African Crop Science Journal, Vol. 20, No. 1, pp. 1 - 16
ISSN 1021-9730/2012 $4.00

BAMBARA NUT: A REVIEW OF UTILISATION, MARKET POTENTIAL AND CROP IMPROVEMENT

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(Received 19 May, 2011; accepted 7 November, 2011)

ABSTRACT

Bambara groundnut (*Vigna subterranea* (L.) Verdc.) originated in West Africa but has become widely distributed throughout the semi-arid zone of sub-Saharan Africa (SSA). Sharing a high nutritive value with other widely consumed legumes, bambara has an appealing flavour which is reflected in demand from small local and niche markets. Despite its high and balanced protein content, bambara remains under-utilised because it takes a long time to cook, contains anti-nutritional factors and does not dehull easily. Bambara yields well under conditions which are too arid for groundnut *(Arachis hypogea)*, maize *(Zea mays* L.) and even sorghum *(Sorghum bicolar)*. Its drought tolerance makes bambara a useful legume to include in climate change adaptation strategies. Existing bambara products are not well promoted in the local or international markets and new products are needed that highlight its inherent nutritional and culinary advantages. A number of projects on bambara, involving several countries in SSA since the 1980s, have failed to stimulate a sustainable increase in the production of the crop. The absence of functioning value chains has been a factor in this failure, as accessible market outlets might provide the required incentive for smallholder households to obtain improved seed and invest more of their land and labour in the crop. There is little documented evidence of trade in bambara but circumstantial evidence indicates considerable international demand. More attention should be given, therefore, to market research and development, with crop improvement programmes being more market-led, if bambara is to make a greater contribution to household income and rural development in SSA.

Key Words: Anti-nutritional factors, *Vigna subterranea*

RÉSUMÉ

Les arachides Bambara (*Vigna subterranea* (L.) Verdc.) d'origine Ouest Africaine ont été largement répandues dans la zone semi aride sub saharienne. Avec sa valeur nutritive élevée à côté d'autres légumes largement consommées, bambara a une saveur attractive qui se reflète dans sa demande sur des petits marchés locaux. Malgré sa teneur équilibrée en protéines, bambara reste sous utilisé par suite du long moment de cuisson, contient des facteurs anti-nutritionnels et sa coque ne s'enlève pas facilement. Bambara produit de bons redements dans des conditions qui sont trop arides pour les arachides (*Arachis hypogea*), le ma¿s (*zea mays*) et même le sorgho *(sorghum bicolar)*. Sa tolélance en sécheresse fait du bambara une légume utile surtout lorsqu'il s'agit des stratégies d'adaptation au changement climatique. Les produits existants de bambara ne sont pas bien promus sur des marchés locaux ou internationaux et de nouveaux produits montrant tous les avantages nutritionnels et culinaires sont désirés. Un nombre de projets sur bambara impliquant plusieurs pays d'Afrique Sub Saharienne depuis 1980, ont échoué de stimuler une augmentation durable de la production de cette culture. L'absence de chaînes des valeurs fonctionnelles a été un facteur de cet échec, étant donné que des points de vente sur les marchés accessibles devraient motiver les petits ménages pour obtenir des semences améliorées et plus investir dans leurs terres et la main d'oeuvre. Il ya très peu d'évidence documentée sur le commerce du bambara mais des évidences circonstancielles font montrent d'une demande internationale considérable. Si bambara doit considérablement contribuer à la génération des revenus des ménages et le développement rural en Afrique Sub Saharienne, un effort doit être mis dans la recherche et développement, avec des programmes soutenus d'amélioration de la culture orientés vers le marché.

Mots Cles: Facteurs anti-nutritionels, *Vigna subterranea*

INRODUCTION

Bambara groundnut [BG] (*Vigna subterranea* (L.) Verdc.) is an African species, the cultivation of which predates that of groundnut. Although occasionally grown in Asia and elsewhere, its cultivation is rare outside the African continent. The distribution of wild bambara groundnut is known to extend from Jos Plateau and Yola in Nigeria, to Garoua in Cameroon (Goli, 1997). It is in West Africa that most of the world's BG is grown and where the crop is most prominent in the traditions of rural communities. According to Yao *et al*. (2005), for instance, BG plays a key role in the traditional food and culture of peoples in the western and northern parts of Côte d'Ivoire. Bambara groundnut is now widely distributed in the semi-arid zone of sub-Saharan Africa (SSA) and most authors seem to support the view that there, it is the third most important food legume after cowpea *(Vigna unguiculata)* and groundnut (Mkandawire, 2007).

