %E <sup>§</sup>       | 4.33            | 26.70         | 8.15                |
| LSD (5%)              | 6.84            | 9.66          | 6.69                |

<sup>†</sup> Stored for 20 months.

<sup>‡</sup> %V is the ratio of the variance among entries to the total phenotypic variance being calculated on an entry mean basis. %V is equal to heritability, when the entries are a random set of lines from some reference population. The range of %V is from 0 to 100. A high %V indicates (1) that there is variability among the entries in the test, and (2) that the differences among the entries is repeatable from replicate to replicate and from environment to environment.

<sup>§</sup> %E is the ratio of the plot-to-plot error variance (pooled over environments) to the total phenotypic variance. It is an estimate of the precision of the measurements for the trait of interest. %E will usually decrease with increasing number of replicates and environments.

Results from Experiment 2 indicate that between paper (BP) is probably the most ideal inert media, as is shown by the generally high percentage germinations. Compared with sand, BP recorded 7% more normal seedlings than the number noted across the bambara groundnut genotypes. Differences in germination percentages among the genotypes were significant ( $P < 0.05$ ). The black seeds gave the highest germination percentage, compared with the cream and red seeds from the 92 seedlots. The enhanced germination capacity of the black-seeded genotype could have resulted from operational selection, among other factors, which has hitherto focused on genotypes which facilitate harvesting and have faster and more uniform germination (Hepper 1970).

Of interest is the significant difference between the Black 94 and Black 92. The seed, which had been under storage for 20 months, gave a higher germination than fresh seed, perhaps as a result of the seed dormancy of the black-seeded landrace. This observation contradicts data from other investigators (Sreeramula 1983; Mabika 1991). Based on LSD analysis, the differences between the Black 92 and Black 94 seedlots were significant ( $P = 0.05$ ). This observation was not reflected in the red and cream-seeded genotypes. Germination of the black-seeded genotype originating from the 1994/95 crop was below 75%. Thus, the 1994/95 crop would have been rejected for seed production.

Predictably, the proportion of seeds that produced robust seedlings in soil under field conditions was less than the germination obtained in sand and BP. The overall reduction in germination/emergence between the two inert media on one hand, and in soil on the other, was 34%. However, there were discernible differences among the genotypes regarding the numbers of seedlings recorded. Hence, genotypes and seeds from different seedlots could be broadly categorized into (i) seeds that performed well/high-vigour seeds, and (ii) those that performed poorly/low-vigour seeds.

In the former category, the black-seeded genotype (94) produced the highest number of robust seedlings, equivalent to 64% field emergence. Cream 94 gave 55% field emergence. The worst performer in the category of low-vigour seeds was Cream 92, which had a field emergence of 19%. Statistical differences in percentage field emergence among the bambara groundnut genotypes were significant ( $P < 0.001$ ). Generally, on inert media, field emergence was positively correlated to germination capacity. Perry (1981) stated that the causes of variations in vigour are several. Among these, genetic constitution was highlighted as being crucial. Table 1 shows that %V (91.85) for field emergence was high. This indicated high heritability for vigour, and that the differences between the entries could be repeated in other edaphic environments.

Overall, experimental data across the three media indicate that there is variability among the test entries, as shown by the high %V. The high %V also shows that germination and early seedling vigour in bambara groundnuts have high heritabilities. Thus genetic enhancement of these two traits would be a feasible breeding objective. Testa colour is not always a reliable descriptor for a genotype; several instances of re-segregating populations have been recorded (Mittelholzer 1969; Linnemann 1990). Additional criteria, besides the use of the appearance of the seed coat as a means of genotypic identification, could facilitate the implementation of an integrated programme to assess and improve the genetic potential of bambara groundnut in the future.

### **Acknowledgements**

The authors wish to thank Godfree Chigeza and Lameck Chatyoka for their valuable contributions to the research project. Many thanks to Fungai Simbi for his helpful comments and Gilbert Mutseyekwa for his help with the statistical analysis.

## **An overview of bambara groundnut production and research by the Farming Systems Research Unit (FSRU) in Zimbabwe: a case study in the Chivi Communal area**

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### **Introduction**

#### **Background to the study area**

Chivi lies in the semi-arid southern part of Zimbabwe. Rainfall is low, variable and unpredictable. An annual average range of rainfall of 400-600 mm falls between October and May. Various soil types are found in Chivi, ranging from heavy clays to sandy soils. Generally, soils are of poor-to-medium fertility, with low levels of organic matter, and have low pH values, ranging from 4.2 to 4.8.

#### **Farming systems research**

The Farming Systems Research Unit (FSRU) was initiated in Zimbabwe after independence, and was mandated to study mixed crop and livestock production systems in order to identify opportunities for, and major constraints to, improved crop production. Two representative sites, Chivi and Mangwende, were chosen for carrying out the study. Mangwende is a high-potential area in the northern part of Zimbabwe. Just after the formation of the Farming Systems Research Unit in 1984, surveys were conducted to identify constraints in crop production. These were identified as low soil fertility, unreliable rainfall, lack of established market outlets and lack of adequate cash.

#### **Bambara groundnut production**

Bambara groundnut did not emerge as a priority crop for production. The probable reasons for this are (i) farmers give priority to satisfying food requirements first, and (ii) the perception of bambara groundnut as a less important 'woman's crop'. The total hectareage of bambara groundnut is very low, compared with crops such as maize, peanut and sorghum. A recent monitoring survey carried out by the FSRU revealed that as long ago as 1990-91, the average area under bambara groundnut cultivation was 2-5% of arable land. Female-headed households allocated a high percentage of arable land to bambara groundnut, i.e. 4%, while male-headed households allocated about 1%.

Bambara groundnut is usually grown on sandy soils, either as a single crop or in mixed stand with other crops, notably maize, but also groundnut, cotton or sorghum. Harvesting of bambara groundnut is very labour-intensive. Historically, bambara groundnut was grown in once-fallow land; however, with an increasing population, the average land-holding per household is currently 2 ha, making it difficult to leave fallow land that could be planted with the crop. Although bambara groundnut is cultivated on the poorest soils, no fertilizers are added.

#### **Marketing**

Bambara groundnut has always been traded informally, which probably explains the low hectareage put to the crop. In Chivi, particularly during the 1994/95 season, there was a great change in the marketing of bambara. Traders from all over the country



and abroad have been buying the crop at Ngundu, at an average price of US\$ 0.50/kg. The reasons for this lie in the 1994/95 drought, which increased the importance of the bambara groundnut crop in the area, owing to its higher yields compared with such crops as maize.

### Research

For many years, there was no research on bambara groundnut by FSRU in the area. Research efforts were concentrated on crops such as maize, peanuts, pearl millet and sorghum. Bambara research only began after participatory rural appraisals in 1993/94, when two groups of farmers, mainly composed of women, drew attention to the need to carry out soil fertility studies on bambara groundnut on sandy soils. This has created gender awareness, particularly in the cultivation of crops such as bambara groundnut. Farmers experiencing problems with the production of bambara on sandy soils grouped together to discuss with researchers ways of enhancing soil fertility. Local varieties, which included a mixture of red and cream lines, were planted in 45-cm rows, spaced 10 cm apart. The treatments applied (Table 1) included leaf litter (7.13 t/ha), ant-heap soils (12.1 t/ha), gypsum (200 kg/ha) and a combination of gypsum and single superphosphate (200 kg/ha each). As can be seen from Table 1, it appears that ant-heap soils improve bambara groundnut yield. Although labour requirements are high when these soils are used, farmers opt for these less costly treatments.

**Table 1. Farmer assessment of various fertility options (1994/95).**

| Treatment                           | Labour requirements | Cost (US\$) | Yield (kg/ha) |
|-------------------------------------|---------------------|-------------|---------------|
| Leaf litter                         | 5                   | 1           | 2170.10       |
| None                                | 0                   | 0           | 2209.01       |
| Gypsum                              | 2                   | 6           | 1820.39       |
| Single superphosphate (SSP) +gypsum | 3                   | 9           | 2151.27       |
| Ant-heap soils                      | 10                  | 4           | 2278.85       |
| <b>Total scores</b>                 | <b>20</b>           | <b>20</b>   |               |

### Preliminary results

Days to physiological maturity ranged from 102 to 115 days. Bambara groundnut emerged within 10-12 days. Number of pods per plant ranged from 13 to 38, and shelling percentage ranged from 25 to 93%, depending on the season and the treatments applied. Generally, yields were lower for the 1993/94 season, ranging from 403.74 to 1039 kg/ha.

### The role of bambara groundnut in crop rotation

Being a leguminous crop, bambara groundnut can be used in rotation with maize. Compared with maize, the hectareage put to bambara groundnut is so low that rotation would only be feasible on small areas. Some farmers in Chivi have reported that bambara 'kills soil', or damages the field. It is believed to produce little organic matter, and only a few of its leaves can be incorporated in the soil for nutrient cycling. While the potential of bambara in cereal/legume rotation has been scientifically proven, some farmers remain unconvinced.

Mukurumbira (1985) reported that higher yields were obtained when a maize crop succeeded a bambara groundnut crop on station than when it succeeded peanut, maize and fallow. Nitrogen uptake was also highest in maize succeeding a bambara crop, which was attributed to the ease of mineralization of the bambara leaves, compared with those of groundnut and maize. Researchers should test this hypothesis, together with farmers, so that both gain confidence in the role of bambara groundnut in soil fertility improvement on-farm.

### **Germplasm diversity**

The various types of germplasm available in the area are little known to researchers, and appear to include the cream, red and black-seeded varieties. Characterization of such germplasm in terms of days to physiological maturity, shelling percentage, yield, disease resistance, drought tolerance and biomass production has not been carried out. If farmers were to characterize such attributes as the taste and suitability for cooking of the varieties they grow, this might form a practical basis for bambara breeding.

If diversity of bambara groundnut germplasm exists in the Chivi area, how might scientists and farmers maintain this diversity? The experience of working with groups of farmers, particularly those growing bambara groundnut, showed that more women than men participated in the trials. Women possess a high level of indigenous knowledge of the characteristics of bambara groundnut and its storage (it is stored in its shells and kept in jute sacks, and only when the rainy season starts is it shelled; seed selection is carried out after shelling, on the basis of size, colour and condition). Future research on bambara groundnut, therefore, should make use of women's valuable knowledge of the crop.

### **Conclusions**

For a long time, bambara has received little attention from the Farming Systems Research Unit in the Chivi Area. Farmer assessment of trials does not depend on yield alone, but also on such economic aspects as labour and cost.

The contribution of bambara to soil fertility, particularly in sandy soils, is a grey area for some farmers. Further research on such aspects are recommended. There is considerable potential to improve bambara groundnut breeding in the country, by using farmer groups, particularly women, to assess germplasm.

Bambara groundnut hectareage is quite low in Chivi, ranging from 2 to 5% of arable land. Given the crop's high potential in dry years, efforts should be made to promote its cultivation in the Communal areas.

## Characterization and evaluation of IITA's bambara groundnut collection

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### Introduction

Bambara groundnut is an important food legume in Africa, which has a long tradition of cultivation in the continent. However, no significant research has been undertaken to improve the crop. The availability of germplasm materials is vital to crop breeding. The International Institute of Tropical Agriculture (IITA) made a commendable effort to gather nearly 2000 accessions of the crop from most countries in Sub-Saharan Africa. Thanks to a GTZ-funded special project at IITA, this important bambara groundnut collection was effectively characterized, evaluated and documented, and its data made available to all potential users around the world.<sup>11</sup>

### Materials and methods

Field characterization and evaluation of the accessions mainly took place at the IITA research station, located in Nigeria. A total of 1384 accessions were planted for characterization and evaluation in 1985 and 1986. Planting took place on ridges, spaced 100 cm apart. Intra-ridge spacing was about 20 cm. Each accession occupied a single row, the length of which varied from 1.5 to 6 m, depending on the quantity of seeds available. Pesticides and irrigation were applied whenever it was necessary.

The accessions were evaluated for 38 characters, according to the internal bambara groundnut descriptor list (IBPGR, IITA and GTZ 1987), which is presently under revision, and measured, both in the field during vegetative growth, and after harvesting.

### Results

Table 1 provides a summary of the basic statistics for the quantitative characters. For most characters, including the qualitative ones not listed in Table 1, the high- and low-scoring accessions are listed. It is worth noting that the results for most quantitative traits were environment-specific. The humid ecology of Ikenne somewhat depressed the growth and productivity of the plants. The frequency distributions of the accessions are indicated in Figures 1-23 for each continuously varying character.

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<sup>11</sup> All data can be accessed online via internet at <http://www.dainet.de/genres/bambara/bambara.htm>.

**Days to maturity**

Accessions maturing within 100 days:

- TVSU 459, 460, 604, 606, 607, 610, 614, 615, 616, 618, 620, 622, 623, 624, 626, 662, 1154, 1155.

Accessions maturing after 160 days:

- TVSU 30, 123, 557, 701, 956, 957, 961, 964, 971, 1060, 1116, 1215.

**Vigour index**

Accessions rated 9 for vigour index:

- TVSU 726, 1071, 1299, 1341.

**Growth habit**

This character was visually rated, 11 weeks after planting, taking into consideration both the spreading of the plants and the internode length. The scale used was:

1 = plants in a bunch conformation; leaves in a cluster as a result of short internodes

2 = plants have a semi-bunch conformation; in general, internodes moderately elongated

3 = plants with spreading or trailing stem system; internodes usually long.

It was observed that plants of poor vigour tended to have a bunch conformation.

Distribution of the accessions over the three growth-habit groups was 45, 47 and 8%, for groups 1, 2 and 3, respectively.

**Plant height**

Accessions with plant height equal to or greater than 35 cm:

- TVSU 747, 1254, 1279, 1280, 1281, 1366, 1376.

Accessions with plant height equal to 10 cm:

- TVSU 44, 90, 101, 110, 166, 168, 201, 241, 245, 302, 306, 420, 425, 528, 964.

**Canopy width**

Accessions with canopy width equal to 90 cm:

- TVSU 1277, 1344, 1351, 1356, 1357, 1359, 1361, 1362, 1366, 1374, 1377.

Accessions with canopy width less than 20 cm:

- TVSU 30, 90, 110, 166, 168, 241, 306, 525, 528, 623, 629, 701, 846, 964, 1057, 1095, 1199, 1209.

**Number of leaves per plant**

Accessions with more than 300 leaves per plant:

- TVSU 1157, 1170, 1174, 1208, 1235, 1244, 1338, 1340, 1351, 1358.

Accessions with less than 20 leaves per plant:

- TVSU 30, 162, 285, 388, 394, 525, 528, 701, 1057.

**Leaflet shape**

A visual rating of the shape of the medium leaflet took place 11 weeks after planting, according to the following scale:

1 = narrow leaflet

2 = oval shape

3 = broad, roundish leaflet.

The distribution of the accessions over the three groups of leaflet-shape patterns was 8, 78 and 14% for groups 1, 2 and 3, respectively.

**Terminal leaflet length**

Accessions with median leaflet length equal or greater than 90 mm:

- TVSU 227, 318, 1046, 1289, 1291, 1292, 1299, 1303, 1304, 1331, 1341, 1344, 1351, 1354, 1356, 1357, 1359, 1360, 1362, 1367, 1373.

Accessions with median leaflet length less than 35 mm:

- TVSU 17, 90, 166, 168, 205, 263, 325, 326, 425, 525, 528, 701, 838, 1057, 1199, 1334.

**Terminal leaflet width**

Accessions with median leaflet width equal to or greater than 50 mm:

- TVSU 194, 295, 579, 672, 703, 1360.

Accessions with median leaflet width equal to or less than 12 mm:

- TVSU 90, 101, 211, 212, 525, 528, 701.

**Petiole length**

Accessions with petiole length equal to or greater than 27 cm:

- TVSU 1309, 1334, 1341, 1351, 1356, 1357, 1359, 1361, 1362, 1368, 1372, 1374, 1376, 1377.

Accessions with petiole length less than 6 cm:

- TVSU 90, 261, 425, 428, 1057, 1078.

**Petiole colour**

The petiole and veins of the leaves were either green or reddish. These two colourations were assigned the indexes 1 and 2, respectively. Out of 1307 accessions observed, only 14 were assigned the index 2. In other words, almost 99% of the accessions had a green petiole and veins.

**Number of stems per plant**

Accessions with more than 14 stems per plant:

- TVSU 104, 114, 218, 226, 737, 742, 743, 879, 880, 896, 941, 946, 951, 985, 1089, 1223, 1231, 1246, 1249.

Accessions with less than 4 stems per plant:

- TVSU 30, 47, 591, 702, 858, 1060.

**Number of branches per stem**

Accessions with more than 7 branches per stem:

- TVSU 29, 256, 258, 276, 369, 376, 638, 732, 742, 743, 880, 951, 985, 1089, 1223, 1231, 1246, 1248.

**Number of nodes per stem**

Accessions with more than 22 nodes per stem:

- TVSU 116, 136, 376, 571, 687, 732, 951, 1015, 1089, 1141, 1176, 1223, 1231, 1246, 1304, 1341, 1359, 1367.

**Internode length**

Accessions with internodes longer than 18 mm:

- TVSU 29, 92, 225, 234, 235, 490, 537, 574, 635, 637, 1057, 1113, 1223, 1283, 1309.

Accessions with internodes shorter than 6 mm:

- TVSU 90, 174, 302, 425, 428, 487, 509, 525, 787.

Table 1. Characterization and evaluation of bambara groundnut.

| Character                                   | Min. | Max.  | Mean  | N*   | SD    | Variance | CV     | Skewness | Kurtosis |
|---|------|-------|-------|------|-------|----------|--------|----------|----------|
| Days to 50% emergence                       | 7    | 14    | 8     | 857  | 1.06  | 1.13     | 12.88  | 1.27     | 2.76     |
| Days to first flower                        | 37   | 55    | 38    | 849  | 2.2   | 4.84     | 5.71   | 1.98     | 5.78     |
| Days to 50% flowering <sup>1</sup>          | 37   | 70    | 43    | 810  | 5.54  | 30.69    | 12.96  | 1.87     | 4.4      |
| Days to maturity <sup>2</sup>               | 90   | 165   | 128   | 1309 | 15.3  | 235      | 11.93  | 0.35     | -0.82    |
| Vigour index <sup>3</sup>                   | 1    | 9     | 5     | 1292 | 1.52  | 2.31     | 31.42  | 0.19     | -0.32    |
| Plant height <sup>4</sup> (cm)              | 10   | 38    | 22.3  | 1321 | 4.8   | 20.11    | 20.13  | -0.06    | -        |
| Canopy width <sup>5</sup> (cm)              | 11   | 90    | 47    | 1321 | 13.10 | 171.67   | 27.91  | 0.37     | 0.79     |
| No. leaves/plant <sup>6</sup>               | 8    | 328   | 106   | 1293 | 48.5  | 2352     | 46     | 1.29     | 3.03     |
| Terminal leaflet length <sup>7</sup> (mm)   | 7    | 124   | 61    | 1293 | 11.80 | 139.20   | 19.21  | 0.34     | 2.14     |
| Terminal leaflet width <sup>8</sup> (mm)    | 3    | 72    | 28    | 1293 | 6.44  | 41.48    | 23.02  | 0.82     | 4.34     |
| Petiole length <sup>9</sup> (cm)            | 1.2  | 34    | 15.1  | 1293 | 39.46 | 1556     | 26.12  | 0.69     | 1.94     |
| No. stems/plant <sup>10</sup>               | 1    | 20    | 8     | 1284 | 2.14  | 4.58     | 24.85  | 0.06     | 0.45     |
| No. branches/stem <sup>10</sup>             | 2    | 12    | 4     | 1284 | 1.22  | 1.48     | 28.38  | 0.67     | 2.28     |
| No. nodes/stem <sup>10</sup>                | 2    | 25    | 12    | 1284 | 3.90  | 15.19    | 33.04  | 0.68     | 0.56     |
| Internode length <sup>10</sup> (mm)         | 3    | 21    | 11    | 876  | 2.5   | 6.11     | 21.55  | 0.21     | 0.86     |
| Pod length <sup>11</sup> (mm)               | 5    | 37    | 20    | 1284 | 3.92  | 15.37    | 19.97  | 0.38     | 0.58     |
| Pod width <sup>11</sup> (mm)                | 5    | 22    | 13    | 1284 | 2.40  | 5.77     | 17.69  | 0.23     | 0.44     |
| Shell thickness <sup>12</sup> (mm)          | 0.1  | 2     | 0.35  | 1275 | 0.21  | 0.05     | 61.7   | 2.5      | 9.3      |
| Shell percentage <sup>13</sup> (%)          | 5    | 90    | 29.7  | 1256 | 9.93  | 98.57    | 33.42  | 1.49     | 4.96     |
| Seed length (mm)                            | 7    | 18.0  | 11.8  | 1260 | 1.5   | 2.11     | 12.25  | 0.16     | 0.65     |
| Seed width (mm)                             | 6.2  | 12.5  | 9.3   | 1260 | 0.97  | 0.95     | 10.45  | -0.04    | 0.12     |
| No. pods/plant <sup>14</sup>                | 10   | 201   | 23    | 1381 | 22.49 | 505.75   | 97.78  | 2.38     | 8.76     |
| No. seeds/pod <sup>15</sup>                 | 1    | 2.0   | 1.11  | 1262 | 0.16  | 0.03     | 14.86  | 2.57     | 8.38     |
| Weight of 100 seeds (g)                     | 1    | 98.00 | 42.44 | 1266 | 15.64 | 244.62   | 36     | 0.41     | 0.52     |
| Seed yield/plant <sup>16</sup> (g)          | 0.03 | 97.00 | 11.51 | 1262 | 12.57 | 157.92   | 109.22 | 2.36     | 7.49     |
| Virus resistance <sup>17</sup>              | 1    | 8.0   | 3.6   | 1320 | 1.5   | 2.24     | 41.08  | 0.42     | -0.21    |
| Cercospora disease resistance <sup>18</sup> | 1    | 7.0   | 2.15  | 1320 | 1.04  | 1.09     | 48.57  | 1.30     | 2.55     |

\* Number of observations.