Bambara groundnut is important for smallholders and their households because the beans are an important source of food security, being nutritious and high in protein. Although, in common with other legumes, bambara is deficient in sulphur-containing amino acids (Azam-Ali *et al*., 2001), some genotypes contain higher amounts of methionine and lysine than is found in other legumes (NRC, 2006).

As a nitrogen-fixing legume, bambara also contributes to the maintenance of soil fertility. Although normally grown in areas where cowpea and groundnut are grown, BG is considered to have an advantage over those crops in its adaptation to poor soils and tolerance to drought. BG yields well under conditions which are too arid for groundnut, maize and even sorghum (Thottappilly and Rossel, 1997).

During the 1980s, the International Institute for Tropical Agriculture (IITA) undertook a detailed investigation of its BG collection and in 1985, an initial database was established in ORACLE format. Passport, characterisation and evaluation data of 1378 accessions were recorded (Begemann, 1995). This led to the establishment of the International Bambara Groundnut Database, compiled by D. Jiménez, J. Krause and F. Begemann in 1995; by merging data from a number of collections in addition to IITA, primarily the Zambian Bambara Groundnut Improvement Programme at the University of Zambia. The database is accessible on Internet through the Information Centre for Genetic Resources (IGR) of the Centre for Agricultural Documentation and Information (ZADI) in Bonn, Germany, [http://www.dainet.de/genres/bambara/bambara.htm].

A number of reviews of BG have been published previously and one of the more recent general reviews is by Linnemann (1987). A review of BG production in Africa by Mkandawire (2007) was published on-line. The most comprehensive published information on the crop is contained in the proceedings of a workshop in Zimbabwe, on the conservation and improvement of BG (Heller *et al*., 1997) which contains a review of published literature, up to 1995 (Goli, 1997). Azam-ali *et al*. (2001) reviewed the contribution of research towards developing the potential of bambara nut. Although initiatives to develop and commercialise the crop have been largely unsuccessful, primarily due to barriers to the establishment of functional value chains, this is the first review of bambara to include aspects of commodity marketing.

NUTRIENT VALUE

Bambara groundnut seeds contain 63% carbohydrate, 19% protein and 6.5% oil (Linnemann, 1987). The gross energy value of bambara groundnut seed is greater than that of other common pulses such as cowpea, lentil (*Lens esculenta*) and pigeonpea (*Cajanus cajan*) (FAO, 1982). De Kock (undated) provides the following nutritional breakdown: carbohydrates: 54.5 - 69.3%, protein 17 - 24.6% and fat 5.3 - 7.8%. BG is a good source of fibre, calcium, iron and potassium. The red seeds could be useful in areas where iron deficiency is a problem, as they contain almost twice as much iron as the cream seeds (de Koch, undated).

Often, it is the cream or white seeded BG which are more sought after and command up to a 10% premium in Ghana (Quaye and Kanda, 2004). Red seeds are more popular than the cream seeds in Zimbabwe, where they command a higher price with the Grain Marketing Board. BG has the potential to provide a balanced diet in areas where animal protein is scarce and/or expensive and where the cultivation of other legumes is risky due to low rainfall. BG compares favourably in nutritional status, with other well known and highly commercialised beans (Table 1).

Information on nutrient content and anti-nutritional factors was presented in a paper from Nigeria on the nutritional effect of three traditional processing methods (Ijarotimi and Esho, 2009). Fermentation improved the mineral composition, but had little effect on the amino acid content and decreased the anti-nutritional factors; oxalate, tannic acid, phytic acid and trypsin (Table 2a, b, c).

PRODUCTION PRACTICES

Bambara groundnut grows close to the ground and the nuts are produced underground. It is therefore, a difficult crop to harvest mechanically which discourages large-scale commercialisation, but it is an ideal crop for smallholder households. The crop yields reasonably well on poor soils in areas of low rainfall (500 – 800 kg ha^{-1}) and can be grown without fertilisers and chemicals which are costly and often difficult to access in more remote areas. It grows well on acidic laterite soils which are common in Africa, but less well on calcareous soils (Mkandawire, 2007).

Bambara groundnut is suitable for intercropping with other crops and does not take up large areas of land that could be used for other crops considered more important or lucrative. BG is useful in crop rotation because it contributes nitrogen to the soil at a level similar to other legumes (20 – 100 kg ha^{-1}) (Ncube and Twomlow, 2007). Traditionally, BG has being seen as a snack or food supplement, but not a lucrative cash crop. In Zimbabwe, the crop is usually grown by women and so, it is often given a lower priority within the village, in the allocation of land. Seeds for growing BG are rarely purchased by farmers because the women are responsible for passing the seed down through the generations, and

TABLE 1. Nutritional status of bambara compared to other common legumes

	Bambara groundnut	Soya	*Phaseolus* bean	Cowpea	Faba bean	Chickpea
Calories	390	416	343	333	341	364
Protein (%)	21.8	36.5	23.8	23.6	26.1	19.3
Carbohydrate (%)	61.9	30.2	59.6	60.0	58.3	60.6
Fat (%)	6.6	19.9	2.1	0.8	5.7	6.0

Source: de Kock (undated report)

TABLE 2a. Mineral content [mg 100 g^{-1}] in raw bambara nut and its fermented flour

	Ca	K	Mg	Na	Fe	Se	P
Raw nut	16.3	74.1	66.7	26.1	0.38	0.12	164.7
Fermented flour	20.7	80.6	69.3	26.0	0.43	0.14	110.2

Source: Ijarotimi and Esho (2009

storing the dried beans for food security. Women are usually given seed by female relatives (mother in law) when they are married. Sometimes the local chief gives them the seed when they move into the area (de Kock, undated).

Bambara groundnut is grown predominantly on the flat but sometimes, on mounds or ridges which may be beneficial in wetter areas, as the crop does not tolerate water-logging. BG is typically a short-day plant and flowering and nut development may be delayed or prevented by long-day conditions (Mkandawire, 2007). In Zimbabwe, the crop is normally intercropped with maize, and planting takes place in November/ December; while harvesting is done 5-6 months later. There is a close association between yield and planting, date which becomes more pronounced further from the equator. This may relate both to the effect of longer days and intolerance of very wet conditions.

TABLE 2b. Amino acid content (g 100 g^{-1}) of raw bambara nut and its fermented flour

Amino acid	Raw nut	Fermented flour
Lysine	3.0	4.8
Histidine	2.3	2.1
Arginine	3.8	5.2
Aspartic acid	4.9	10.1
Threonine	2.6	2.1
Glutamic acid	15.8	13.6
Glycine	3.6	4.0
Alanine	3.4	1.8
Cystine	0.6	1.0
Methionine	1.8	1.2
Isoleucine	3.8	4.1
Leucine	6.7	6.3
Tyrosine	3.1	3.0
Phenylalanine	4.4	4.3

Source: Ijarotimi and Esho (2009)

In a field experiment in Tanzania, pod yield declined from >3000 kg ha^{-1} to zero when sowing date was delayed by 60 days (Collinson *et al*., 2000). In Côte d'Ivoire, the highest yields were obtained with high density planting (250,000 plants ha^{-1}) in flat seedbeds using semi-bunch types (Kouassi and Zoro, 2010).

Bambara groundnut is widely grown in Nigeria, particularly in the Southern Guinea Savanna belt, where it is mostly grown as a mixed crop with cowpea, maize, sorghum and groundnut (Thottappilly and Rossel, 1997). In Ghana, BG is sometimes planted on yam mounds, protecting the mound from erosion (Doku and Karikari, 1971). Most of the country reports presented at a workshop in Zimbabwe (Heller *et al*., 1997), estimate the average yield in the smallholder sector at around 500 kg ha^{-1}. Yields obtained from germplasm screening in Ghana and Tanzania ranged from less than 10 kg ha^{-1} to over 800 kg ha^{-1} (Dakora, 2006).

Azam-Ali *et al*. (2001) used computer-based analytical tools, mainly crop simulation models, and geographic information systems (GIS) to evaluate the productive potential of regions Africa, where BG has been grown for centuries, but where experimental evidence is scarce. In addition, new regions not previously associated with the cultivation of BG, but where the combination of environmental factors indicate a potential for productive growth without costly inputs, such as irrigation were defined. The simulation model predicted that within Africa, largest potential yields would occur in South, East and Central Africa. The land area considered suitable for BG cultivation was for example; Swaziland 100%, Uganda 98%, Zambia 95%, Burundi 89%, Zimbabwe 84% and Central African Republic 79%. Parts of the Mediterranean basin of Europe and some parts of Australia were also

TABLE 2c. Anti-nutritional (mg 100 g^{-1}) factors in raw bambara nut and its fermented flour

	Oxalate	Tannic acid	Phytic acid	Phytin phosphorus	Trypsin
Raw nut	2.7	0.39	46.4	13.1	6.7
Fermented flour	2.3	0.29	28.1	7.6	4.2

Source: Ijarotimi and Esho (2009)

predicted to be suitable for BG cultivation. Potential pod yields of over 3000 kg ha^{-1} were predicted for large parts of the semi-arid zone in eastern and southern Africa. The major limitations of the model are in the exclusion of information on soils and pests and diseases to explain local variation in yields.