- <sup>1</sup> It was observed that plants of a given accession sometimes flowered several days apart. As a result, data from accessions with very few plants may not be statistically accurate. In general, stunted or less vigorous plants flowered later.
- <sup>2</sup> Days from planting to maturity of about 90% of the plants. Maturity is indicated by uniform browning and drying of the foliage.
- <sup>3</sup> Rated 10 weeks after planting, on a scale of 1-9, index 1 was assigned to stunted or poorly developed plants, while index 9 was given to very vigorous plants.
- <sup>4</sup> The distance from ridged ground level, to the tip of the central leaflets, 11 weeks after planting.
- <sup>5</sup> Average diameter of the foliar crown of single plants, 11 weeks after planting.
- <sup>6</sup> Average, counted on a sample of 3 plants, 11 weeks after planting.
- <sup>7</sup> Average length of the median leaflet blade, measured on leaf, at the 2nd node.
- <sup>8</sup> Average width of the median leaflet blade, measured on leaf at the 2nd node.
- <sup>9</sup> Measured from the stem node to the junction of the 3 leaflets.
- <sup>10</sup> Average, determined on a 3-plant sample.
- <sup>11</sup> Average, after harvesting.
- <sup>12</sup> Average, after harvesting and drying of the pods.
- <sup>13</sup> The ratio of shell weight/entire pod weight, determined after pod drying.
- <sup>14</sup> The average, determined on a 3-plant sample, after harvesting.
- <sup>15</sup> This figure was obtained by dividing the total no. of seeds by the total no. of pods on a 3-plant sample.
- <sup>16</sup> The seeds, obtained from a 3-plant sample, were threshed from air-dried pods.
- <sup>17</sup> Infection by viruses naturally present in the field, was visually rated on a scale of 1-9. Index 1 was assigned to accessions without, or with very little, virus infection. Accessions severely attacked by viruses were indexed as 9.
- <sup>18</sup> Plants growing in field were visually evaluated for leaf spots caused by *Cercospora* spp. The 1-9 scale was used, with index 1 being assigned to accessions free of leaf spots, and index 9 to those heavily infected by the fungi.

**Pod length**

Accessions with pods longer than 30 mm:

- TVSU 258, 472, 637, 669, 839, 948, 1076, 1285, 1348, 1366.

Accessions with pods shorter than 12 mm:

- TVSU 126, 175, 201, 542, 559, 596, 611, 521, 626, 676, 755, 814, 862, 977, 1062, 1068.

**Pod width**

Accessions with pod width greater than 20 mm:

- TVSU 82, 213, 426, 549, 585, 669, 1362.

**Pod shape**

Pod shape was visually rated, using the following scale:

1 = pod almost spherical

2 = pod pointed at one end, and round at the other

3 = pod pointed at one end, with a hook at the other

4 = pod pointed at both ends.

Distribution of the accessions over the different types of pod shape was 10, 81, 7.5 and 1.5%, respectively, for groups 1, 2, 3 and 4.

**Pod texture**

A visual rating of pod texture took place after harvesting, according to the following scale:

1 = smooth pod

2 = slightly grooved pod

3 = moderately grooved pod

4 = heavily grooved pod.

The distribution of the accessions over the four types of pod texture was 2, 13, 70.5 and 14.5% for groups 1, 2, 3 and 4, respectively.

**Pod colour**

A visual rating of pod colour took place after harvesting and drying, according to the following scale:

1 = yellowish-brown

2 = brown

3 = reddish dark brown.

The distribution of the accessions over the three colour groups was 81, 16 and 3% for groups 1, 2 and 3, respectively.

**Shell thickness**

Accessions with shells thicker than 1 mm:

- TVSU 575, 1271, 1276, 1278, 1283, 1285, 1291, 1320, 1336, 1362, 13674, 1377, 1378, 1461.

Accessions with shells thinner than 0.12 mm:

- TVSU 269, 300, 383, 615, 754, 774, 790, 799, 826, 873, 909, 919, 924, 935, 1068, 1092, 1126, 1190, 1195, 1210.

**Shell percentage**

Accessions with more than 70% shell:

- TVSU 181, 219, 262, 362, 428, 451, 558, 1252, 1253, 1328.

Accessions with less than 10% shell:



- TVSU 613, 804, 809, 823, 931, 1200, 1269.

#### **Seed length**

Accessions with seed length greater than 16 mm:

- TVSU 22, 1076, 1124, 1133, 1144, 1220, 1225.

Accessions with seed length less than 4 mm:

- TVSU 1050, 1233, 1237, 1251.

#### **Seed width**

Accessions with seed width equal to or greater than 12 mm:

- TVSU 561, 1143, 1220, 1240.

Accessions with seed width less than 7 mm:

- TVSU 123, 239, 249, 676, 969, 978, 985, 1050, 1232, 1429, 1251, 1252, 1255.

#### **Seed shape**

Seed shape was rated using the following index:

1 = round

2 = oval

3 = flat at one end.

Distribution of the accessions over the three types of seed shape was 30, 60 and 10% for groups 1, 2 and 3, respectively.

#### **Testa pattern**

Nine testa patterns were observed in the collection. These patterns contained in the bambara groundnut descriptors are shown in Fig. 24. Frequency distribution for testa pattern is shown in Fig. 18.

#### **Eye pattern**

In total, eight eye patterns were identified in the collection, reported in the bambara groundnut descriptors booklet, as shown in Fig. 25. Frequency distribution for eye pattern is shown in Fig. 19.

#### **Ground colour of testa and eye**

The colour of the seed testa and eye was assessed using the Munsell colour charts. Subsequently, the range of colours was subdivided into 19 groups. This grouping is presented in detail in the bambara groundnut descriptors. About 55% of the accessions had a creamy seed coat, while up to 86% had a dark brown eye.

#### **Pigmentation around the eye**

About 47% of the accessions had pigmentation around the seed eye, while the remaining 53% did not. These two groups were designated by the symbols '+' and '0', respectively.

#### **Number of pods per plant**

Accessions with 100 pods/plant or more:

- TVSU 173, 372, 380, 855, 935, 938, 963, 1057, 1086, 1108, 1223, 1231, 1244, 1254, 1316.

#### **Number of seeds per pod**

Accessions with 1.81 to 2 seeds per pod:

- TVSU 142, 253, 260, 714, 993, 1065, 1128, 1189, 1193, 1196, 1283, 1284, 1449.

#### **Weight of 100 seeds**

Accessions with a 100-seed weight higher than 85 g:

- TVSU 1, 22, 36, 176, 366, 572, 613, 864, 916, 1076, 1201, 1327, 1337, 1341, 1346, 1351.

Accessions with a 100-seed weight less than 10 g:

- TVSU 49, 81, 185, 194, 219, 270, 440, 472, 799, 1082, 1253, 1301, 1303, 1311, 1329, 1334, 1368, 1378.

#### **Seed yield per plant**

Accessions with seed yield equal to or higher than 60 g/plant:

- TVSU 119, 173, 515, 613, 688, 702, 840, 870, 879, 880, 922, 924, 938, 949, 1023, 1034, 1061, 1231, 1244, 1254, 1279, 1347, 1378.

#### **Virus resistance**

As can be seen from Fig. 26, about 11% of the accessions were assigned the index 1.

#### **Cercospora disease resistance**

Nearly 27% of the accessions had very little, or no, leaf spots (see Fig. 27).

#### **Correlation among selected characters**

The correlation matrix in Annex A helps to determine pairs of characters that vary in the same or opposite directions. It is a useful guide, especially for plant breeders who may want to associate a set of traits in their selection programmes. Correlations between pairs of characters are reliably significant, when the absolute values of the coefficient are greater than 0.20. Some of the relationships discovered are discussed below.

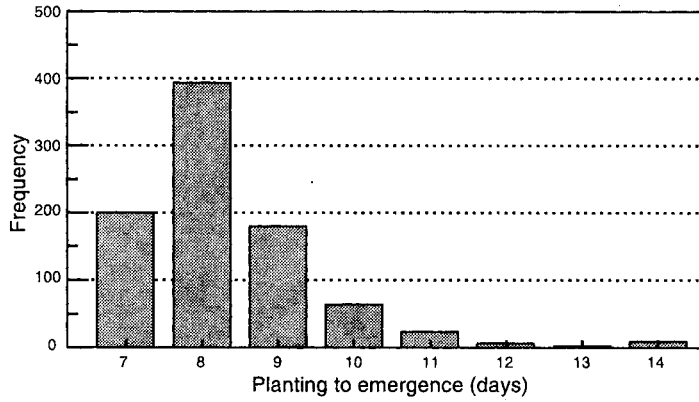
The characters most strongly correlated with yield per plant (YLD) were the number of pods per plant (POD), shell thickness (SHL), number of leaves per plant (LPP), and weight of 100 seeds (SWT). The correlations were all positive, and these traits were obviously also positively correlated with each other.

Plants with more stems, branches or nodes matured later. This is indicated by the positive correlation between days to maturity (DMT), and the number of stems, branches or nodes. In fact the latter three characters are highly positively correlated. The negative correlations between DMT and Cercospora or virus indexes provided evidence that diseased plants matured earlier. A negative correlation was also revealed between DMT and SWT, indicating that small-seeded plants matured later.

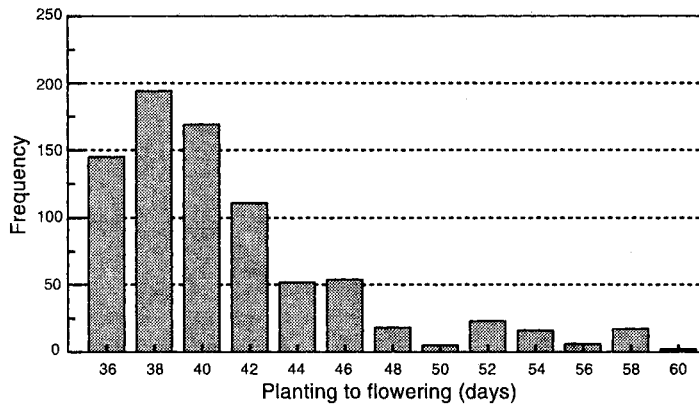
The number of days to 50% flowering was only positively correlated with MAT. The number of seeds per pod (SPP) could be an important character to consider, but it was not significantly associated with most of the selected traits. Plants with short petioles tended to have more seeds per pod.

### **Conclusions**

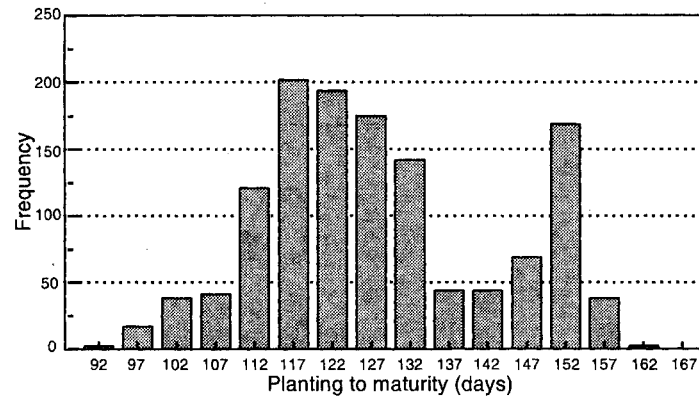
The characterization and evaluation of the bambara groundnut collection at IITA revealed an enormous agromorphological diversity, which can be used for crop improvement. Nevertheless, the agromorphological diversity should be confirmed by molecular and genetic studies. The germplasm materials as well as all related data are available to all potential users at the Genetic Resources Unit of the Institute. It is hoped that national agricultural research services in Africa will build upon this initial work on bambara groundnut to develop strategies for the crop's adoption, improvement and use.



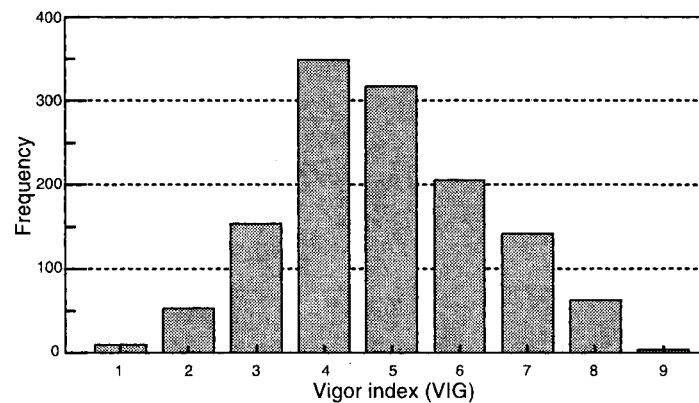
**Fig. 1.** Frequency distribution for days to emergence (EMG).



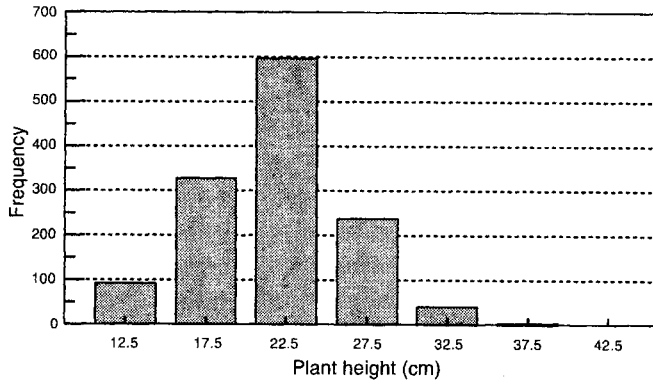
**Fig. 2.** Frequency distribution for days to 50% flowering (HFL).



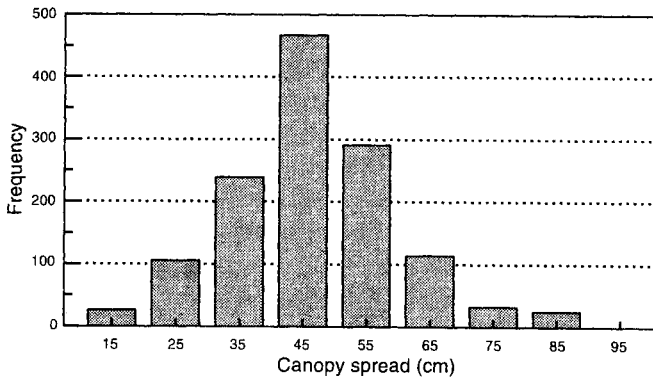
**Fig. 3.** Frequency distribution for days to maturity (DMT).



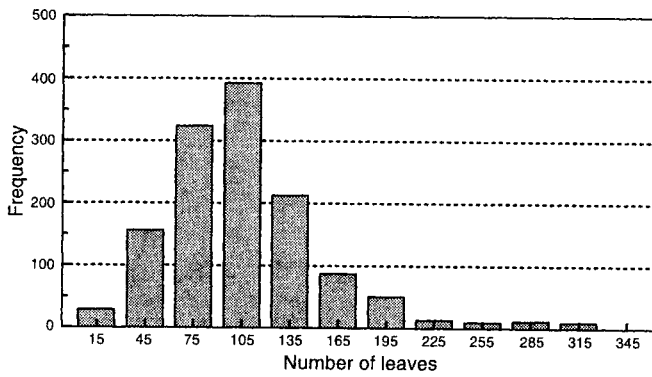
**Fig. 4.** Frequency distribution for vigor index (VIG).



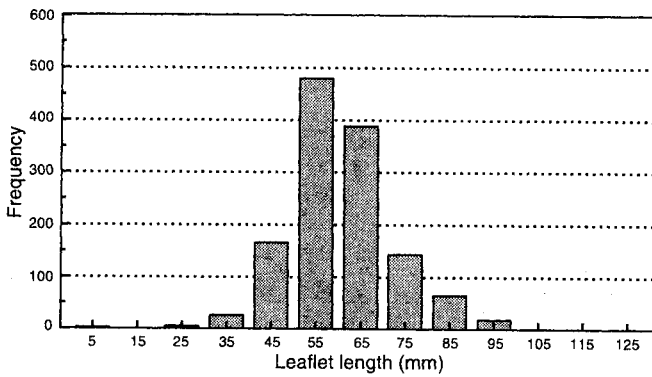
**Fig. 5.** Frequency distribution for plant height (PHT).



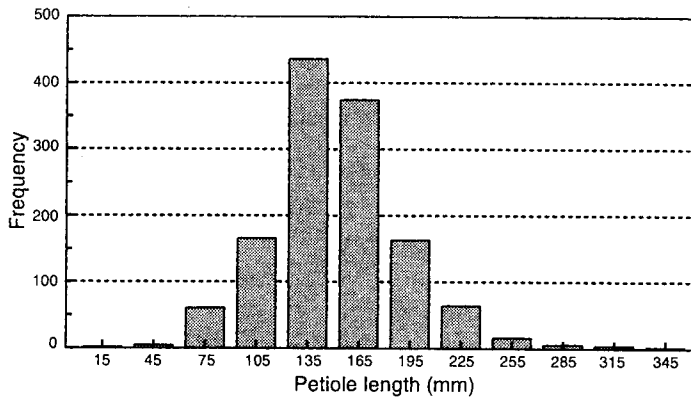
**Fig. 6.** Frequency distribution for canopy spread (SPR).