CROP UTILISATION

Despite its high and balanced protein content, BG remains under-utilised because it takes a long time to cook and contains anti-nutritional factors such as tannins and trypsin inhibitors, and it has poor milling characteristics, as it does not dehull easily (Barimalaa and Anoghalu, 1997). The long cooking time consumes more fuel and water than might be required for cowpea or phaseolus bean. Boiling from fresh may take 45-60 minutes, while dried beans may take as much as 3-4 hours.

Although it is considered to be an underutilised crop, BG is widely distributed in SSA, and is a popular 'backyard' and 'snack' crop. In Nigeria and other West African countries in general, there are numerous traditional recipes. In the Ibo States of Nigeria, BG seeds are roasted and chewed with palm kernel as a snack item, or they may be milled into flour and used to prepare bean balls ('akara') after frying the paste in vegetable oil Alternatively, the slurry may be used to prepare a steamed gel, also known as 'okpa' (Uvere *et al*., 1999).

Bambara groundnut seeds can be eaten fresh, or cooked while still immature. At maturity, they become very hard and, therefore, require boiling before further 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, pulverised and used to make a soup. The flour can also be used to make a stiff porridge. Roasted seeds can be boiled, crushed and eaten as a relish.

In Zimbabwe, the nuts are eaten fresh, and also dried and stored for later consumption. The fresh nuts may also be roasted and eaten as a snack. BG can be pounded and made into a relish mixed with onions, tomatoes and oil. The seeds may be milled into flour and used to make small flat cakes or biscuits or mixed with cereals and used to make a porridge. The seeds are sometimes boiled and eaten together with plantains (de Kock, undated).

Bambara groundnut shows potential for the fortification of traditional weaning foods in Africa. Protein content was increased from 10 to 16.4% when boiled BG was added to fermented maize dough. The pH decreased with an increase in moisture, fat, ash, lysine and tryptophan content, compared to unfortified maize dough. It was concluded that the most appropriate technique for the production of bambara-fortified high protein fermented maize dough, would be to incorporate boiled whole seeds in soaked maize, before milling and fermentation. Organoleptic evaluation indicated that there was no change in the acceptability of the weaning food after the addition of BG (Mbata *et al*., 2006; 2009).

The nutritional composition of cooking banana as a weaning food can be enhanced through supplementation with fermented BG flour. At the Federal University of Technology in Nigeria, the process and ingredients were shown to be accessible to low-income mothers. The composition of the formulated weaning food containing 70% cooking banana and 30% BG flour, is nutritionally adequate to support child growth and development. The banana/bambara mixture, can be used as a substitute for more expensive commercial weaning products (Ijarotimi, 2008).

Research in Nigeria has shown that flour yield from BG can be improved by malting (Uvere *et al*., 1999), with the added benefit of a decrease in milling energy, which would reduce the tedium of repeated milling and sieving during flour extraction from unmalted BG seeds. However, the malted flour was less acceptable to consumers, due to its darker colour and altered taste which increased with prolonged malting period. Malting resulted in a reduction in flatulence and toxic factors, lectins and trypsin and lessening of the 'beany' flavor of 'okpa' which certain cultures found objectionable.

The possibility of malting bambara nut seeds for the production of high energy, low viscosity weaning foods merits further investigation, given its high carbohydrate and protein contents. It was concluded in the study that malting for 1–2 days, and drying at 40–50 °C, would produce an acceptable product.

Research conducted at the University of Yaounde in Cameroon, has shown that treatment of BG flour with 60% alcohol, decreases anti-nutritional factors associated with BG and eliminates flatulence-inducing sugars (Mune Mune *et al*., 2007). Blends of the treated flours with freeze-dried fermented maize dough were considered to be good sources of nutrients for young infants It was concluded that the use of these blends for preparation of gruels in developing countries will require supplementation with minerals and vitamins, as well as addition of an amylase source, to reduce bulk and allow the incorporation of larger quantities of flour blends in the gruels, without changing their semi-liquid consistency.

Brough *et al*. (2003) prepared a vegetable milk by soaking shelled bambara nuts in water overnight, homogenising and removing insoluble material. The beany taste could be removed by dry-frying the beans after soaking and before homogenisation. Milk from BG was preferred in taste and colour to those produced from cowpea, pigeonpea and soybean (*Glycine max*).

WORLD PRODUCTION AND TRADE

There is little authoritative information on the amount of BG produced around the world. The Food and Agriculture Organisation of the United Nations (FAO, 2009) has production data from only four countries: Burkina Faso, the Democratic Republic of Congo, Cameroon and Mali. This suggests a recorded worldwide production level in 2008 of just over 100,000 metric tonnes, with Burkina Faso being the largest producer. However, using a range of sources (Table 3), Africa-wide production is estimated to be over 330,000 t annually. This figure seems to have been originally estimated by Coudert (1984), and available literature indicates that this figure is a reasonable estimate.

Production statistics for individual countries are scarce. In Zimbabwe, during the 1990s, approximately 50 t a year were produced by 3,500 smallholders, on an area of 2,300 ha, with an average yield of 650 kg ha^{-1}. In addition and prior to the farm invasions, 48 large-scale farms grew the crop on a total of 48 ha but de Kock (undated) believes that it is unlikely that there are any commercial farmers in Zimbabwe growing BG. Karikari *et al*. (1995) describe BG (‘ditloo’ in Setswana) as prominent in Botswana’s farming systems, being the third most important legume after cowpea and groundnut. It is grown over an estimated area of 1500 ha, producing about 400 t of seed annually.

In Kenya, BG is a minor crop and is used as a traditional food only by the Luhya, Giriama and Kambe at the coast, and to a lesser extent by the

TABLE 3.   Bambara production in Africa

Country	Estimated Bambara Production (metric tonnes)	Sources of information
Nigeria	100,000	Rachie and Roberts (1974) quoted in IPGRI (1997)
Botswana	6,000	Von Rudolf (1993) quoted in IPGRI (1997)
Togo	4,400	Office of Agricultural statistics (1994) quoted in IPGRI (1997)
Burkina Faso	44.712	FAOSTAT (2009)
Cameroon	24,000	FAOSTAT (2009)
DR Congo	10,000	FAOSTAT (2009)
Mali	25,165	FAOSTAT (2009)
Zambia	18,750	Heller *et al*. (1997)
Zimbabwe	750	Central Statistics Office (1993) quoted in IPGRI (1997)
Ghana	20,000	Duke (1981) quoted in Greenhaulgh (2000)
Niger	30,000	Duke (1981) quoted in Greenhaulgh (2000)
Cote d’Ivoire	7,000	Duke (1981) quoted in Greenhaulgh (2000)
Chad	20,000	Duke (1981) quoted in Greenhaulgh (2000)

Source: C. Bennett, unpublished market research

Luo (Ngugi, 1995). The total annual production in the period 1992-94 from four Districts was 190 t, with yields averaging 400 – 600 kg ha^{-1}. No figures for production in Malawi, Tanzania or Mozambique are available in literature or databases of world production or trade. Although no production figures are available for Namibia, Fleissner (undated) reports that 82% of households in north-central Namibia and 67% in Kavango, grow BG over a total area of 3000 ha, producing an estimated 750 t $year^{-1}$, based on an assumed average yield of 500 kg ha^{-1}. This level of production does not satisfy the demand for BG in Namibia and the shortfall is made up through informal imports from neighbouring Angola. The crop can usually be found on sale in local markets throughout Africa, often commanding high prices, as most of the production is consumed by the households that grow it. It is believed that in Malawi, demand for BG often exceeds supply (Mkandawire, 2007).

Anecdotal evidence and casual observation, suggests that production is far more widespread than is evident from the literature. In West Africa, all countries in the region are known to grow the crop on some scale and there is some evidence that Nigeria, Ghana, Togo, Cote d'Ivoire, Chad, and Benin; each produces more than 10,000 t annually (Greenhalgh, 2000). Another 6 countries in eastern and southern Africa grow the crop, but there are no production statistics (IPGRI, 1997).

A review of the production and trade data shows that there are areas of known production where no data is available. This makes planning value chains based on regional or international trade very difficult because it is not possible to tell prospective buyers how much throughput might be achieved. If a new product is to be launched based on BG, then an answer to the question of gross product availability will be needed before any investment in product launch can be made.

There is very little BG traded internationally, though it is highly likely that the trade statistics hide the data on BG within other tariff codes such as "bean" or "groundnuts". BG is classified as an edible leguminous vegetable and falls into Chapter 7 of the Harmonized Tariff code System (HS) as fresh (HS0708) or dried (HS0713). FAOSTAT (2009) data set on trade, which has a category for 'Bambara Beans' reveals no recorded international trade.

Notwithstanding the complete absence of data, there is anecdotal and circumstantial evidence that some trade in BG exists. For example:

(i) UK retailers of fresh BG have been sourcing supplies from Ghana by air-freight;
(ii) French retailers of canned, fresh BG have been importing from Madagascar [where it is known as '*voanjobory*' meaning 'round peanut' (personal communication, S.A. Racines, Parc Scientifique Agropolis, Montpellier, France)];
(iii) Several South Africa bean packing and distribution companies offer BG and some of this comes from Zimbabwe; and
(iv) Small quantities of fresh and dried BG reach the French and Canadian retail markets from various West African sources including Cameroon and Burkina Faso (Ben Bennett, unpublished market research).