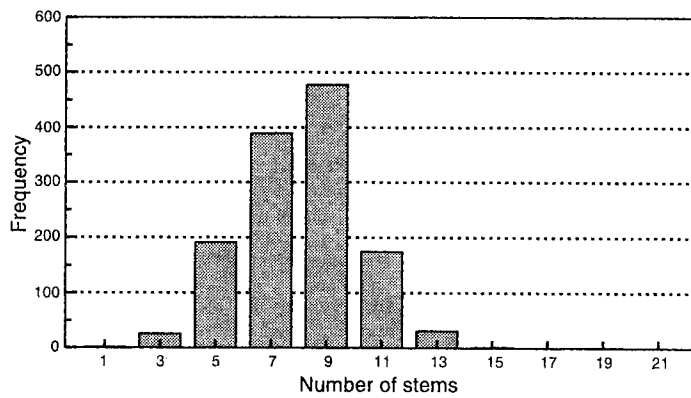
**Fig. 7.** Frequency distribution for number of leaves per plant (LPP).



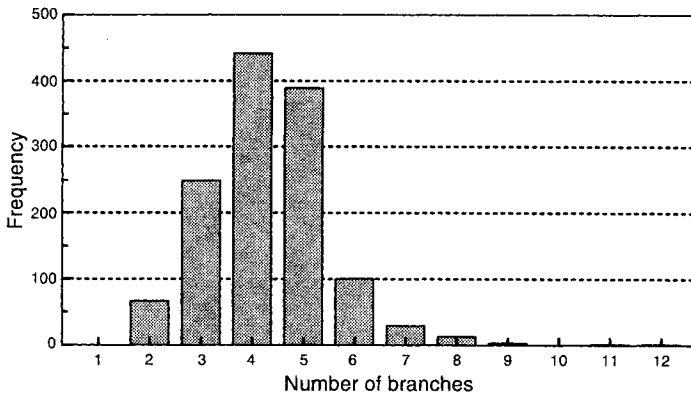
**Fig. 8.** Frequency distribution for terminal leaflet length (TLL).



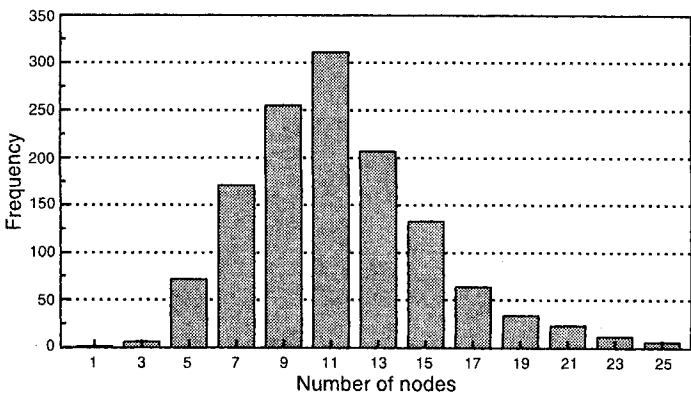
**Fig. 9.** Frequency distribution for petiole length (PTL).



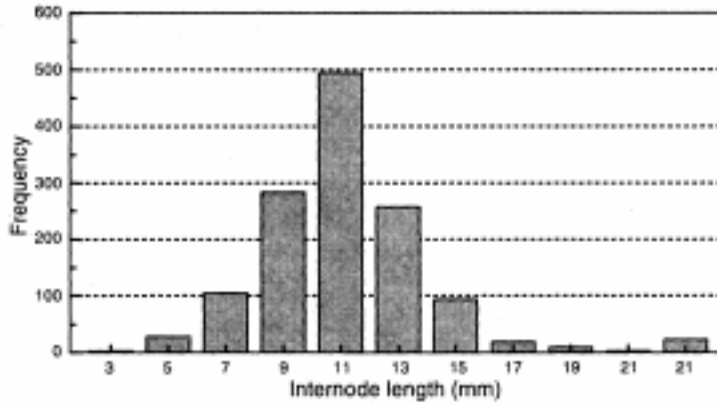
**Fig. 10.** Frequency distribution for stems per plant (STM).



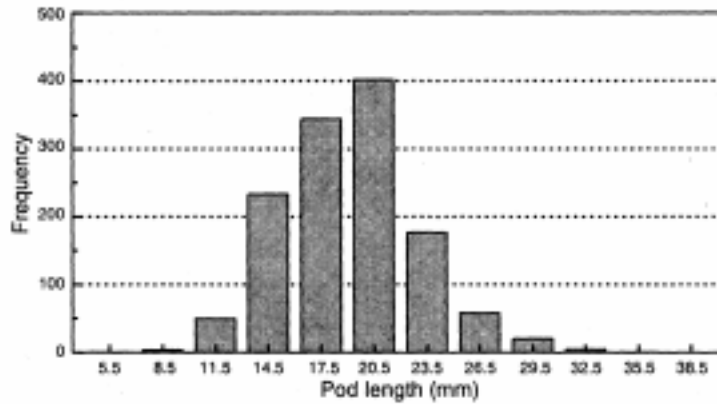
**Fig. 11.** Frequency distribution for number of branches per stem (BRC).



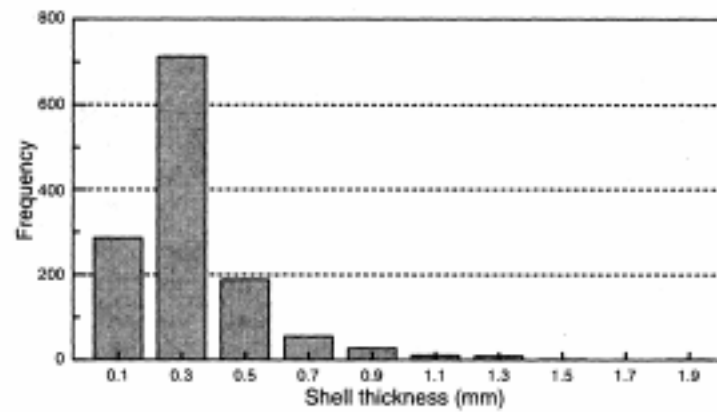
**Fig. 12.** Frequency distribution for number of nodes per stem (NOD).



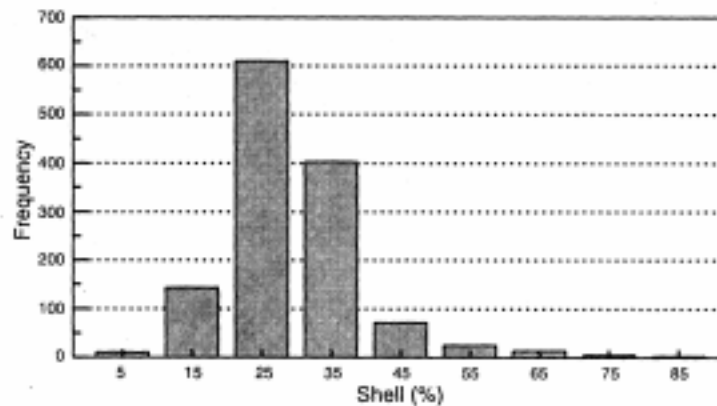
**Fig. 13.** Frequency distribution for internode length (INL).



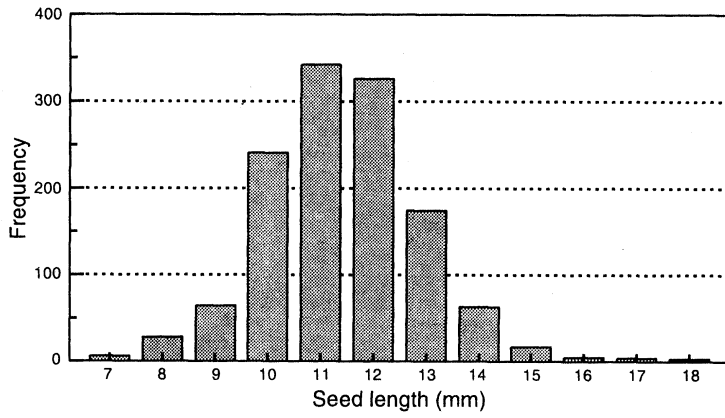
**Fig. 14.** Frequency distribution for pod length (PDL).



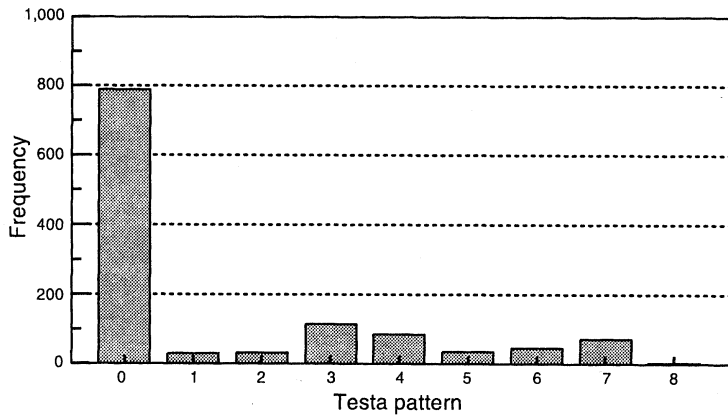
**Fig. 15.** Frequency distribution for shell thickness (SHL).



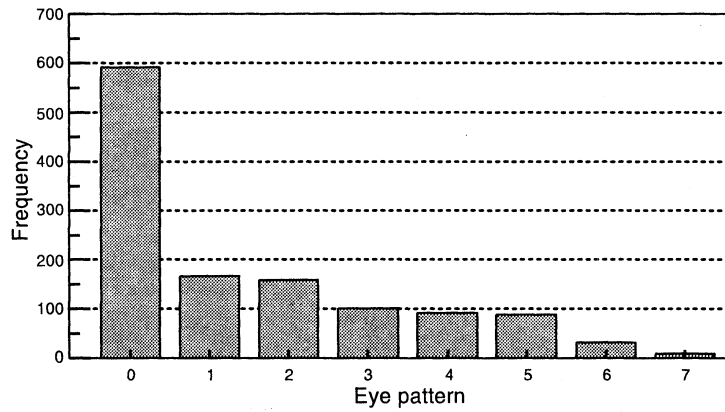
**Fig. 16.** Frequency distribution for shell percentage (SHP).



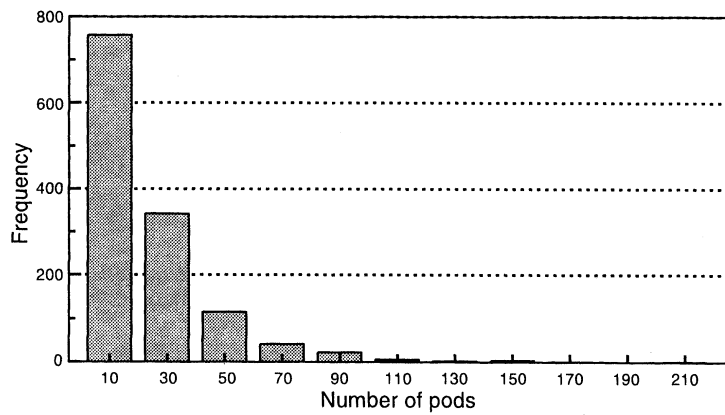
**Fig. 17.** Frequency distribution for seed length (SDL).



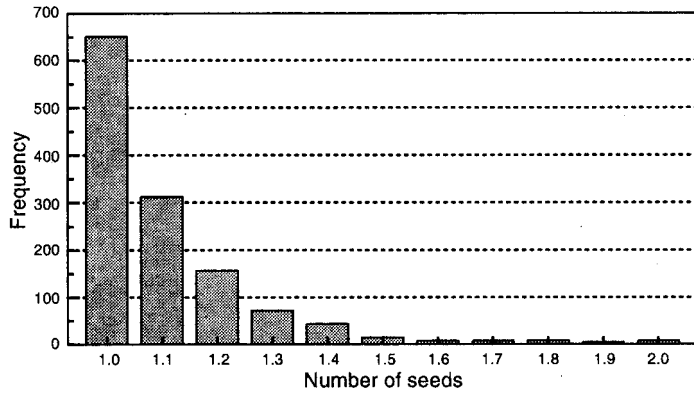
**Fig. 18.** Frequency distribution for testa pattern (TPA).



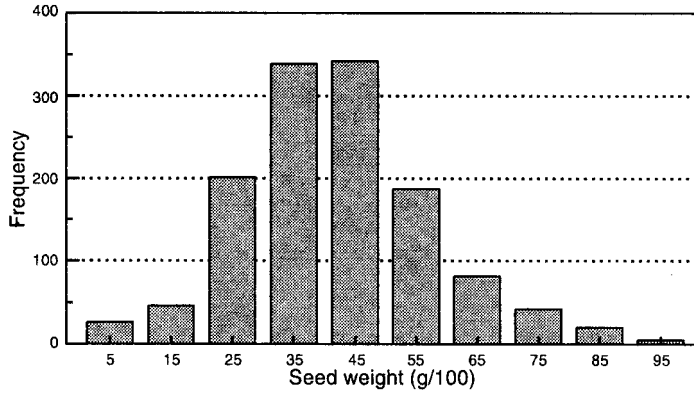
**Fig. 19.** Frequency distribution for eye pattern (EPA).



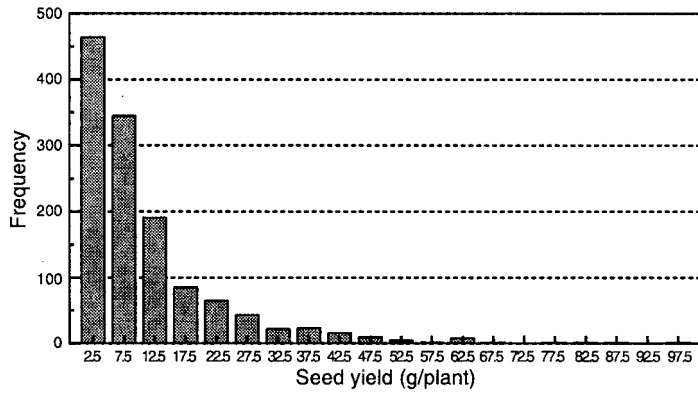
**Fig. 20.** Frequency distribution for number of pods per plant (POD).



**Fig. 21.** Frequency distribution for number of seeds per pod (SPP).

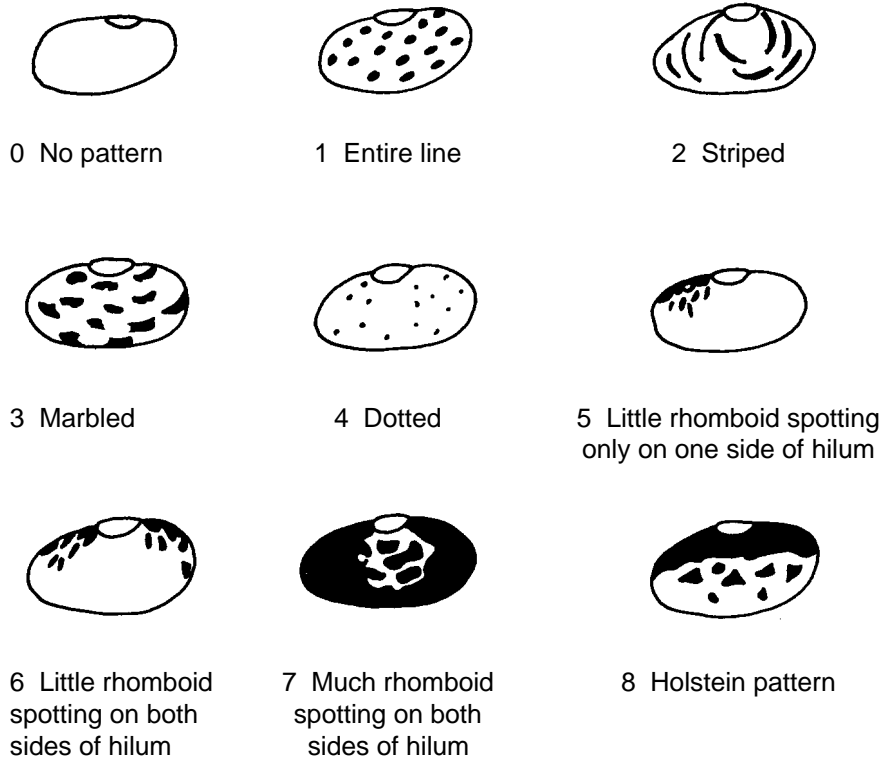


**Fig. 22.** Frequency distribution for seed weight (SWT).

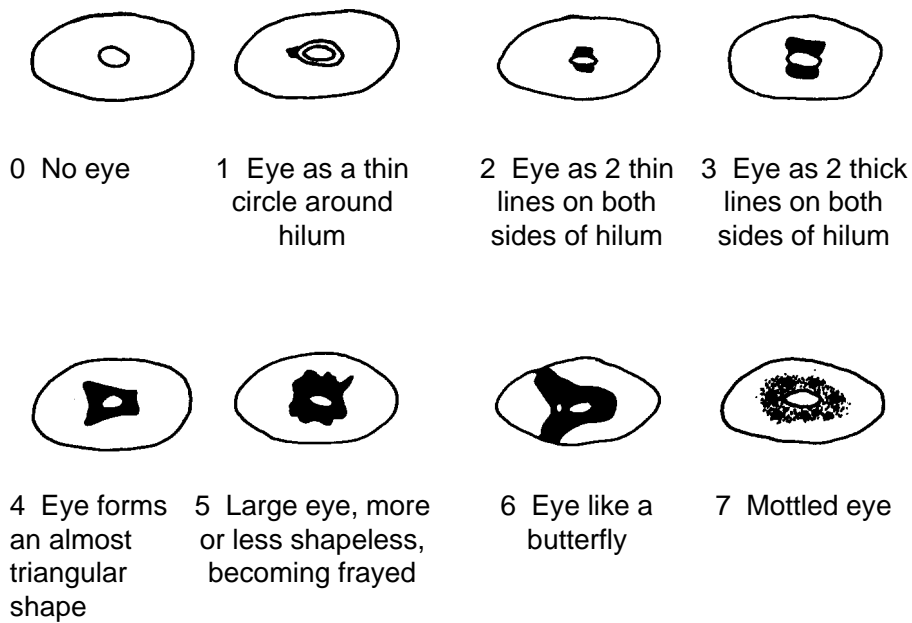


**Fig. 23.** Frequency distribution for seed yield per plant (YLD).





**Fig. 24.** Kinds of testa pattern.



**Fig. 25.** Kinds of eye pattern.

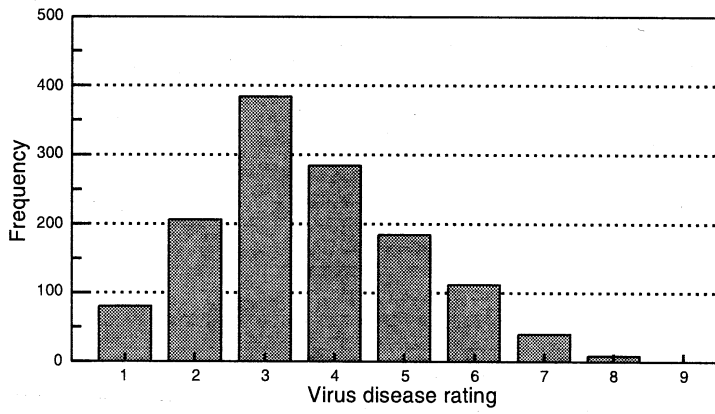


Fig. 26. Frequency distribution for virus disease incidence.

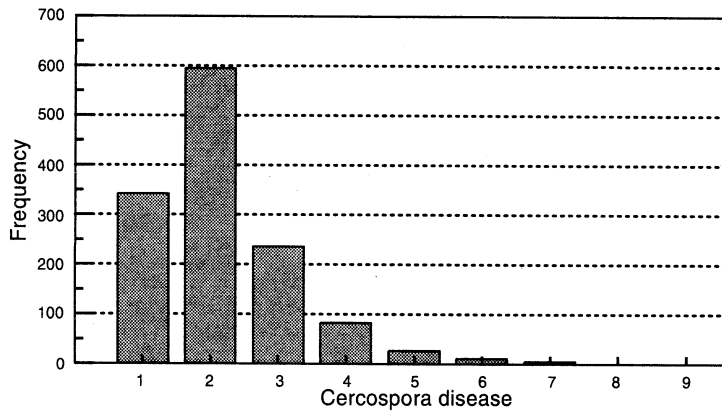


Fig. 27. Frequency distribution for cercospora disease incidence (CER).