MARKET POTENTIAL

Despite having nutritional advantages over competing legume crops, such as higher content of methionine, BG has not developed as a traded commodity. BAMLINK, a project funded by the EU, asked the question "is there economic demand for Bambara" but did not provide a comprehensive answer, beyond suggesting further research into international markets and niches (Azam-Ali *et al.*, 2001). Research into value added BG products, such as high quality flour in Ghana, seems to have been inconclusive and not to have resulted in new value chains (Yawson and Wilhelmina, 2004). The main reason for this failure appears to be the high cost of BG, compared to competing products such as cowpea (*Vigna unguiculata*) and beans (*Phaseolus vulgaris*) (A. Graffham pers comm. Natural Resources Institute, UK).

The most substantial effort recently, to develop BG have been conducted by the EU funded Bamlink project (Mayes *et al.*, 2009). This project identified that there is insufficient demand in the formal market for BG to justify further expensive development research. The conclusions drawn by the only two researchers that have considered the marketing issue, Greenhalgh (2000) and de Kock (undated), a Zimbabwean bambara canner, are summarised as follows:

(i) Greater volume of product is needed to meet demand and reduce prices;
(ii) Existing bambara products are not well marketed or promoted in the local market (or internationally); and
(iii) New bambara products are needed that highlight its inherent advantages (e.g. nutrition, taste and tradition).

Closer examination of the few examples of commercial exploitation of BG, suggests that compared to groundnut and some other legumes, the issue is rather a lack of promotion of BG and little investment in the development of functional value chains, than lack of demand (Yawson and Wilhelmina, 2004). Commercial canning of BG has been done in both west and Southern Africa. In Ghana, the nuts were at one time canned in gravy by a Government factory and over 40, 000 cans were produced annually (Doku and Karikari, 1971; Begemann, 1986). During the 1990s, the company 'Speciality Foods' based in Harare, Zimbabwe, canned bambara and marketed it as 'Tulimara Canned Nyimo Beans; which was available in all the major supermarkets (de Kock, undated). It was mixed with brine (salt water) ready to serve from the can. The nuts were recommended for addition to soups, stews and salads. There has been a revival of interest in canning bambara in Ghana and Nigeria, as a way to make the product available to consumers throughout the year and some research has been conducted on processing methods. Blanching and soaking before canning was found to decrease the content of phytates and tannins which act as anti-nutritional factors (Afoakwa *et al.*, 2007).

SUPPLY-SIDE CONSTRAINTS

De Kock (undated) discussed some of the constraints in the value chain for BG in Zimbabwe: The first of these was the short season when the beans were available from small farmers. The entire crop was available at the same time which decreased prices for the growers. Collection of the nuts was expensive and time consuming for the food company, because the small-scale farmers were remote and spread over large areas, served by badly maintained roads. Speciality Foods was in competition with buyers from South Africa, which inflated the price on local markets, making the beans unaffordable for low-income earners in the cities. Supply was not guaranteed because in times of drought when other crops failed, farmers were not willing to sell their beans because they were essential to their food security strategy. This indicates that the demand actually exceeded supply.

The Crop Post Harvest Programme of the UK Department for International Development (DFID), supported a project on BG marketing of value-added product based BG. Through a series of projects in Ghana from the late 1990 through to 2004, groups were trained in the production of high quality bambara flour [HQBF], and market research was conducted. Although this resulted in an improvement in flour quality, attempts to go beyond household level consumption and develop the market for packaged HQBF were largely unsuccessful. This was due to the absence of advertising and a lack of awareness of the product among consumers. Larger supermarkets sold small quantities of BG flour but it was absent from the shelves of smaller retailers. It was concluded from market studies with retailers, that much more effort was required to promote the product with consumers before more stores would be willing to stock it (Yawson and Wilhelmina, 2004).

In Zimbabwe, storage and processing also posed a problem for the commercialisation of BG. There were no companies or individuals able to provide reliable supply of dried nuts all year around, so it was necessary to purchase a year's supply at harvesting time. Morevoer, the nuts are highly susceptible to bruchid (*Callosobruchus maculatus*) and have to be fumigated in the warehouse monthly or stored in cold rooms to avoid contamination. Grading of the nuts after purchase is time consuming because of broken nuts, stones and insects mixed in with the nuts (de Kock, undated).

Informal discussion with food products trading companies suggested the following potential markets:

Diaspora markets (UK, France, USA, Canada and South Africa). The limited research conducted among traders of bambara in Europe and North America, suggests that there may be a market among expatriate (diaspora) consumers. This market is relatively insensitive to price, but wants the product all year round rather than seasonally. This presents a challenge for fresh products and suggests that fresh-frozen might allow the product to be available year-round.

As a competitor to fresh legumes and soya beans. While bambara is likely to be more expensive, due to under-production, it may have potential as a novel alternative to peas, certain beans and soya beans in the fresh vegetable and salad markets. For this market, a considerable effort would be needed to launch the products by persuading chefs to try it out and by explaining the product qualities to perspective buyers. The way to 'test' this market would be to present bambara in a suitable international trade fair.

Bambara snacks. Snacks made from fresh BG may have potential in the fast growing developed world snacks food market, which is always looking for novelty. Bambara snacks would have to compete with various nuts, particularly peanut, which is very cheap by comparison. A key element of the snack market is its investment in packaging and promotion. Previous efforts to launch new nuts have not been very successful because of this high entry cost. However, bambara has sufficient qualities of nut size, taste and high protein content, that it might, with a suitable partner, be a potential new international snack.

Market fragmentation. A number of potential market categories for BG are described in Table 4. The five market segments are: fresh salad ingredients (e.g. Bambara peas), fresh vegetables for home cooking (e.g. Bambara peas), cooked snacks (e.g., Bambara nuts, boiled or roasted), preserved vegetables for home cooking (e.g., Bambara beans, semi-processed and preserved), dried beans for home cooking (e.g., Bambara groundnuts) and a specialist milled product for use as a food ingredient (Bambara flour).

Summarising information gathered from trading companies; the consumer response seems to be better to the fresh product than the processed one. The high cost of BG and its similarity to other, much cheaper, dried beans and legumes seems to indicate that dried BG will always be a niche market, mainly for the diaspora. Fresh BG has a number of unique selling propositions. It is nutritious, looks attractive, has a good story associated with it, and has a good flavour/texture profile. In Europe and America, the West African diaspora market is looking for fresh, rather than dried BG. Fresh BG would make an excellent and healthy salad ingredient. The growing health food sector in South Africa may represent a potential and accessible market for countries in southern Africa, although food quality and traceability issues would have to be addressed. Some technical problems would have to be considered for fresh BG. On-farm removal of the shell from fresh product may be inefficient and the possibility of a centralised system might be considered. Centralising shell removal in collection centres might also address possible food safety concerns.

TABLE 4. Possible Bambara value chains

Market category	Use	Competitor	Possible name
Fresh legume	Salads	Peas, soya bean	Bambara peas
Cooked legume	Vegetable	Peas, chickpeas	Bambara peas
	Snack	Groundnuts, cashew	Bambara nuts
Preserved legume (frozen, canned etc.)	Vegetable	Various beans and	Bampara beans
Dried legume	Stew ingredient	Various pulses and groundnut	Bambara beans
Middle dried legume	Flour	Food ingredient	Bambara flour

CROP IMPROVEMENT

Since the 1980s, several countries in SSA have been involved in projects on BG, funded mainly by the EU, FAO, McKnight Foundation and/or from local resources (Table 5). Most have these projects have involved collection and screening of local BG germplasm. None have addressed the issue of incentive for smallholders to invest further in crop expansion and crop improvement initiatives have not been market-led.

Germplasm collection and screening. BG is present all over Africa and land races are abundant. IITA has a large number of accessions collected from countries across Sub-Saharan Africa. The IITA collection has been characterised and evaluated by Goli (1997). During the 1990s, the next largest collection was held by ORSTOM in France, while in Africa, the largest collection was at the University of Zambia.

Cultivated BG genotypes are landraces that have evolved under domestication directly from their wild relatives. They have adapted to hostile environments and are popular among farmers for their yield stability under different environmental conditions. The change from a spreading/trailing to bunch growth habit, decreased shell thickness and fewer days to flowering are conspicuous adaptations to domestication (Doku and Karikari, 1971; Basu *et al*., 2007). Plants with bunched growth habit are easier to harvest than the spreading types. Until recently, because of geotropic pod formation and the difficulty of intra-specific hybridisation, breeding of BG has been confined to selection between and within populations. At IITA for instance, single plants or entire accessions were selected on the basis of their vigour, resistance to fungal diseases and seed yield. During the 1980s, 25 promising accessions were retained for further trials. Yields varied between years with a strong location effect (Goli, 1997).

In Zimbabwe a number of promising accessions were identified among locally collected germplasm and high yields were obtained, where soil fertility was good and rainfall well distributed (Madamba, 1997). Yield among smallholders in Zimbabwe in marginal areas ranged from 80 – 400 kg ha^{-1}, but some accessions when well managed on research stations, yielded over 500 kg at a dry site, over 2000 at a high potential site and reached 4000 kg ha^{-1} under supplementary irrigation.