Annex A. Pearson correlation coefficients

| PHT*  | SPR   | STM   | BRC   | NOD   | INL   | POD   | PDT   | PDL   | PDW   | SHL   | SPP   | SWT   | YLD   | VIG   | LPP   | TLL   | TLW   | PTL   | LSP   | GHB   | CER   | VIR   | DMT   | PHT   | SPR  | STM  | BRC  | NOD  | INL  | POD  | PDT  | PDL  | PDW  | SHL  | SPP  | SWT  | YLD  |      |
|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| 0.61  | 0.66  | 0.27  | 0.21  | 0.27  | 0.22  | 0.22  | 0.08  | 0.18  | 0.18  | 0.16  | -0.03 | 0.11  | 0.09  | 0.09  | 0.12  | 0.14  | 0.13  | 0.12  | -0.04 | 0.05  | -0.07 | -0.12 | -0.01 | 0.08  | 0.15 | 0.02 | 0.01 | 0.05 | 0.04 | 0.30 | 0.03 | 0.10 | 0.08 | 0.09 | 0.88 | 0.13 |      |      |
| 0.42  | 0.59  | 0.25  | 0.16  | 0.24  | 0.21  | 0.36  | 0.08  | 0.16  | 0.15  | 0.27  | -0.04 | 0.15  | 0.12  | 0.42  | 0.59  | 0.25  | 0.16  | 0.24  | -0.06 | 0.19  | -0.12 | -0.27 | 0.78  | 0.36  | 0.36 | 0.25 | 0.74 | 0.37 | 0.75 | 0.69 | 0.25 | 0.33 | 0.33 | 0.30 | 0.30 | 0.30 | 0.30 |      |
| 0.45  | 0.57  | 0.19  | 0.12  | 0.19  | 0.22  | 0.27  | 0.13  | 0.27  | 0.28  | 0.37  | 0.00  | 0.23  | 0.14  | 0.45  | 0.57  | 0.19  | 0.12  | 0.19  | -0.02 | 0.26  | -0.18 | -0.39 | 0.13  | 0.33  | 0.36 | 0.29 | 0.25 | 0.37 | 0.75 | 0.69 | 0.25 | 0.33 | 0.33 | 0.30 | 0.30 | 0.30 | 0.30 |      |
| 0.49  | 0.56  | 0.18  | 0.13  | 0.19  | 0.22  | 0.24  | 0.13  | 0.31  | 0.28  | 0.29  | 0.01  | 0.24  | 0.17  | 0.49  | 0.56  | 0.18  | 0.13  | 0.19  | 0.02  | 0.26  | -0.11 | -0.27 | 0.78  | 0.36  | 0.36 | 0.29 | 0.25 | 0.37 | 0.75 | 0.69 | 0.25 | 0.33 | 0.33 | 0.30 | 0.30 | 0.30 | 0.30 |      |
| 0.70  | 0.77  | 0.33  | 0.21  | 0.33  | 0.31  | 0.24  | 0.14  | 0.23  | -0.15 | 0.09  | -0.00 | 0.07  | 0.05  | 0.70  | 0.77  | 0.33  | 0.21  | 0.33  | -0.02 | 0.26  | -0.11 | -0.27 | 0.78  | 0.36  | 0.36 | 0.29 | 0.25 | 0.37 | 0.75 | 0.69 | 0.25 | 0.33 | 0.33 | 0.30 | 0.30 | 0.30 | 0.30 |      |
| -0.14 | -0.19 | -0.01 | -0.02 | -0.04 | -0.05 | -0.07 | -0.05 | -0.16 | 0.18  | -0.09 | 0.00  | 0.07  | 0.05  | -0.14 | -0.19 | -0.01 | -0.04 | -0.04 | 0.00  | 0.07  | -0.07 | -0.14 | -0.01 | 0.08  | 0.15 | 0.02 | 0.05 | 0.04 | 0.30 | 0.03 | 0.10 | 0.08 | 0.09 | 0.88 | 0.13 | 0.13 |      |      |
| 0.42  | 0.50  | 0.26  | 0.19  | 0.26  | 0.21  | 0.08  | 0.09  | 0.17  | 0.18  | 0.11  | 0.00  | 0.07  | 0.05  | 0.42  | 0.50  | 0.26  | 0.19  | 0.26  | 0.00  | 0.07  | -0.07 | -0.14 | -0.01 | 0.08  | 0.15 | 0.02 | 0.05 | 0.04 | 0.30 | 0.03 | 0.10 | 0.08 | 0.09 | 0.88 | 0.13 | 0.13 |      |      |
| -0.17 | -0.27 | -0.12 | -0.06 | -0.11 | -0.10 | -0.23 | -0.04 | -0.07 | -0.08 | -0.09 | 0.00  | -0.07 | -0.07 | -0.17 | -0.27 | -0.12 | -0.06 | -0.11 | 0.00  | -0.07 | -0.07 | -0.14 | -0.01 | 0.08  | 0.15 | 0.02 | 0.05 | 0.04 | 0.30 | 0.03 | 0.10 | 0.08 | 0.09 | 0.88 | 0.13 | 0.13 | 0.13 |      |
| -0.36 | -0.39 | -0.18 | -0.16 | -0.18 | -0.12 | -0.31 | 0.08  | -0.08 | 0.08  | -0.11 | 0.02  | -0.14 | -0.01 | -0.36 | -0.39 | -0.18 | -0.16 | -0.18 | 0.02  | -0.07 | -0.07 | -0.14 | -0.01 | 0.08  | 0.15 | 0.02 | 0.05 | 0.04 | 0.30 | 0.03 | 0.10 | 0.08 | 0.09 | 0.88 | 0.13 | 0.13 | 0.13 |      |
| 0.19  | 0.13  | 0.33  | 0.22  | 0.23  | 0.15  | -0.05 | 0.04  | -0.05 | 0.23  | 0.13  | -0.02 | 0.11  | 0.08  | 0.19  | 0.13  | 0.33  | 0.22  | 0.23  | 0.02  | 0.07  | -0.07 | -0.14 | -0.01 | 0.08  | 0.15 | 0.02 | 0.05 | 0.04 | 0.30 | 0.03 | 0.10 | 0.08 | 0.09 | 0.88 | 0.13 | 0.13 | 0.13 |      |
|       | 0.78  | 0.36  | 0.29  | 0.32  | 0.22  | 0.23  | 0.11  | 0.19  | 0.23  | 0.13  | -0.02 | 0.11  | 0.08  | 0.19  | 0.13  | 0.33  | 0.22  | 0.23  | 0.02  | 0.07  | -0.07 | -0.14 | -0.01 | 0.08  | 0.15 | 0.02 | 0.05 | 0.04 | 0.30 | 0.03 | 0.10 | 0.08 | 0.09 | 0.88 | 0.13 | 0.13 | 0.13 |      |
|       |       | 0.36  | 0.25  | 0.37  | 0.30  | 0.14  | 0.12  | 0.14  | 0.21  | -0.06 | -0.02 | 0.16  | 0.15  | 0.21  | -0.06 | -0.02 | -0.02 | -0.02 | 0.00  | 0.07  | -0.07 | -0.14 | -0.01 | 0.08  | 0.15 | 0.02 | 0.05 | 0.04 | 0.30 | 0.03 | 0.10 | 0.08 | 0.09 | 0.88 | 0.13 | 0.13 | 0.13 |      |
|       |       |       | 0.74  | 0.69  | 0.25  | 0.09  | 0.09  | 0.13  | 0.18  | 0.10  | -0.04 | -0.02 | 0.05  | 0.18  | 0.10  | 0.09  | 0.09  | 0.13  | 0.09  | 0.04  | 0.07  | -0.07 | -0.14 | -0.01 | 0.08 | 0.15 | 0.02 | 0.05 | 0.04 | 0.30 | 0.03 | 0.10 | 0.08 | 0.09 | 0.88 | 0.13 | 0.13 | 0.13 |
|       |       |       |       |       | 0.38  | 0.18  | 0.17  | 0.20  | 0.25  | 0.04  | -0.04 | -0.02 | 0.05  | 0.18  | 0.10  | 0.09  | 0.13  | 0.20  | 0.25  | 0.04  | 0.07  | -0.07 | -0.14 | -0.01 | 0.08 | 0.15 | 0.02 | 0.05 | 0.04 | 0.30 | 0.03 | 0.10 | 0.08 | 0.09 | 0.88 | 0.13 | 0.13 | 0.13 |
|       |       |       |       |       |       | 0.18  | 0.11  | 0.18  | 0.20  | 0.17  | -0.03 | 0.05  | 0.04  | 0.20  | 0.11  | 0.17  | 0.20  | 0.25  | 0.04  | 0.07  | -0.07 | -0.14 | -0.01 | 0.08  | 0.15 | 0.02 | 0.05 | 0.04 | 0.30 | 0.03 | 0.10 | 0.08 | 0.09 | 0.88 | 0.13 | 0.13 | 0.13 |      |
|       |       |       |       |       |       |       | -0.01 | 0.28  | 0.60  | 0.64  | -0.02 | 0.29  | 0.10  | 0.32  | 0.17  | 0.26  | 0.29  | 0.32  | 0.04  | 0.07  | -0.07 | -0.14 | -0.01 | 0.08  | 0.15 | 0.02 | 0.05 | 0.04 | 0.30 | 0.03 | 0.10 | 0.08 | 0.09 | 0.88 | 0.13 | 0.13 | 0.13 |      |
|       |       |       |       |       |       |       |       |       | 0.60  | 0.18  | -0.05 | 0.48  | 0.08  | 0.60  | 0.18  | 0.26  | 0.29  | 0.32  | 0.04  | 0.07  | -0.07 | -0.14 | -0.01 | 0.08  | 0.15 | 0.02 | 0.05 | 0.04 | 0.30 | 0.03 | 0.10 | 0.08 | 0.09 | 0.88 | 0.13 | 0.13 | 0.13 |      |
|       |       |       |       |       |       |       |       |       |       | 0.18  | -0.03 | 0.07  | 0.08  | 0.60  | 0.18  | 0.26  | 0.29  | 0.32  | 0.04  | 0.07  | -0.07 | -0.14 | -0.01 | 0.08  | 0.15 | 0.02 | 0.05 | 0.04 | 0.30 | 0.03 | 0.10 | 0.08 | 0.09 | 0.88 | 0.13 | 0.13 | 0.13 |      |
|       |       |       |       |       |       |       |       |       |       |       | -0.03 | 0.07  | 0.08  | 0.60  | 0.18  | 0.26  | 0.29  | 0.32  | 0.04  | 0.07  | -0.07 | -0.14 | -0.01 | 0.08  | 0.15 | 0.02 | 0.05 | 0.04 | 0.30 | 0.03 | 0.10 | 0.08 | 0.09 | 0.88 | 0.13 | 0.13 | 0.13 |      |
|       |       |       |       |       |       |       |       |       |       |       |       | 0.07  | 0.08  | 0.60  | 0.18  | 0.26  | 0.29  | 0.32  | 0.04  | 0.07  | -0.07 | -0.14 | -0.01 | 0.08  | 0.15 | 0.02 | 0.05 | 0.04 | 0.30 | 0.03 | 0.10 | 0.08 | 0.09 | 0.88 | 0.13 | 0.13 | 0.13 |      |
|       |       |       |       |       |       |       |       |       |       |       |       |       | 0.07  | 0.08  | 0.60  | 0.18  | 0.26  | 0.29  | 0.32  | 0.04  | 0.07  | -0.07 | -0.14 | -0.01 | 0.08 | 0.15 | 0.02 | 0.05 | 0.04 | 0.30 | 0.03 | 0.10 | 0.08 | 0.09 | 0.88 | 0.13 | 0.13 | 0.13 |
|       |       |       |       |       |       |       |       |       |       |       |       |       | 0.07  | 0.08  | 0.60  | 0.18  | 0.26  | 0.29  | 0.32  | 0.04  | 0.07  | -0.07 | -0.14 | -0.01 | 0.08 | 0.15 | 0.02 | 0.05 | 0.04 | 0.30 | 0.03 | 0.10 | 0.08 | 0.09 | 0.88 | 0.13 | 0.13 | 0.13 |
|       |       |       |       |       |       |       |       |       |       |       |       |       | 0.07  | 0.08  | 0.60  | 0.18  | 0.26  | 0.29  | 0.32  | 0.04  | 0.07  | -0.07 | -0.14 | -0.01 | 0.08 | 0.15 | 0.02 | 0.05 | 0.04 | 0.30 | 0.03 | 0.10 | 0.08 | 0.09 | 0.88 | 0.13 | 0.13 | 0.13 |
|       |       |       |       |       |       |       |       |       |       |       |       |       | 0.07  | 0.08  | 0.60  | 0.18  | 0.26  | 0.29  | 0.32  | 0.04  | 0.07  | -0.07 | -0.14 | -0.01 | 0.08 | 0.15 | 0.02 | 0.05 | 0.04 | 0.30 | 0.03 | 0.10 | 0.08 | 0.09 | 0.88 | 0.13 | 0.13 | 0.13 |
|       |       |       |       |       |       |       |       |       |       |       |       |       | 0.07  | 0.08  | 0.60  | 0.18  | 0.26  | 0.29  | 0.32  | 0.04  | 0.07  | -0.07 | -0.14 | -0.01 | 0.08 | 0.15 | 0.02 | 0.05 | 0.04 | 0.30 | 0.03 | 0.10 | 0.08 | 0.09 | 0.88 | 0.13 | 0.13 | 0.13 |
|       |       |       |       |       |       |       |       |       |       |       |       |       | 0.07  | 0.08  | 0.60  | 0.18  | 0.26  | 0.29  | 0.32  | 0.04  | 0.07  | -0.07 | -0.14 | -0.01 | 0.08 | 0.15 | 0.02 | 0.05 | 0.04 | 0.30 | 0.03 | 0.10 | 0.08 | 0.09 | 0.88 | 0.13 | 0.13 | 0.13 |
|       |       |       |       |       |       |       |       |       |       |       |       |       | 0.07  | 0.08  | 0.60  | 0.18  | 0.26  | 0.29  | 0.32  | 0.04  | 0.07  | -0.07 | -0.14 | -0.01 | 0.08 | 0.15 | 0.02 | 0.05 | 0.04 | 0.30 | 0.03 | 0.10 | 0.08 | 0.09 | 0.88 | 0.13 | 0.13 | 0.13 |
|       |       |       |       |       |       |       |       |       |       |       |       |       | 0.07  | 0.08  | 0.60  | 0.18  | 0.26  | 0.29  | 0.32  | 0.04  | 0.07  | -0.07 | -0.14 | -0.01 | 0.08 | 0.15 | 0.02 | 0.05 | 0.04 | 0.30 | 0.03 | 0.10 | 0.08 | 0.09 | 0.88 | 0.13 | 0.13 | 0.13 |
|       |       |       |       |       |       |       |       |       |       |       |       |       | 0.07  | 0.08  | 0.60  | 0.18  | 0.26  | 0.29  | 0.32  | 0.04  | 0.07  | -0.07 | -0.14 | -0.01 | 0.08 | 0.15 | 0.02 | 0.05 | 0.04 | 0.30 | 0.03 | 0.10 | 0.08 | 0.09 | 0.88 | 0.13 | 0.13 | 0.13 |
|       |       |       |       |       |       |       |       |       |       |       |       |       | 0.07  | 0.08  | 0.60  | 0.18  | 0.26  | 0.29  | 0.32  | 0.04  | 0.07  | -0.07 | -0.14 | -0.01 | 0.08 | 0.15 | 0.02 | 0.05 | 0.04 | 0.30 | 0.03 | 0.10 | 0.08 | 0.09 | 0.88 | 0.13 | 0.13 | 0.13 |
|       |       |       |       |       |       |       |       |       |       |       |       |       | 0.07  | 0.08  | 0.60  | 0.18  | 0.26  | 0.29  | 0.32  | 0.04  | 0.07  | -0.07 | -0.14 | -0.01 | 0.08 | 0.15 | 0.02 | 0.05 | 0.04 | 0.30 | 0.03 | 0.10 | 0.08 | 0.09 | 0.88 | 0.13 | 0.13 | 0.13 |
|       |       |       |       |       |       |       |       |       |       |       |       |       | 0.07  | 0.08  | 0.60  | 0.18  | 0.26  | 0.29  | 0.32  | 0.04  | 0.07  | -0.07 | -0.14 | -0.01 | 0.08 | 0.15 | 0.02 | 0.05 | 0.04 | 0.30 | 0.03 | 0.10 | 0.08 | 0.09 | 0.88 | 0.13 | 0.13 | 0.13 |
|       |       |       |       |       |       |       |       |       |       |       |       |       | 0.07  | 0.08  | 0.60  | 0.18  | 0.26  | 0.29  | 0.32  | 0.04  | 0.07  | -0.07 | -0.14 | -0.01 | 0.08 | 0.15 | 0.02 | 0.05 | 0.04 | 0.30 | 0.03 | 0.10 | 0.08 | 0.09 | 0.88 | 0.13 | 0.13 | 0.13 |
|       |       |       |       |       |       |       |       |       |       |       |       |       | 0.07  | 0.08  | 0.60  | 0.18  | 0.26  | 0.29  | 0.32  | 0.04  | 0.07  | -0.07 | -0.14 | -0.01 | 0.08 | 0.15 | 0.02 | 0.05 | 0.0  |      |      |      |      |      |      |      |      |      |

| LPP  | TLL  | TLW  | PTL  | LSP   | GHB   | CER   | VIR   | DMT   | VIG | LPP | TLL | TLW | PTL | LSP | GHB | CER | VIR | DMT | VIG |
|------|------|------|------|-------|-------|-------|-------|-------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 0.52 | 0.45 | 0.52 | 0.63 | -0.15 | 0.37  | -0.10 | -0.37 | -0.02 |     |     |     |     |     |     |     |     |     |     |     |
|      | 0.41 | 0.36 | 0.48 | -0.03 | 0.17  | -0.22 | -0.17 | -0.05 |     |     |     |     |     |     |     |     |     |     |     |
|      |      | 0.68 | 0.58 | -0.11 | 0.27  | -0.22 | -0.29 | -0.05 |     |     |     |     |     |     |     |     |     |     |     |
|      |      |      | 0.55 | -0.29 | 0.39  | -0.13 | -0.30 | -0.09 |     |     |     |     |     |     |     |     |     |     |     |
|      |      |      |      | -0.12 | 0.42  | -0.27 | -0.38 | 0.22  |     |     |     |     |     |     |     |     |     |     |     |
|      |      |      |      |       | -0.21 | -0.04 | 0.07  | 0.13  |     |     |     |     |     |     |     |     |     |     |     |
|      |      |      |      |       |       | 0.00  | -0.17 | 0.09  |     |     |     |     |     |     |     |     |     |     |     |
|      |      |      |      |       |       |       | 0.25  | -0.26 |     |     |     |     |     |     |     |     |     |     |     |
|      |      |      |      |       |       |       |       | -0.15 |     |     |     |     |     |     |     |     |     |     |     |

\* Abbreviations: BRC - no. of branches per stem, CER - Cercospora diseases, DMT - days to maturity, GHB - growth habit, INL - internode length, LPP - no. of leaves per plant, LSP - leaflet shape, NOD - no. of nodes per stem, PDL - pod length, PDT - pod texture, PDW - pod width, PHT - plant height, POD - number of pods per plant, PTL - petiole length, SHL - shell thickness, SPP - no. of seeds per pod, SPR - spreading of canopy, STM - no. of stems per plant, SWT - 100-seed weight, TLL - terminal leaflet length, TLW - terminal leaflet width, VIG - vigour index, VIR - virus diseases, YLD - yield per plant.

## The ORSTOM bambara groundnut collection

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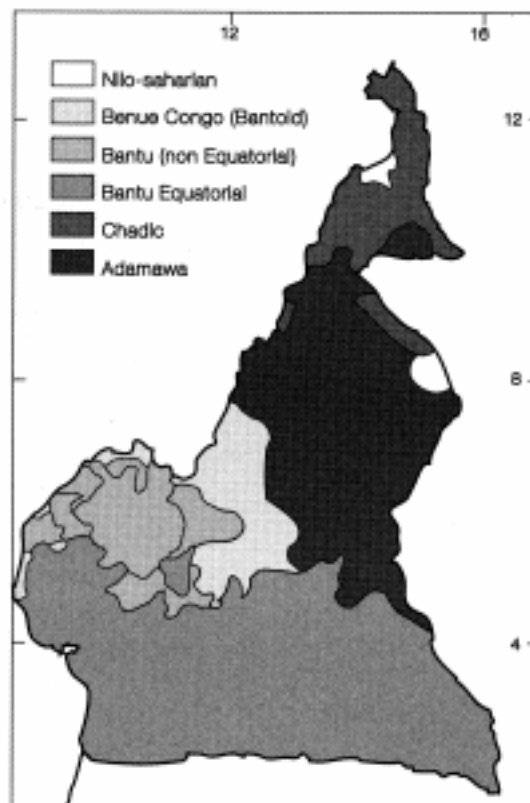
### Introduction

Cameroon lies on the edge of the Guinea Gulf, between West and Central Africa, and crosses both Guinean and Sudanian phytogeographical areas. All along this south-north axis, there is a continuous contrast between lowland and highland areas. Cameroon is the home of numerous ethnic groups, belonging to three different linguistic phyla, and material cultural traits are well conserved. These factors make Cameroon a valuable resource for ethnobotanic studies (Figs. 1, 2 and 3).

The ORSTOM-MESIRES project, 'Agrosystems and cultivated plant diffusion' was initiated and coordinated by Christian Seignobos. Within this project, a study of pulses was undertaken by the authors. Results on cowpea have been published (Pasquet and Fotsó 1994) and results on *Phaseolus* beans are in preparation.



**Fig. 1.** Administrative map of Cameroon.



**Fig. 2.** Linguistic phyla of Cameroon.

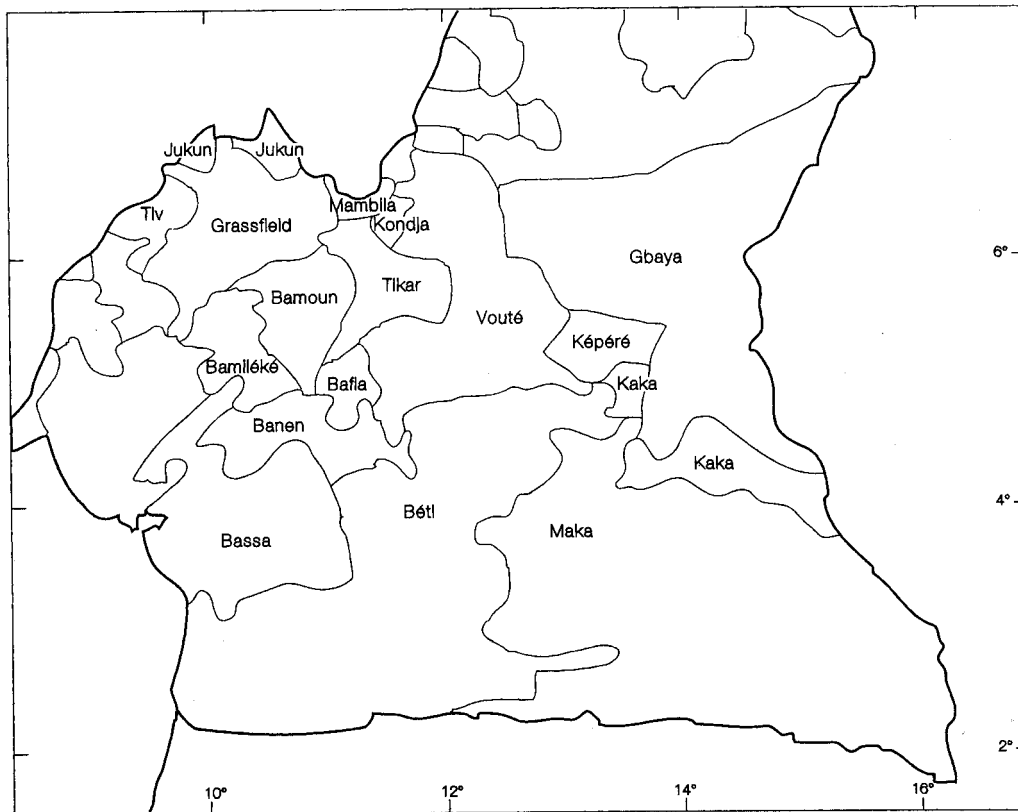


Fig. 3. Ethnic groups in south Cameroon.

### Collecting

Pulse seed samples were collected in 893 localities (but only 702 localities yielded bambara groundnut samples). Collecting trips, lasting more than a total of 6 months, were undertaken by the authors during several dry seasons, between March 1985 and December 1989. The expected collecting density was one locality for every 100 km<sup>2</sup>. However, this was often modified according to ethnolinguistic criteria. At the same time, seed samples were collected by village representatives from the following parapublic organizations:

- SODECOTON, Société de Développement du Coton, in the Nord and Extrême Nord provinces
- NEBBP, Nord-Est Bénoué Basin Project, in Nord province
- MIDENO, Mission de Développement du Nord-Ouest, in Nord-Ouest province
- UCCAO, Union des Coopératives de Café Arabica de l'Ouest, in Ouest province
- SODECAO, Société de Développement du Cacao, in Centre and Sud provinces.

A slight correlation between population density and density of localities sampled was observed. In highly settled areas – the northern Mandara mountains (densely surveyed because of the high variability encountered), southern Diamaré, and west Cameroon highlands – collecting density was high. On the other hand, poorly settled areas such as the southeastern forest areas and the savannas south of Adamaoua had a markedly lower collecting density.

### Condition and size of the bambara groundnut collection

The collection presently includes approximately 1200 cultivated accessions (Table 1) from 702 localities (Fig. 4). However, many accessions are a mix of several different cultivars, which are not yet divided. When the mixed accessions are separated, the collection is expected to exceed 2000.

The collection also includes 60 wild and weedy accessions from 29 localities (Fig. 5). The map shows many more localities with wild and weedy bambara groundnut than previously known through herbarium specimens from K, P and YA herbaria. Wild bambara groundnut seems to be widely distributed, although rare, between 7°N and 11°N.

**Table 1. Origin of Cameroonian bambara groundnut accessions.**

|                                     | No. localities | No. accessions |
|-------------------------------------|----------------|----------------|
| <b>Collecting trips</b>             |                |                |
| Pasquet <i>et al.</i>               | 190            | 298            |
| <b>Parapublic societies surveys</b> |                |                |
| SODECOTON                           | 227            | 533            |
| NEBBP                               | 60             | 111            |
| MIDENO                              | 24             | 26             |
| UCCAO                               | 27             | 32             |
| SODECAO                             | 174            | 219            |
| <b>Total</b>                        | <b>702</b>     | <b>1219</b>    |

#### **Traditional landraces**

According to seed colour, colour pattern, seed size and number of seeds per pod, accessions were assigned to approximately 30 different cultivars. Most cultivars are traditional landraces, but some large-seeded cultivars have been introduced during the last 20 years. No bred varieties seem to have been distributed by agricultural services, either before or after the independence of Cameroon.

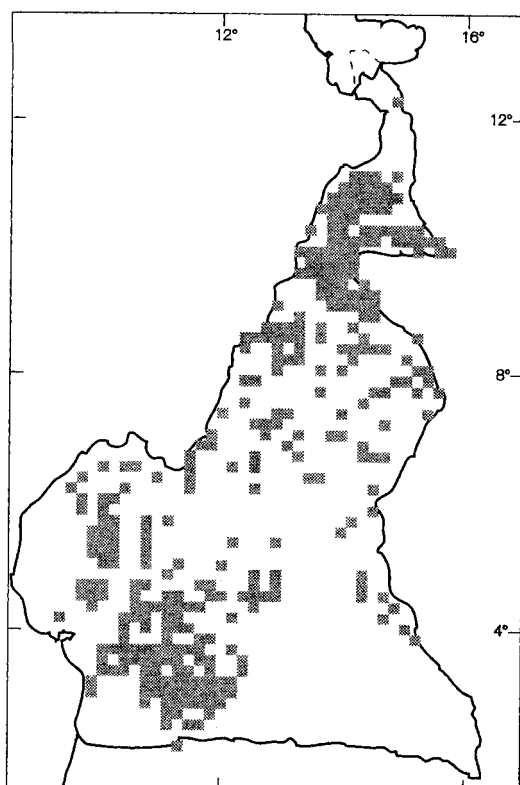
#### **Conservation techniques**

A collection of 1-50 seeds per accession is now housed at ORSTOM, Montpellier (France) in a cold room at 5°C and 20% humidity.

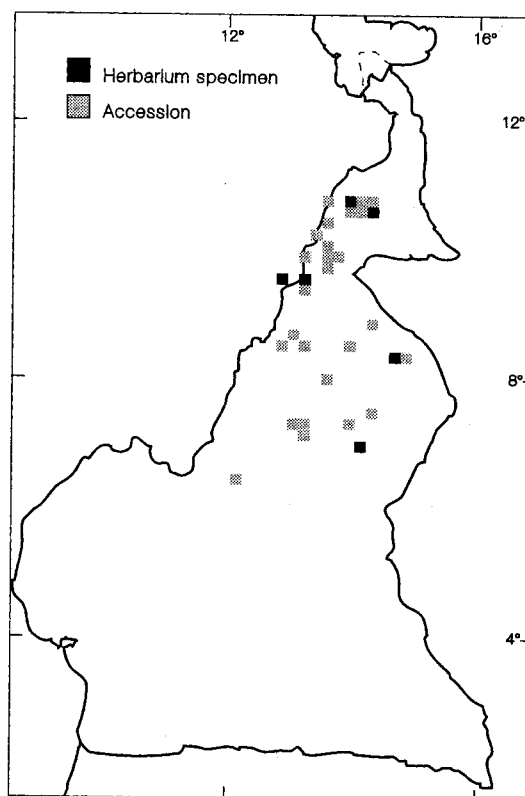
#### **Description of the range of diversity in the collection**

A total of 50 accessions, including two weedy and one wild, were morphologically characterized. Analysis of the data produced the following results (see Table 2). As expected, the wild and weedy accessions show smaller leaves, smaller seeds (unfortunately, seed size was not accurately recorded), very long internodes and a spreading growth habit.

Most interestingly, cultivated accessions could be split into two distinct groups: a northern group, characterized by 1-seeded pods, and a southern group, characterized by 2-4 seeded pods, as those reported by Russell (1960), a slightly less bushy habit, and more robust plants. This latter group does not seem to have been studied by Begemann (1988a).



**Fig. 4.** Localities where bambara groundnut was sampled.



**Fig. 5.** Wild and weedy bambara groundnut: localities of previously known herbarium specimens and localities of recently collected accessions.

**Table 2.** Characterization results (Pasquet and Fotso, unpublished data)

| Character                   | Accessions |       |             |             |             |
|-----------------------------|------------|-------|-------------|-------------|-------------|
|                             | Wild       | Weedy | North       | South       | West        |
| 1st leaflet length (mm)     | 48.0       | 73.0  | 63.0 ± 7.0  | 64.1 ± 6.1  | 64.5 ± 7.4  |
| 1st leaflet width (mm)      | 9.0        | 18.0  | 18.2 ± 4.6  | 22.0 ± 2.0  | 25.5 ± 1.9  |
| leaflet length (mm)         | 49.0       | 64.0  | 50.5 ± 6.3  | 63.4 ± 4.0  | 59.5 ± 2.7  |
| leaflet width (mm)          | 16.0       | 13.0  | 22.3 ± 2.9  | 33.3 ± 3.6  | 33.6 ± 2.5  |
| petiole length (mm)         | 53.0       | 82.5  | 85 ± 15     | 96 ± 21     | 142 ± 15    |
| 4th internode length (mm)   | 74.5       | 76.0  | 21.1 ± 7.4  | 22.8 ± 2.1  | 28.5 ± 4.0  |
| stem number                 | –          | –     | 6.3 ± 1.5   | 7.2 ± 1.9   | 8.5 ± 1.7   |
| flower length (mm)          | –          | –     | 9.7 ± 0.6   | 10.2 ± 0.4  | 10.8 ± 0.3  |
| flower width (mm)           | –          | –     | 8.38 ± 0.98 | 9.00 ± 0.36 | 9.02 ± 0.48 |
| percentage of 1-seeded pods | 100        | 97.6  | 90.9 ± 9.5  | 53.8 ± 12.8 | 49.8 ± 10.7 |

### Other important issues

The border between the area of cultivation of these groups follows a line south of Adamaoua, which separates the two main areas of Cameroon: the northern (sorghum) area, where only one crop per year is viable, and the southern (maize) area, where two crops may be grown annually. A similar phenomenon is observed with cowpea. To the north of this line, the cultigroups *Biflora* and *Melanophthalma*



(which display low ovule numbers) are found, and to the south, the cultigroup *Unguiculata* (which displays high ovule numbers) (Pasquet and Fotso 1994). As cultigroups *Biflora* and *Melanophthalma* are photosensitive, and *Unguiculata* is photo-independent, it seems reasonable to suppose that the bambara groundnut cultigroups in the northern localities may be photosensitive and those in the south, photo-independent.

This frontier is also a cultural boundary between the Chadic and Adamawa linguistic groups of the north, and the Bantoid and Bantu linguistic groups of the south (Fig. 2). The ethnobotanical and linguistic data gathered suggest that bambara groundnut is associated with Adamawa, Bantoid and Bantu language speakers, and cowpea with the Chadic language speakers (Pasquet and Fotso 1991).

It is also interesting to note the three areas which are more or less devoid of bambara groundnut. There is no bambara groundnut in the flooded plains which surround Lake Chad. In precolonial times, bambara groundnut was imported for consumption, primarily from the Mandara mountains. Bambara groundnut was not cultivated and used by the ethnic groups from southwest Cameroon, perhaps because some of these groups were yam bean cultivators, and other groups relied on hunting for their protein needs. Bambara groundnut was not cultivated by the Béti, who expressed a preference for, and were proud of possessing, peanut. In this area, bambara groundnut cultivation is restricted to the former Bassa area, which was conquered by the Béti a few decades before the colonial period. Legumes are traditionally cultivated by women, and as the Béti kept the Bassa women, the existence of bambara groundnut in this region continues as remnant of the Bassa culture. Bambara groundnut is found throughout the *Lophira alata* forest area, which formed part of the once much more extensive Bassa region (Letouzey 1968).

### **Acknowledgements**

We would like to thank Mr Audebert and Njigi Fouda (SODECAO), Mr Gaudard and Mambou (SODECOTON), Mr Custers, Dewaele and Meurillon (NEBBP), Mr Asah and Parkinson (MIDENO), Mr Piedjou and Mr Simon (UCCAO), who allowed us to carry out the surveys.

The characterizations of bambara groundnut were done within the SODECAO-CCCE 'Nyong et Mfoumou' project. We thank Mr Simon (CCCE), Mr Audebert (Directeur des Opérations Agricoles, SODECAO), Mr Paul Mbida (Directeur de la station de Mengang) and Mr Bernatin Mvondo Nkoe.

We also thank S. Bahuchet, D. Barreteau, M. Dieu, E. Dounias, J.G. Gauthier and Ch. Seignobos for the seed samples they kindly provided.

## Development of the International Bambara Groundnut Database

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### Introduction

#### **Bibliographic information**

A first attempt was made to provide comprehensive information on bambara groundnut (*Vigna subterranea* (L.) Verdc.), previously known as *Voandzeia subterranea* (L.) Thou. ex DC.), when the International Institute of Tropical Agriculture (IITA) published the first bibliography with abstracts of world literature from 1900 to 1978 (IITA 1978). A total of 260 entries were listed, and grouped according to their relevance in (a) general and reference works, (b) agronomy, (c) physiology, growth and development, (d) chemical composition, (e) botany, taxonomy and geographical distribution, (f) genetics and plant breeding, (g) insect pests and control, (h) plant pathology, (i) nutritional studies and (j) other uses.

In addition, IITA provided some specific background information in the areas of crop production, plant breeding, and crop protection, utilization and economics (Begemann 1986a,b; Ng *et al.* 1985). IITA's bibliography was subsequently updated by A. Linnemann (1992). Her revised and updated bibliography comprises some 500 references, mostly annotated, and covers the period up to the year 1992. No regular updating of bambara groundnut bibliographic information has yet been established.

For many years, additional information on the origin of genetic resources collections, and the qualitative and quantitative properties of numerous landraces, has been recorded at numerous research institutions. These records, however, are scattered, and difficult to trace and interpret, partly due to a lack of appropriate communication tools, and partly, to the lack of standardization of the format and content of collections. It was for this reason that central crop databases and standard descriptor lists have been established for many crops (Hazekamp 1995; Knüpffer 1995).

#### **Bambara groundnut descriptors**

In the mid 1980s, F. Begemann and N. Q. Ng proposed standard descriptors. These were accepted and published by IBPGR, IITA and the German Agency for Technical Cooperation (GTZ) (1987), to facilitate the exchange of data and comparison of research results between different germplasm collections. They were structured according to the recommendations of IBPGR, who had by then adopted the following definitions in genetic resources documentation:

- (i) passport (the recording by collectors of accession identifiers and information)
- (ii) characterization (the recording of those characters which are highly heritable, can be easily seen by the eye, and are expressed in all environments)
- (iii) preliminary evaluation (the recording of a limited number of additional traits thought desirable by a consensus of users of the particular crop).

Hence, the bambara groundnut descriptors included passport, characterization and preliminary evaluation, as well as further characterization and evaluation data.

### Data documentation

As IITA's collection can be regarded as the largest collection of this crop, it was crucial to examine the properties of its accessions. With the support of GTZ, IITA undertook a detailed investigation of its collection (Begemann 1988a, 1988b; Goli *et al.* 1991). Based on these trials, in 1985, an initial database was established in ORACLE format. Passport, characterization and evaluation data of 1378 accessions had been recorded.

### Present status of the International Bambara Groundnut Database

The International Bambara Groundnut Database (Fig. 1) was compiled by D. Jiménez Krause and F. Begemann in 1995, by merging data from various sources, the main ones to date being:

- the joint research project between GTZ and the Genetic Resources Unit of IITA (Begemann 1988a)
- the Genetic Resources Unit of IITA (Begemann 1988a; Goli *et al.* 1991)
- the Zambian Bambara Groundnut Improvement Programme at the University of Zambia (UNZA) (Begemann 1990, 1991; Mbewe and Begemann 1990).

The International Bambara Groundnut Database contains:

- passport data on about 2100 accessions, originating from 28 countries
- characterization data on about 1400 accessions
- evaluation data on about 1400 accessions (Fig. 2).

The database is being offered on Internet by the Information Centre for Genetic Resources (IGR) of the Centre for Agricultural Documentation and Information (ZADI) in Bonn, Germany, and is located at the following web site: <http://www.dainet.de/genres/bambara/bambara.htm>. The database can also be obtained from the author on four diskettes as a Foxpro 2.6 application, to be installed in MS Windows (approx. 6MB) (Jiménez Krause 1995). Yet to be included in the database are project, literature and meta data, and updated information on these will have to be provided by members of the new International Bambara Groundnut Network (IBGN). A very limited number of projects are listed in the SPAAR-database, and are available through the same above-mentioned internet web site, or upon request from the author.

### Recommendations

#### Revision of the bambara groundnut descriptors

Based on the experience of using the bambara groundnut descriptors as they are published, some of them seem to be very difficult to follow, i.e. the seed colour and pattern descriptors. The passport data requested seem too numerous to record. Furthermore, the present structure no longer matches the latest IPGRI format (Hazekamp 1995). A revision of the descriptor list is therefore recommended, to consider in particular:

- fewer passport descriptors
- restructuring of the characterization and evaluation data
- a more user-friendly method of describing the seed colour and pattern, including testa and eye, and pigmentation around eye
- the inclusion of some molecular data.

Along these lines, a revised descriptor list has been drafted and circulated among selected experts of the crop.

### Maintenance, development and distribution of the International Bambara Groundnut Database

As the information contained in the International Bambara Groundnut Database is highly relevant to any improvement programme for this crop, it is recommended that the database be maintained, further developed and freely distributed. ZADI is currently offering to develop the database, with the support of all members of the IBGN, and to maintain and distribute it on-line via Internet, and on diskette (Foxpro with distribution kit, or other software). Recently, ZADI has also established the Bambara Groundnut Online Database, which provides for qualified and flexible online searches directly.

### Availability of updated bibliographic information

In order to increase the efficiency of future research activities, it is recommended that up-to-date information on projects and literature be provided. These activities should be seen to be connected to the future development of the International Bambara Groundnut Database. New developments on Internet, which may provide tools for this undertaking, should be investigated.

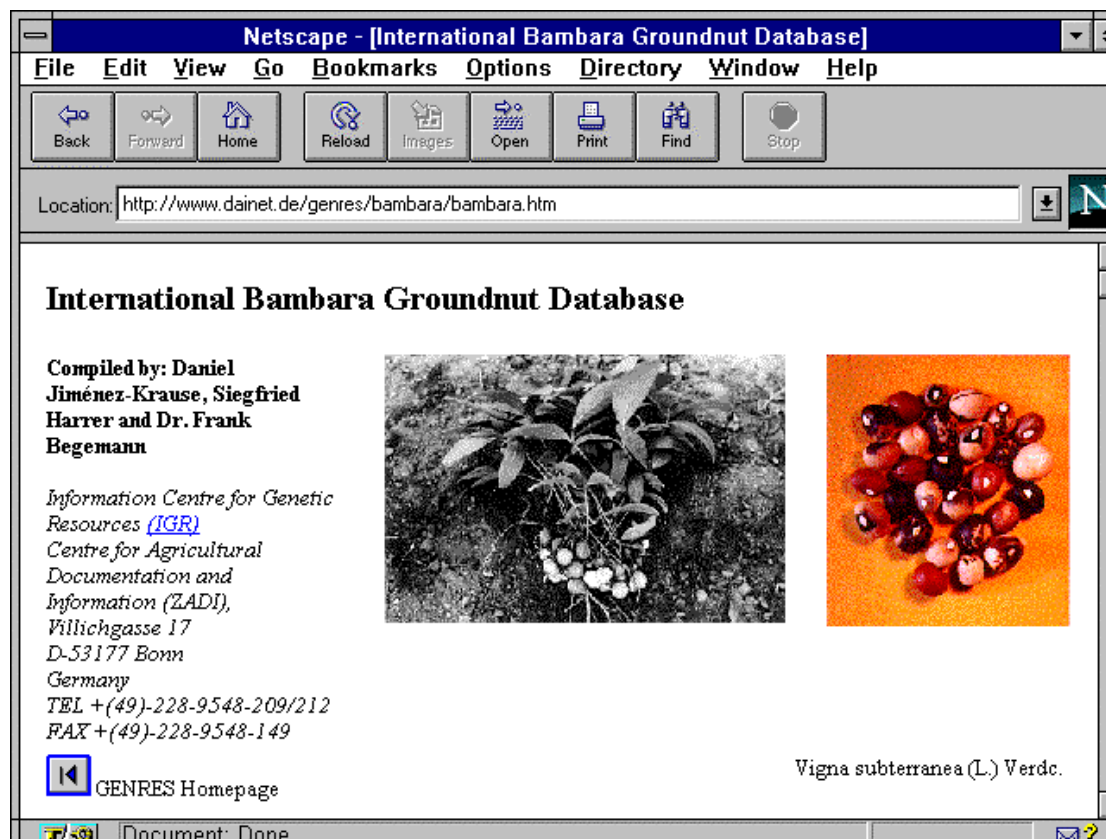


Fig. 1. International Bambara Groundnut Database on the Internet.

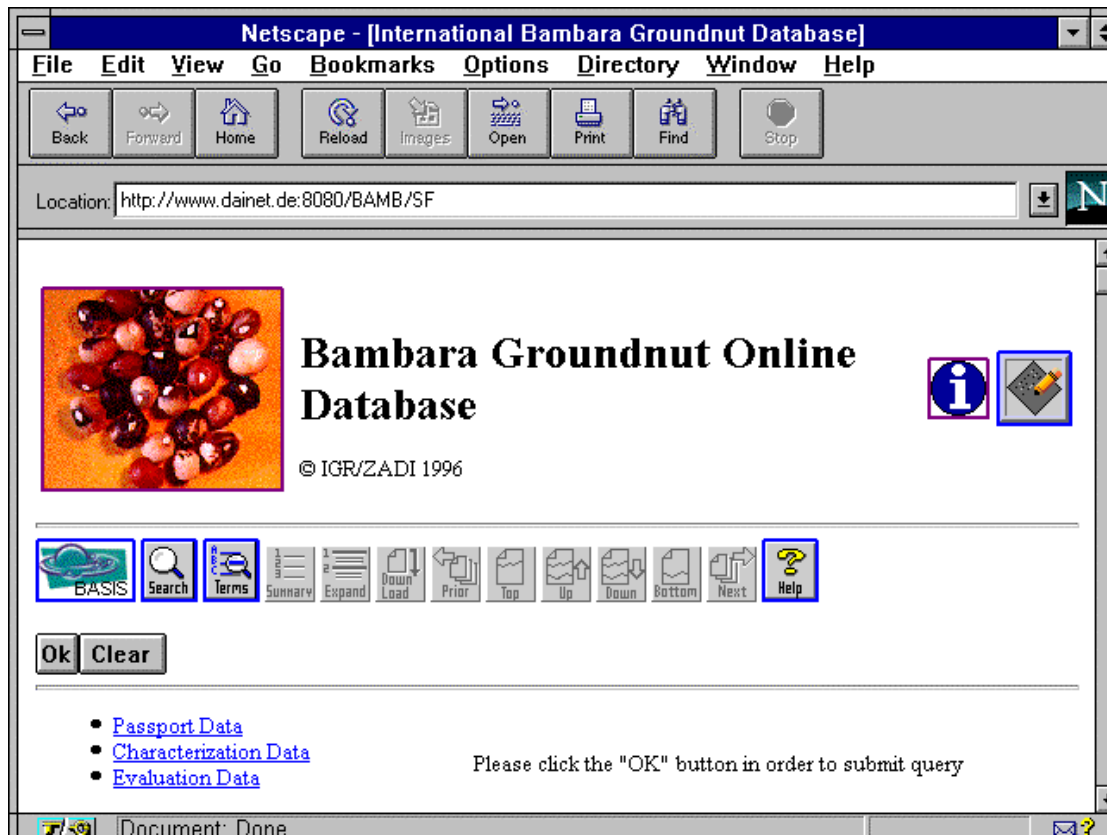


Fig. 2. Bambara Groundnut Online Database on the Internet.

## Breeding bambara groundnut varieties suitable for Zimbabwean conditions

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### Introduction

In the communal and resettlement areas of Zimbabwe, bambara groundnut (*Vigna subterranea* (L.) Verdc.) is the third most important grain legume after peanut (*Arachis hypogaea* L.) and cowpea (*Vigna unguiculata* (L.) Walp). The crop is grown in diverse agro-ecological regions. The regions vary in temperature, rainfall and soil types (Vincent and Thomas 1961). It is principally grown by the communal farmers located in the country's dry natural regions – IV, V and part of region III. These regions are characterized by very low rainfall (less than 400 mm/year), which is unreliable and poorly distributed. The growing seasons are short, usually less than 4 months. Communal farmers grow bambara groundnut mainly for subsistence purposes, and use little or no fertilizer, pesticides or irrigation. Commercial farmers have recently begun to show interest in bambara groundnut and, unlike communal farmers, they grow the crop using these inputs.

Bambara groundnut is grown in both pure and mixed stands. Current production figures of bambara groundnut in the country are quite low. For example, in 1993, a total of 1491 tonnes of unshelled nuts were produced by the large and small-scale commercial farmers, and the resettlement area farmers, with a national average yield of 530 kg/ha. Production figures for the communal area farmers are not yet available, but are likely to be higher than this (CSO 1994).

Bambara groundnut production is limited by shortage of seed and the use of unimproved local races, which are inherently low yielding. Droughts, improper crop management (including delayed planting, low plant populations and poor earthing practices) and pests such as wild animals and aphids also limit production.

Apart from some exploratory work done on bambara groundnut in the early 1920s, the crop was neglected by researchers, as it was considered a 'poor man's crop', of little economic importance (Smartt 1959). Mundy (1932) described bambara groundnut as a pulse of the African native, which despite being a good drought resister, had low yields and hence was uninteresting to European farmers.

In the early 1980s, the Zimbabwean government acknowledged the role played by indigenous crops, especially in the improvement of human nutrition in the marginal areas of the country. Some agronomic research on bambara groundnut was begun in the mid-1980s and a bambara groundnut breeding programme was launched in 1989. Its major objectives are to collect germplasm and to develop high-yielding and well-adapted bambara groundnut varieties for Zimbabwean farmers.

### Germplasm collecting and conservation

A germplasm collecting mission was launched in 1990, aimed at local germplasm in the rural areas of Zimbabwe, through agricultural extension workers located in all of the country's eight provinces. To date, a total of 129 active bambara groundnut germplasm accessions have been gathered. This year, more germplasm was collected from Mbare Musika, a fruit and vegetable market in Harare. Foreign germplasm has

been provided by the International Institute of Tropical Agriculture (IITA), Zambia, South Africa, Tanzania and Wageningen Agricultural University. About 80% of the germplasm held is from local collections. Germplasm for medium-term storage is stored in folding envelopes in a cold room at temperatures below 10°C, while the active germplasm is stored at room temperature. Lack of proper long-term storage facilities has hindered progress in germplasm conservation. However, construction of a plant genetic resources unit at Harare Research Station is currently underway, which should solve this problem.

### **Germplasm characterization**

Characterization of the collected bambara groundnut germplasm for different traits has been done, to assess the range of genetic variation. Accessions or lines with desirable traits are also used in the hybridization programme. Lines have been found to differ in growth habit, flower colour, seed shape, seed colour, eye colour and pattern, seed weight, days to 50% flowering and days to 95% physiological maturity (an example is given in Table 1).

### **Variety development**

Varieties are developed through a modified pure-line breeding method, and through hybridization. Introductions from other countries also add to the germplasm. A schematic diagram showing bambara groundnut germplasm flow is shown in Fig. 1.

### **Variety hybridization**

Individual parental lines for crossing are planted in such a way that their flowering periods coincide. These are grown in asbestos pots at the greenhouse site. As bambara groundnut is a self-pollinating plant, the female parent is made by emasculation. A flower bud is selected and all the neighbouring buds are removed. The selected bud should be big enough to be handled by a pair of forceps, but should not be well developed, because bambara groundnut is cleistogamous (i.e. pollen is shed before the flower opens). A pair of forceps is used to open the bud carefully, and the anthers bearing undeveloped pollen grains are then removed. Maximum care should be taken not to damage the stigma. A fully bloomed flower is used as a source of pollen.

On opening of the fully bloomed flower, a white substance, which is the pollen, can be seen with the naked eye. The style of the flower bearing the pollen grains is carefully removed by a pair of forceps, and the pollen grains are squeezed onto the emasculated female flower. Attempted cross-pollinated buds are identified by a thin copper wire, which is folded around the peg. Earthing is done at 2 days after pollination.

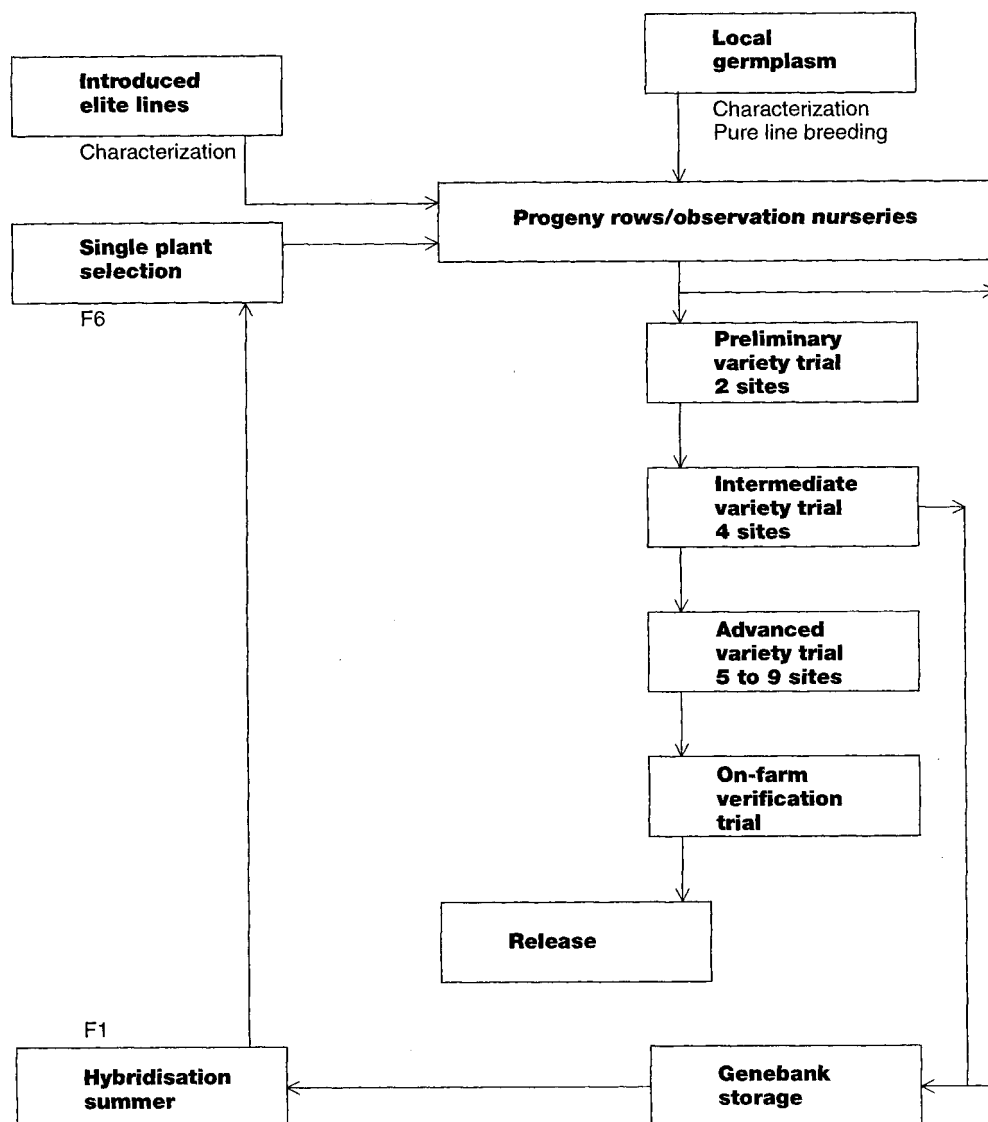
Segregating populations are advanced from  $F_1$  to  $F_5$  through a modified single-seed descent method. Single plant selection is done at  $F_5$  generation, when a high degree of homogeneity is believed to have been achieved. Selection of plants is based on maturity, yield (pods per plant), seed colour and seed size.

Table 1. Characteristics<sup>†</sup> of foreign germplasm accessions.

| Variety            | Growth habit | Plant pigmentation | Days to 50% flowering | Days to 95% maturity | Flower colour | Seed shape | Seed colour | Eye colour  |
|--------------------|--------------|--------------------|-----------------------|----------------------|---------------|------------|-------------|-------------|
| Ankpa              | 2            | G                  | 63                    | 145                  | Y             | 1          | 16          | -           |
| Tali local         | 2            | G                  | 64                    | 133                  | Y             | 2          | 7           | -           |
| Chipata 1          | 1            | G                  | 62                    | 133                  | C             | 1          | 6           | dark brown  |
| Chipata 2          | 2            | P                  | 63                    | 140                  | Y             | 2          | 3           | light brown |
| Yola               | 2            | G                  | 64                    | 139                  | Y             | 2          | 3           | -           |
| Potiskum           | 2            | G                  | 64                    | 137                  | Y             | 1          | 7           | purple      |
| Nubig              | 1            | G                  | 62                    | 133                  | Y             | 2          | 4           | -           |
| Chipata 3          | 1            | G                  | 64                    | 136                  | Y             | 2          | 3           | -           |
| Riga cikum         | 2            | P                  | 63                    | 134                  | C             | 2          | 7           | light brown |
| Pateg stripe brown | 2            | G                  | 65                    | 140                  | Y             | 2          | 7           | -           |
| Tigancury          | 1            | G                  | 65                    | 132                  | Y             | 2          | 7           | -           |
| Mutanda 1          | 1            | G                  | 65                    | 132                  | Y             | 2          | 7           | purple      |

<sup>†</sup> Growth habit (1 = bunch type, 2 = semi-bunch type, 3 = spreading type); Plant pigmentation (G = green, P = purple); Flower colour (Y = yellow, C = creamy); Seed shape (1 = round, 2 = oval); Seed colour (3 = light brownish red, 4 = light brown, 5 = dark brown, 6 = yellow, 7 = cream, 16 = purplish red).





**Fig. 1.** Flow chart of bambara groundnut improvement programme.

#### Handling local germplasm

The local landraces are so heterogeneous that more than 10 different types of bambara groundnut can be found in a single crop. True breeding varieties are developed from the local landraces, through a modified pure-line breeding method. The locally collected seed is initially sorted by seed colour and is then grown in different plots in the field. Within a plot, plants with similar morphological features are selected and grouped to form progenies. These progenies are then grown at Harare Research Station for multiplication purposes. Although diseases are not a major constraint to bambara groundnut production, progenies showing disease symptoms are instantly discarded. Introduced exotic lines and those developed through hybridization are initially evaluated in the same way, in progeny-row plots in the field.

## Germplasm evaluation

Agronomically superior lines from the progenies enter into several stages of testing, conducted at sites located in all the agro-ecological regions of Zimbabwe. These trials are conducted to assess the range of adaptation of the developed varieties. The selected lines from the progenies are first evaluated for yield and other agronomic characteristics, in unreplicated double-row observation plots. They are tested at a high-potential site (Harare Research Station), and a marginal dryland area (Matopos Research Station). Varieties with good agronomic performance in at least one of the two environments progress into the Preliminary Variety Trials (PVT). The PVTs are conducted in 4-row plots, 3 m long. The intra-row spacing is 15 cm; inter-row spacing is 45 cm. The design is a Randomized Complete Block Design (RCBD), replicated twice. The PVTs are conducted on at least two sites. At this stage, selection is based both on reaction to disease, and on the yield potential of the varieties at the two different sites.

The selected lines from PVTs progress to Intermediate Variety Trials (IVT). These are conducted at 4-5 sites, using a RCBD replicated three times. This trial consists of 4 rows per plot, 4.5 m long. Agronomically superior varieties in the IVTs progress into the Advanced Variety Trials (AVT), which are conducted at 5-8 sites. The sites used are chosen to represent all the agro-ecological regions of Zimbabwe. The plots contain 6 rows, with each row being 4.5 m long in a RCBD, with four replications. A few selected varieties (3-5) from the AVTs are tested on-farm. At all testing sites, except Gwebi Variety Testing Centre (GVTC), the trials are conducted under strictly rain-fed conditions. Supplementary irrigation is applied at GVTC, to assess the varieties' full genetic potential. This information is also important to the large-scale commercial farmers, who produce bambara groundnut with many inputs.

### Research activities: 1993/94

In the 1993/94 summer season, a total of 100 progenies made from the local germplasm were evaluated for yield, and some of them were quite promising. A hybridization programme was initiated in the 1994 summer season, and five different crosses were made among six promising bambara groundnut varieties with different seed colour: SA 37 and ZVS-564; BGM 1B and ZVS-564; Variety 10 and ANKPA 4; ZVS-564 and SA 37, and Variety 5 and ANKPA 4.

The crosses yielded poorly, probably owing to the use of clay soil, which compacted and hindered pod development when irrigated. In future, sandy soils will be tried. Ten bambara groundnut lines, including a local variety, were tested in the preliminary variety trial. Two lines, ANKPA 4 and TALI LOCAL, significantly ( $P < 0.05$ ) outyielded the local Variety 10, while the varieties ZVS-580 and CHIPATA 1 compared very favourably with it.

Also in the 1993/94 summer season, 18 experimental varieties, including both foreign and locally developed ones, were evaluated for their yield performance under various environmental conditions in the AVTs. The two sites – Makoholi and Mlezu – are located in low-potential areas, whereas Kadoma, Harare and GVTC are high-potential sites.

In the AVTs, significant differences ( $P < 0.05$ ) were found in the grain yields of the varieties at four sites (Table 2). At Makoholi and Mlezu testing sites, which are marginal rainfall areas, lower mean site yields ( $< 400$  kg/ha) were recorded. In these areas, some of the varieties yielded only  $< 200$  kg/ha. However, some varieties attained reasonable yields at these sites. For example, the variety ZVS-564 yielded

538 kg/ha at Makoholi experimental station, and the variety 3806/90 yielded 811 kg/ha at Mlezu. These results are very good, since the current average yield for the marginal rainfall areas is 80-400 kg/ha.

**Table 2. Bambara groundnut yields (kg/ha) at different sites (advanced variety trial, summer 1993/94).**

| Variety    | Makoholi | Mlezu | Kadoma | Gwebi | Harare | Mean | Rank |
|------------|----------|-------|--------|-------|--------|------|------|
| ZVS-503    | 327      | 272   | 1332   | 3273  | 1302   | 1301 | 12   |
| ZVS-524    | 313      | 397   | 1475   | 2078  | 1740   | 1271 | 14   |
| ZVS-530    | 375      | 133   | 1114   | 3292  | 1448   | 1283 | 13   |
| SA 16      | 353      | 611   | 1324   | 4200  | 1419   | 1683 | 2    |
| ZVS-509    | 308      | 347   | 718    | 2009  | 1119   | 900  | 18   |
| ZVS-391    | 199      | 255   | 996    | 2818  | 1295   | 1112 | 17   |
| ZVS-537    | 399      | 391   | 1157   | 3522  | 1938   | 1590 | 6    |
| ZVS-531    | 207      | 294   | 897    | 2792  | 1231   | 1162 | 15   |
| ZVS-561    | 274      | 347   | 2139   | 2933  | 1732   | 1439 | 8    |
| ZVS-534    | 370      | 161   | 1012   | 3180  | 2228   | 1417 | 9    |
| ZVS-339    | 261      | 321   | 1262   | 2664  | 1126   | 1127 | 16   |
| SA-37      | 255      | 403   | 1905   | 3536  | 2543   | 1728 | 1    |
| ZVS-564    | 538      | 485   | 1809   | 3673  | 1908   | 1682 | 3    |
| SA-28      | 433      | 480   | 2214   | 3025  | 1728   | 1667 | 4    |
| SA-12      | 376      | 281   | 1408   | 3945  | 1291   | 1635 | 5    |
| 3806/90    | 250      | 811   | 1558   | 3323  | 1600   | 1509 | 7    |
| 3804/90    | 188      | 413   | 1119   | 3257  | 1565   | 1308 | 11   |
| Variety 10 | 286      | 103   | 1499   | 3326  | 934    | 1381 | 10   |
| Mean       | 317      | 364   | 1385   | 3158  | 1564   | 1400 | –    |
| SE         | –        | 93    | 229    | 386   | 135    | –    | –    |
| CV         | 46       | 44    | 29     | 21    | 15     | –    | –    |
| LSD 5%     | –        | 267   | 659    | 1109  | 389    | –    | –    |

The testing sites in wetter agro-ecological zones had good mean yields: 1385 kg/ha and 1564 kg/ha at Kadoma and Harare Research Stations, respectively. The variety SA 28 attained the highest yield at Kadoma (2214 kg/ha), but SA 37 was highest at Harare Research Station (2543 kg/ha). GVTC, also situated in wetter zones, received supplementary irrigation, and had a very high site mean yield (3158 kg/ha). Yields recorded at this site ranged from 2009 kg/ha (ZVS-509) to 4200 kg/ha (SA 16).

In the high-potential areas, in both dryland and irrigated blocks, yields were impressive, given that the average yield for the commercial farmers located in these regions is less than 1000 kg/ha (CSO 1994). The highest yield (4200 kg/ha), obtained at GVTC, compares very favourably with the highest yields obtained from other grain legumes such as soybean (4500 kg/ha) and groundnuts (4300 kg/ha). The current market price of bambara groundnut is three times that of soybean and peanuts, which makes it a potentially more profitable crop, in both the commercial and communal farming sectors.

From the results in Table 2, it can be concluded that bambara groundnut is a crop with the potential to produce reasonable yields, averaging 300 kg/ha under marginal conditions and 4000 kg/ha under good environmental conditions. Bambara groundnut can therefore be grown successfully in all agro-ecological regions of Zimbabwe, by both the commercial and the communal farming communities. Table 3 shows some of the agronomic characteristics of the bambara groundnut varieties tested in the AVTs during the 1993/94 summer season.

Compared with peanuts, bambara groundnut had a higher shelling percentage; on average it is about 78%, whereas that of peanuts is 60% (Crop Breeding Institute Annual Reports 1993-94, unpublished data). However, the bambara groundnut crop requires a long period to reach flowering and physiological maturity. On average, it takes 62 days to attain 50% flowering (i.e. when half of the plants in a plot are at full bloom) and 140 days to reach physiological maturity. This is not a desirable characteristic, because of the shorter growing seasons characterizing most of the bambara groundnut growing regions in Zimbabwe.

**Table 3. Agronomic characteristics of bambara groundnut (advanced variety trial, summer 1993/94).**

| Variety    | Percentage stand | Days to 50% flower | Days to 95% maturity | Shelling percentage |
|------------|------------------|--------------------|----------------------|---------------------|
| ZVS-503    | 89               | 62                 | 141                  | 78                  |
| ZVS-524    | 80               | 61                 | 141                  | 82                  |
| AVS-530    | 86               | 62                 | 139                  | 78                  |
| SA-16      | 87               | 61                 | 141                  | 78                  |
| ZVS-509    | 75               | 61                 | 140                  | 76                  |
| ZVS-391    | 83               | 62                 | 141                  | 76                  |
| ZVS-537    | 84               | 63                 | 140                  | 82                  |
| ZVS-531    | 86               | 62                 | 141                  | 76                  |
| ZVS-61     | 82               | 62                 | 140                  | 76                  |
| ZVS-534    | 85               | 61                 | 140                  | 78                  |
| ZVS-339    | 82               | 62                 | 141                  | 80                  |
| SA-37      | 88               | 62                 | 138                  | 82                  |
| ZVS-564    | 83               | 60                 | 139                  | 78                  |
| SA-28      | 82               | 62                 | 139                  | 76                  |
| SA-12      | 84               | 62                 | 142                  | 82                  |
| 3806/90    | 80               | 62                 | 139                  | 74                  |
| 3804/90    | 84               | 61                 | 139                  | 78                  |
| Variety 10 | 82               | 61                 | 141                  | 78                  |
| Mean       | 84               | 62                 | 140                  | 79                  |

### Conclusions

Four high-yielding varieties, capable of producing about 300 kg/ha under marginal rainfall conditions and over 4000 kg/ha in high-rainfall areas, have been identified: SA 16, SA 37, ZVS-564 and 3806/90. These are being tested extensively on-farm before they can be recommended for production by the farmers. Short-duration varieties (TVSU 354, TVSU 1130, TVSU 228, TVSU 158 and TVSU 949) taking less than 100 days to physiological maturity have been identified, and would thus suit Zimbabwe's short growing seasons. Although inherently low yielding, their performance will be improved through a hybridization programme. In the 1995/96 hybridization programme, 10 planned crosses will be made between high-yielding, long-duration and short-duration varieties. While progress has been made in germplasm collecting, germplasm conservation is currently constrained by a lack of proper long-term storage facilities.

## An experiment to cross bambara groundnut and cowpea

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### Introduction

Bambara groundnut (*Vigna subterranea* (L.) Verdc.) belongs to the family *Leguminosae*, subfamily *Papilionoideae*. Recent electrophoretic studies by Howell (1990) confirmed the close relationship between bambara groundnut and several species of the genus *Vigna*. According to Linnemann (1992), the nature and extent of the gene pools in cultigens of the genera *Phaseolus* and *Vigna* were reviewed by Smartt (1981), as indicated by studies of experimental interspecific hybridization. In all cases, a primary gene pool exists which has evolved distinct wild and cultivated subgene pools. For bambara groundnut, no secondary or tertiary gene pools had been identified.

Many authors (Begemann 1988a; Goli *et al.* 1991; IITA 1978; Linnemann 1992) have reported bambara groundnut to be adapted to poor and sandy soils and low precipitation. Hence, bambara groundnut is a crop well suited for the semi-arid areas, such as the savanna regions. Generally, cowpea (*Vigna unguiculata*) seems to require a more humid environment and richer soils than bambara groundnut. Besides, bambara groundnut has been reported to be less susceptible to pest and diseases than cowpea (IITA 1978).

Cowpea is the most widely grown legume in Sub-Saharan Africa. However, bambara groundnut, despite having been marginalized by farmers in recent years, is still of great value to local farming communities. It therefore seems worthwhile to investigate whether or not some valuable characters, i.e. resistance to biotic and abiotic stresses of both crops, could be exchanged. To do so, it was necessary to perform a crossing experiment to determine whether bambara groundnut and cowpea partly belong to the same gene pool and could be crossed easily.

### Materials and methods

Between 1985 and 1987, an experiment was carried out at the International Institute of Tropical Agriculture (IITA), in the glasshouse at the Ibadan campus, to attempt to cross bambara groundnut and cowpea. The accessions used in the experiment were TVU-13677 (cowpea) and TVSU-501 (bambara groundnut); TVU-13677 served as the female plant, and pollen was taken from TVSU-501. The pollination was carried out by hand, without additional inputs.

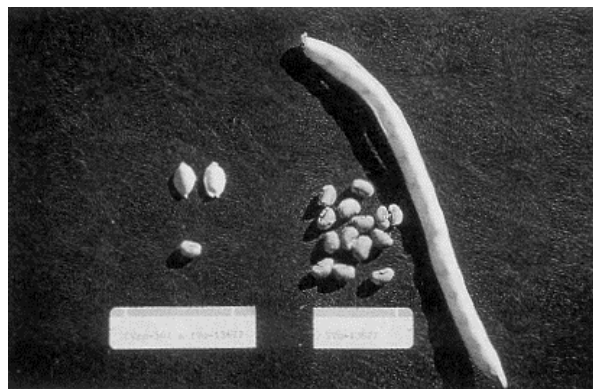
### Results and discussion

The experiment showed that the pollinated flower of the TVU-13677 plant produced an abnormally short pod (approx. 1 cm), with only one seed per pod, while all other flowers of the same plant which had not been pollinated with bambara groundnut pollen produced pods of normal length (approx. 10 cm) (see Fig. 1). Figure 2 shows the pod and harvested seed of the TVU-13677 x TVSU-501 experiment, as well as a long pod with 14 seeds, as produced by the TVU-13677

plant with no bambara groundnut pollination. The seed of the supposed cross shows similar seed colour and pattern as the normal TVU-13677 seeds.

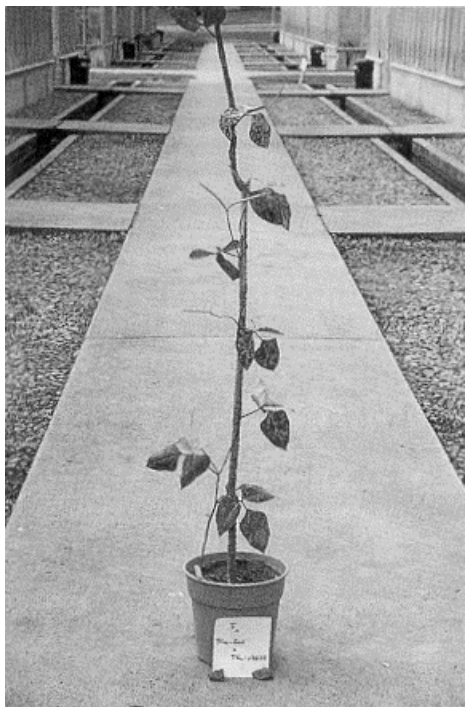


**Fig. 1.** Short pod resulting from cross-pollination.

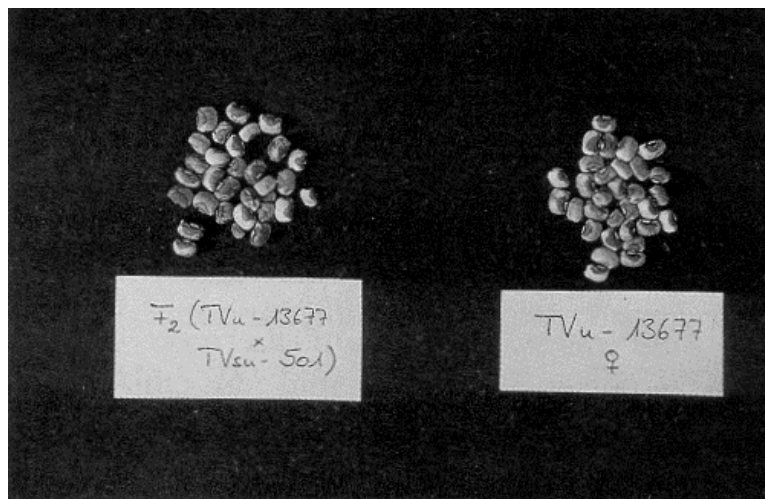


**Fig. 2.** Pod and seeds of TVU-13677 (left) and  $F_1$  crossing (TVU-13677 x TVSU-501, right).

After harvest, the  $F_1$  seed (TVU-13677 x TVSU-501) was planted to test its fertility. It developed a fertile plant which looked very similar to the original TVU-13677. The only agromorphological difference noted was its time to maturity. While TVU-13677 is a 60-day variety, the supposed  $F_1$  cross did not reach maturity at 80 days. Figure 3 shows the still immature plant on the 81st day. The pods and seeds which were later harvested from this attempted  $F_1$  cross looked very similar to those of the TVU-13677, as indicated in Figure 4.



**Fig. 3.**  $F_1$  plant.



**Fig. 4.** Pods and seeds harvested from  $F_1$  cross (left), compared with TVU-13677.

The experiment had to be interrupted at this point because of time and financial constraints, although the trial indicated that crossing of bambara groundnut and cowpea may be feasible, provided that cowpea is used as the female partner and the pollen is taken from bambara groundnut. It was not possible to establish from this experiment whether the cross was successful, however, although the shape and size of the  $F_1$  pod and  $F_1$  seed, as well as the extended time to maturity of the resulting plant, strongly indicated this was the case.

However, using bambara groundnut as the female plant to be pollinated with cowpea pollen, as was attempted by A. Goli in 1986 (pers. comm.), seems to be much more problematic. Part of the difficulty arises from the physical conditions of such an experiment, as the flowers of bambara groundnut are very difficult to trace underground, and are hard to earmark because of their very short internodes, with even more than one flower per node. The results of the trial were in agreement with earlier reports, which had stated a very close relationship between bambara groundnut and other species of the genus *Vigna*. It is nonetheless very surprising that the two crops belong to the same genepool.

### Conclusions and recommendations

If the findings of this trial could be confirmed by other experiments, this would be extremely useful for improvement programmes of the bambara groundnut and the cowpea crops. It is therefore strongly recommended that such an experiment be repeated. The  $F_2$  seeds also could be tested for their viability and used for molecular studies. As the electrophoretic study findings published so far seem insufficient to reveal the genetic diversity of the entire bambara groundnut genepool, some molecular investigations should be undertaken to identify the diversity required for further crosses of the species with cowpea.

If these future crosses are successful, the new possibilities they imply for the improvement programmes of both crops should then be exploited. Doing so would require an analysis of the specific characters of one crop which would be beneficial for the other, e.g. resistances to biotic and abiotic stresses. Furthermore, the possibility of using bambara groundnut as the female plant to be pollinated with cowpea pollen should be further investigated.

## The potential role of NGOs in promoting conservation and use of bambara groundnut

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### Introduction

Since the late 1960s, the countries of Sub-Saharan Africa have been struggling against severe food shortages and the crisis appears to be worsening. A number of factors account for the continent's growing inability to feed its rapidly expanding population. One of these is the erosion of the genetic resources of indigenous African crops, including bambara groundnut. Owing to the recurring droughts in Africa, food insecurity and starvation are constant threats. Researchers have discovered that hunger, malnutrition and household food insecurity are to a large extent caused by poverty, which results from scarce agricultural resources, including agricultural knowledge and its application. This paper discusses the part that non-governmental organizations (NGOs) can play to make these resources available to needy farmers in general.

The paper will specifically discuss the role of NGOs in promoting the conservation and use of crops such as cowpea and bambara groundnut, which are widely grown but largely ignored by most extensionists, researchers, national seed programmes and seed companies. It has been suggested (Diana Callear, pers. comm.) that the best strategy to combat famine is to assist the great majority of the farmers to increase their levels of production and their incomes, as this would increase household food security. It may be easier, and perhaps more lucrative, to identify a famine and provide relief than to address the underlying cause of famine and poverty.

Famine relief also has immediate short-term effects: lives are saved for today, at least (what happens tomorrow is another issue). In most cases, countries that are said to be food sufficient, e.g. India, have high levels of malnutrition. The reasons are that national food availability does not necessarily lead to household food security. The lack of crop diversity in a household might lead to food availability, but an unbalanced diet for the family. The incorporation of grain legumes in the cropping programme of the rural farmers will diversify their protein source.

### Problems encountered in a bid to achieve food security

One of the most crucial factors in crop production is the availability of the appropriate crops and seed when needed. Many reports on individual seed projects and programmes have pointed out the enormous difficulties faced in getting a formal national seed system to provide an effective service to small farmers in marginal, variable environments. Recent studies by Cromwell *et al.* (1992) have confirmed this picture on a wide scale, in developing countries.

The formal sector finds it most profitable to produce hybrid seed, especially vegetable crops. It also concentrates on the seed of crops with high sowing rates (meaning that large quantities will be bought) and high multiplication rate (i.e. more can be produced quickly). The sector, therefore, tends to ignore certain crops that are important to small farmers, such as self-pollinated varieties of cereals and legumes.



These tend to be less profitable for seed companies and face stiff competition from farm-saved seed. This situation is aggravated by the methods and orientation of plant breeding and researchers within the formal agricultural research system. Thus, with regard to both the product required and the distribution system, the formal sector often cannot provide an effective seed service in the marginal, variable environments of developing countries, except for certain 'niche' markets.

The formal seed supply systems, the formal research organizations and the extensionists have all contributed, through the Green Revolution, to the extinction of the more adaptable, drought-tolerant crops, a group which includes millet, sorghum, cowpea, bambara groundnut, chickpea and pigeon pea.

Because of the very limited and erratic nature of rainfall in the semi-arid regions, the high costs of external crop inputs, the unreliability of the agribusiness and the unsustainable nature of alien farming systems in these areas, it is imperative for farmers to develop a low-input-cost farming system that is sustainable. Bambara groundnut is a ubiquitous grain legume, indigenous to Africa. It is primarily grown by peasant farmers, for consumption of the grain. It has an enviable reputation as a hardy crop, owing to its drought tolerance and reasonable yields when grown on poor soil, and therefore has good potential in the semi-arid regions. Both improved and indigenous varieties of bambara groundnut will be adopted and cultivated by smallholders, if the crop is well promoted to them.

Farmers in our country easily adapt to new technologies if they perceive their advantages. Good cases in point are provided by the hybrid maize and 'Moneymaker' tomatoes, planting in rows, planting *Eucalyptus* and the cultivation of burley tobacco, all of which have been introduced in Zimbabwe. If improved varieties of bambara groundnut are advantageous, farmers usually grow them. If, on the other hand, the traditional farmer-managed bambara groundnut varieties are good enough, cultivation of the crop benefits from a viable seed-exchange programme.

Despite existing knowledge of the crop, prudence is called for in its cultivation. If small farmers produce more bambara groundnut than they can consume, and if there is no viable market for this surplus, farmers will be discouraged from cultivating the crop in the future. Such a situation currently exists regarding the adoption of drought-tolerant small grains in Zimbabwe. Any strategy for promoting bambara groundnut needs to address the issue of diverse utilization of the crop.

### NGOs in rural development

The number of development NGOs has increased dramatically during the last decade, and now there are many based in developing countries. An NGO is defined as "any organization that is operationally distinct from government" (ODI 1988). They vary in their historical origins and in their size and significance, compared with other agencies, and the strength of the link with these other agencies. Farrington and Biggs (1990) grouped NGOs in the following categories:

- Service provision, ranging from short-term relief to long-term development.
- Organization-building and local empowerment, working with communities to identify their problems and solve them locally.
- Support and advocacy, including lobbying national and international policy-makers, and providing back-up services, such as research and policy analysis, and information exchange for smaller organizations.

- Volunteer agencies, which are primarily geared to providing volunteer technical assistance to other projects and programmes.

Most NGOs specialized in agriculture base their activities on three premises:

- (i) The existing indigenous knowledge systems of farmers are critical for the success of any initiative.
- (ii) Farmers have the right to be part of the decision-making process in all matters which affect them.
- (iii) Agriculture is but one aspect of development, and it is a means to the end of individuals' development.

### ENDA's experience

ENDA-ZW (Environment and Development Activities in Zimbabwe), as a member of rural development NGOs that specialize in agriculture, adopted an integrated approach to the development of the organizational and individual capacities of the rural people it serves. Its mission statement reads as follows: "ENDA strives to promote and develop opportunities for wealth creation for the rural and urban poor, through sustainable natural resource utilization and the capacity development of Zimbabwean human and institutional resources" (ENDA-ZW 1994). The three most critical issues are sustainability, wealth creation and community participation.

The two agricultural projects which have shown that NGOs can promote the adoption of a technology are ENDA's Seeds Action Project and its Sustainable Agriculture Project. The Seeds Action Project promotes germplasm conservation, both *in situ* and *ex situ*, and seed production by small-scale farmers. The project was started 10 years ago, and its achievements to date are as follows:

- Increased production of local and improved varieties of millets and sorghums in the project areas.
- Small-scale farmers have proved beyond reasonable doubt that they can produce good-quality seed, despite their shared arable areas.
- Farmers can effectively participate and contribute to on-farm characterization.
- Farmers have a defined selection method, which they use when harvesting farm-saved seed.
- Prototype dehullers have been introduced to small-scale farmers, making it easy to process sorghum and millets. This has led to increased use of sorghum and millet products.
- Value-added diverse products of small grains after processing.

The Sustainable Agriculture Project, which is in its third year, promotes soil and moisture conservation techniques and sustainable low-input agricultural practices. On-farm trials are carried out and demonstration plots are established annually. The strength of both projects lies in farmer training, and result and method demonstrations.

### Methods used to promote cultivation and utilization of any crop

ENDA programmes emphasize farmer participation, and stress is therefore placed on a dialogue with farmers. Information is exchanged and assessed, attitudes concerning the introduced or modified technology are noted and misunderstandings that occur during the exchange are quickly identified and rectified. Thus relationships of mutual

respect are built up between farmers and extension agents. ENDA bases its activities on good channels of communication between farmers and its officers, and disseminates information to farmers through:

- Group meetings. These may be divided into
  - (i) information meetings to communicate a specific piece of new information
  - (ii) planning meetings to review a particular problem, suggest a number of solutions, and decide upon a course of action
  - (iii) special-interest meetings to present topics of specific interest to a particular group of people
  - (iv) general meetings, where all general topics affecting the community are discussed.
- Individual visits, usually made as follow-up to group meetings or training sessions to assess the acceptability of issues discussed, and the adoption rate.
- Demonstrations: farmers like to see how a new idea works, and also what effects it can have on increasing their crop production. Both result and method demonstrations are carried out by ENDA officers.
- Field days, to introduce a new idea and/or a new crop, and to stimulate the maximum interest among farmers. These are usually opportunities to hold result and/or method demonstrations.
- Tours: farmers visit farms in other areas to see how the introduced technology works, or to learn of that community's experience of a newly introduced crop.

#### **What effective communication can do in promotion of bambara nut**

In the author's opinion, with effective communication between researchers and extensionists, quite a number of agriculturally oriented or food-security-conscious NGOs would be glad to include any local cultivars or improved varieties of bambara groundnut in their programmes. If a commercial use of bambara can be developed, this would create a reliable and perhaps a viable market for the crop.

Similarities in the uses made of bambara groundnut and cowpea in Africa are well known. Results from a survey on production and utilization of cowpea, conducted in Zimbabwe, suggest that it has the brighter future of the two crops. The survey revealed that, from a total of 145 farming families from 13 districts of six provinces, almost 90% grew and used cowpea.

Bambara groundnut was ranked among the top four most important legumes in SADCC by the grain legume feasibility study (SADCC 1984). However, utilization of grain legumes may be constrained by their limited supply.

#### **Strengths and weaknesses of NGOs**

Compared with formal sector agricultural research and extension institutions, NGOs possess advantages in working together for rural development with small farmers in marginal areas. They are able to respond quickly to local needs, work mainly with the most disadvantaged groups, and are often more participatory than the formal sector. They are independent, and can be flexible in their choice of project, information sources, communication methods, clientele and organizational structure. Furthermore, they can adopt an integrated approach to programmes, which includes attention to the institutional and economic context, as well as to technical factors. In

this respect, NGOs play an important role as bridging organizations, bringing together diverse agents in the development process.

Nonetheless, a number of problems are beginning to emerge. It is becoming clear that the diverse demands placed on NGOs by different clients present almost impossible managerial challenges. It is also unclear whether all NGOs have the time and resources to develop the necessary technical capabilities and links with the sources of innovation. Cooperation with other NGOs and with the formal sector is often weak.

### Conclusions

The evaluation of improved varieties of bambara groundnut, the dissemination of local cultivars, and the promotion of released varieties can be done with the help of NGOs, which provide an outlet through which the government and other sources of innovation can sell their newly developed technologies. Conservation and utilization of bambara groundnut can also be promoted through the collection of local varieties, and the facilitation of an exchange programme of these materials between rural communities, operating through the different NGOs working with them. It is recommended that all the interested parties form a network, share innovations and jointly develop a strategy for bambara groundnut. This will avoid duplication of efforts, and ensure conservation, production and utilization of this protein-rich legume.

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## Recommendations of Working Groups

Recommendations of the workshop were made through group discussions, and were presented in a plenary session.

### 1. Agronomy/ecophysiology

#### 1.1 Preamble

The following areas deserve more attention for future research on bambara groundnut:

- collection of indigenous knowledge on production practices
- on-farm testing
- economic analysis of production packages
- gender issues.

#### 1.2 Priority areas for research

Research should be targeted on the following priority areas:

##### 1.2.1 Cropping systems

- sole cropping
- multiple cropping
- intercropping
- relay cropping
- mixed cropping
- rotation cropping
- water conservation.

##### 1.2.2 Cultivar characterization and evaluation

- identification of early, medium and late maturing cultivars
- growth habit
- population (spacing)
- maturity determination
- photosensitivity.

##### 1.2.3 Nutritional requirements

- cultivar x strain association
- critical nutrient levels.

##### 1.2.4 Earthing-up

- reasons for earthing-up
- method
- timing.

##### 1.2.5 Crop loss assessment and IPM

- cultural
- biological
- chemical.

### 1.2.6 Crop management

- weeding
- planting period
- planting method
- harvesting period.

## 2. Conservation and breeding

### 2.1 Collections

- National Programmes (NP) to make an inventory of their collections.
- NP to liaise with IITA to fill gaps.
- NP to identify national gaps and fill gaps.
- IITA to become the world base collection with a safety-duplicate at a German genebank for that material which is not duplicated under long-term conditions at suitable Regional genebanks.
- ORSTOM to be contacted, to send a duplicate to IITA's world base collection.

### 2.2 Conservation

- accessions to be separated according to different seed patterns/colours
- *ex situ* conservation should be done according to international standards (i.e. IPGRI), as is hoped will be ensured by the NP
- on-farm conservation: NP to be encouraged to make use of on-farm conservation as appropriate.

### 2.3 Characterization

#### 2.3.1 Revision of the descriptor list

- establishment of a 'Committee to revise the descriptor list'
- above Committee to draft a revised descriptor list, by consulting experts as appropriate
- list be finalized and sent to IPGRI
- publication.

#### 2.3.2 NP to follow the standard descriptor list

#### 2.3.3 Characterization to be completed for all national collections

### 2.4 Evaluation

- For further efficient use of the accessions, it is recommended that the National Agricultural Research Systems (NARS) evaluate the collections, according to the guidelines (provided in the descriptor lists), as appropriate in the specific country.
- NPs are encouraged to exchange germplasm, in light of the evaluation done other countries.
- The use of new techniques, e.g. molecular: RAPDs are encouraged to be included in evaluation.

### 2.5 Documentation and information

- NPs should collect all information within their country

- NPs to share this information with the International Bambara Groundnut Database (IBGDB)
- The IBGDB to be disseminated to the NP (to all users, in particular), by making use of all available means, i.e. diskettes, Internet, etc.
- In the initial stages, it is recommended that the IBGDB be located, updated and disseminated at the Centre for Agricultural Documentation and Information (ZADI), Bonn, Germany.

### ***2.6 Pre-breeding and breeding***

- Genetic studies are to be encouraged, to understand the genetic basis of important characters.
- Crossing techniques are to be developed.
- NPs to be encouraged to initiate comprehensive breeding programmes.
- Participatory breeding approach, i.e. within the FSR context, to be encouraged.

### ***2.7 Seed supply***

- NARS are encouraged to ensure sufficient seed supply.

## **3. Promotion of use, marketing and processing**

Strategies for promotion of use, marketing and processing include:

### ***3.1 Promoting production***

The following problems limit the present production:

- lack of high-yielding varieties
- lack of bambara groundnut seed.

Suggested solutions:

#### **Short term**

- availability of seed to farmers through multiplication of the available landraces
- extension to consent farmers to set aside portions of their arable area to bambara groundnut seed.

#### **Long term**

- improve the available landraces
- breeders to breed for high yields.

### ***3.2 Distribution of seed***

- NGOs, other organizations and extension services to assist in distributing seed
- farmer-to-farmer exchange programmes will be the best solution
- countries to identify the optimum strategies for their situation.

### ***3.3 Training***

- training of trainers
- use of the media (radio, programmes, pamphlets, TV)
- inclusion of agronomic information in extension handbooks.

### ***3.4 Utilization***

- identify uses
- compile recipe books in various countries
- establish a newsletter on bambara groundnut
- involve a food technologist to assess digestibility problems
- breeders to include cooking quality in their breeding programmes
- use as a forage or a cover crop
- use in the food industry, e.g. canning, flour making, and other appropriate technologies be developed.

### ***3.5 Marketing***

- urban centres (both formal and informal markets)
- rural centres (to local farmers, middlemen from urban centres in local shops)
- marketed as grain (both fresh and dry), finished products.

### ***3.6 Processing***

- shelling problem (sheller developed in South Africa being investigated)
- mechanical harvesting.

### ***3.7 Way forward***

- find out prices of bambara groundnut in all levels of marketing and the margin for each country.
- market survey, both regional and international.

## Establishment of the International Bambara Groundnut Network (IBGN) and planned activities

Participants unanimously agreed to establish the IBGN, and a Technical Advisory Committee (TAC) was created to guide it. The following persons were elected members of the TAC for the first phase:

|                 |                                       |
|-----------------|---------------------------------------|
| F. Dakora       | Agronomy                              |
| M. Mwala        | Germplasm conservation and management |
| E. Doku         | Breeding                              |
| J. Mulila-Mitti | Sociology                             |
| F. Begemann     | Information and documentation         |
| D. Shumba       | Utilization and processing            |
| IPGRI           | Standing invitation.                  |

Dr. F. Begemann was elected as coordinator of the TAC.

If funds allow, the TAC should meet annually; otherwise, biennially. Members of TAC should attend the meeting of the EC bambara groundnut project, scheduled for 23–25 July 1996, in Nottingham, UK.

### Activities of the International Bambara Groundnut Network (IBGN)

The following concrete activities will be pursued by the IBGN.

#### *Information from other countries*

Country status reports, to be requested from countries which were not present at the Harare meeting.

#### *Preparation of a list of experts*

Letters (questionnaires) will be sent to experts, to identify their area of expertise and the projects they are working on, in order to prepare a directory of bambara groundnut experts.

#### *International Bambara Groundnut Database*

Passport data of collections should be sent to F. Begemann, for incorporation in the International Bambara Groundnut Database (IBGDB). The IBGDB is available upon request on diskettes or online on Internet at the following web site: <http://www.dainet.de/genres/bambara/bambara.htm>. Participants should send references (especially the so-called 'grey literature', e.g. diploma theses from their institutes) to F. Begemann, to update the two bambara groundnut bibliographies published by IITA in 1978, and by the Department of Tropical Crop Science Wageningen Agricultural University (compiled by A. Linnemann), in 1992.

#### *Collections*

Participants should check their collections with IITA's collection, and ask IITA to repatriate the material not available in the national collections, to build up national collections. On the other hand, national collections should be duplicated at IITA.

#### *Revision of bambara groundnut descriptors*



There is a need to revise the 'Bambara groundnut descriptors', published in 1987. An *ad hoc* 'Committee to revise the descriptor list' was formed, consisting of F. Begemann, E. Doku, N. Ng (to be invited) and C. Swanevelder, which is to produce a first draft.

***Newsletter***

A bambara groundnut newsletter will be published once per year. The first issue will be produced by IPGRI, as soon as possible.

***Public awareness***

To create public awareness on bambara groundnut, announcements of the establishment of the IBGN will be published in IPGRI's SSA Newsletter, and in Spore and Monitor, etc.

***Fund-raising***

Preparation of projects and/or assistance for institutions to draft project proposals.

## Appendix A. Workshop Programme

### Tuesday, 14 November

|               |  |                                    |
|---------------|--|------------------------------------|
| 08:30 - 09:20 | <b>Opening session</b>                                       |                                    |
|               | Opening address  | (Mungate)                          |
|               | Introduction   | (Goli)                             |
|               | Workshop organization  | (Heller)                           |
|               | <b>Country presentations (Session 1)</b>                     |                                    |
| 09:20 - 09:40 | Burkina Faso   | (Drabo, Sérémé and Dabire)         |
| 09:40 - 10:00 | Botswana   | (Karikari, presented by Collinson) |
| 10:00 - 10:30 | <i>Coffee break</i>  |                                    |
|               | <b>Country presentations (Session 2)</b>                     |                                    |
| 10:30 - 10:50 | Cameroon   | (Nguy-Ntamag)                      |
| 10:50 - 11:10 | Ghana  | (Doku)                             |
| 11:10 - 11:30 | Kenya  | (Ngugi)                            |
| 11:30 - 11:50 | Mali   | (Kodio)                            |
| 11:50 - 12:10 | South Africa   | (Swanevelder)                      |
| 12:10 - 12:30 | Tanzania   | (Ntundu)                           |
| 12:30 - 14:00 | <i>Lunch</i>   |                                    |
|               | <b>Country presentations (Session 3)</b>                     |                                    |
| 14:00 - 14:20 | Togo   | (Nambou)                           |
| 14:20 - 14:40 | Zambia   | (Mbewe, Mwala and Mwila)           |
| 14:40 - 15:00 | Zimbabwe   | (Mabika and Mafongoya)             |
| 15:00 - 15:20 | Discussion   |                                    |
| 15:20 - 15:40 | Summary of country presentations                             | (Mulila-Mitti)                     |
| 15:40 - 16:10 | <i>Coffee break</i>  |                                    |
| 16:10 - 18:00 | Visit DR & SS campus and presentation of research activities |                                    |

### Wednesday, 15 November

|               |  |                     |
|---------------|--|---------------------|
|               | <b>Agronomy (Session 4)</b>  |                     |
| 08:30 - 08:50 | Agronomical research on bambara groundnut at the Agronomy Institute  | (Mabika)            |
| 08:50 - 09:10 | Nitrogen fixation and nitrogen nutrition in symbiotic bambara groundnut ( <i>Vigna subterranea</i> (L.) Verdc.) and Kersting's bean ( <i>Macrotyloma geocarpum</i> (Harms) Maréchal. et Baud.) | (Dakora and Muofhe) |
| 09:10 - 09:30 | Pests and diseases of bambara groundnut  | (Gwekwerere)        |
| 09:30 - 09:50 | Evaluating the potential for bambara groundnut as a food crop in semi-arid Africa: an approach for assessing the yield potential and ecological requirements of an underutilized crop          | (Collinson)         |
| 09:50 - 10:10 | Toward increased food legume production  | (Mulila-Mitti)      |
| 10:10 - 10:40 | <i>Coffee break</i>  |                     |
|               | <b>Genetic resources/breeding/promotion (Session 5)</b>  |                     |

|               |  |
|---------------|--|
| 10:40 - 11:00 | Preliminary studies on the germinability and vigour of Zimbabwean bambara groundnut ( <i>Vigna subterranea</i> ) genotypes (Zengeni and Mupamba) |
| 11:00 - 11:20 | Characterization/evaluation of IITA's bambara groundnut collection (Goli, Begemann and Ng)   |
| 11:20 - 11:40 | Development of The International Bambara Groundnut Database (Begemann)   |
| 11:40 - 12:00 | The potential role of NGOs in promoting conservation and use of bambara groundnut ( <i>Vigna subterranea</i> ) (Shumba)                          |
| 12:00 - 12:20 | Breeding bambara groundnut suitable for Zimbabwean conditions (Madamba)  |
| 12:20 - 12:40 | Overview of bambara nut production and research by the Farming Systems Research Unit: a case study of Chivi Communal area in Zimbabwe (Chibudu)  |
| 12:40 - 14:00 | <i>Lunch</i>   |
|               | <b>Working groups</b>  |
| 14:00 - 14:10 | Introduction to working group sessions (Heller)  |
| 14:10 - 16:00 | Working group 1 (Agronomy/ecophysiology)   |
| 16:00 - 16:30 | <i>Coffee break</i>  |
| 16:30 - 18:30 | Working group 2 (Conservation and breeding)  |

#### Thursday, 16 November

|               |   |
|---------------|---|
|               | <b>Working groups (cont.)</b>                             |
| 08:30 - 10:00 | Working group 3 (Promotion of use, marketing, processing) |
| 10:00 - 10:30 | <i>Coffee break</i>                                       |
| 10:30 - 12:30 | Network discussion  |
| 12:30 - 13:30 | <i>Lunch</i>  |

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