In Côte d'Ivoire, locally collected germplasm was screened for phenotypic variability and a number of land races identified with short reproductive cycles which was associated with a higher percentage of matured pods at harvest. Early maturity is of benefit in areas with a short wet season and one selection matured in 90 days, compared with 137 days for the latest-maturing types (Yao *et al*., 2005). The average number of days to maturity was around 106, with a range of

TABLE 5. Countries which have collected and evaluated local bambara germplasm

Country	Year	Project	Reference
Botswana	1992-2003	EU Bamlink	Karikari *et al.,* 1995
Burkina Faso	1980s	Local funding	Ouedraogo *et al*., 2008
Cameroon	1990s	Local funding	Nguy-Ntamag, 1997
Côte d'Ivoire	1990s	Local funding	Yao *et al*., 2005
Ghana	1990s	Local funding	Heller *et al*., 1997
	2003-2006	McKnight Foundation	Dakora, 2006
Namibia	2003-2006	EU Bamlink	Massawe *et al*., 2005
Nigeria	1984-1995	Local funding and IITA	Tanimu and Aliyu, 1997
Sierra Leone	1992-1994	EU Bamlink	Heller *et al*., 1997
South Africa	1980s/90s	Local funding	Heller *et al*., 1997
Swaziland	2000-2003	EU Bamlink	Sesay *et al*., 2004
Tanzania	1992-1996	EU Bamlink	Ntundu, 1995
	2003-2006	McKnight Foundation	Dakora, 2006
Zimbabwe	1990-1995	Local funding	Madamba, 1997

100 – 116 days. Collections made in areas with short wet seasons tend to mature more quickly. All the landraces evaluated in Burkina Faso which were collected from areas with annual rainfall between 350 and 600 mm, matured in 90 days or less (Ouedraogo *et al*., 2008).

Artifical hybridisation between BG accessions is difficult because the plant is self-pollinating and cleistogamous (i.e. pollen is shed before the flower opens). A hybridisation technique used in Zimbabwe was described by Madamba (1997), whereby a pair of forceps is used to open the bud and anthers bearing undeveloped pollen grains are removed. The style of the flower bearing the pollen grains is then carefully removed with forceps, and the pollen grains squeezed onto the emasculated female flower. Some hybridisation has been done At the University of Nottingham, but it remains a difficult procedure with the expectation of around 2% successful recovery of hybrid plants (Massawe *et al*., 2005).

Between 1992 and 1996, the University of Nottingham co-ordinated a major European Union (EU) project to assess the agro-ecological potential of BG in some countries in Africa (Collinson, 1997). This programme linked field experiments in Tanzania, Botswana and Sierra Leone, with contained experiments and analysis at Nottingham and Wageningen University. The objectives of the Project were to (i) define sites and seasons for BG cultivation in Tanzania, Botswana and Sierra Leone; (ii) produce a validated, mechanistic model for BG to predict BG performance in contrasting soil and atmospheric environments; and (iii) identify attributes associated with the ability to produce yields under semi-arid conditions.

Field trials in Botswana showed great variation between land races in seed size, pod number, 100 seed weight and total seed yield. Yields equivalent to 3000 kg ha^{-1} could be obtained in controlled environments, where day length was maintained at 12 hr and water supply was optimised. Further research was conducted between 1997 and 2003 in a collaborative project between the University of Nottingham and the Technical University of Munich in Germany, to use molecular techniques to improve the understanding of the diversity between and within accessions, and to further the rational exploitation of these resources in improvement programmes.

Studies conducted using Randomly Amplified Polymorphic DNA (RAPD) and Amplified Fragment Length Polymorphism (AFLP) markers revealed high levels of polymorphism among BG landraces (Massawe *et al*., 2005). There was considerable variation between and within landraces as well as potential for association of AFLP markers and agronomic traits. The work was extended between 2000 and 2003, with a project on increasing the productivity of BG, building upon the previous eight years of research. This time, the African partner countries were Botswana, Namibia and Swaziland. A number of pure lines were developed and combined to constitute ‘multilines’ to retain the genetic diversity which provides yield stability in land races (Massawe *et al*., 2005). The most recent of the EU-funded projects ran from 2006 to 2009 and aimed to develop idealised improved varieties and use molecular techniques (AFLP, SSR and DArT markers) to exploit marker assisted selection in crop improvement.

Inoculating BG with suitable strains of *Bradyrhizobium* can markedly increase yields. Efforts aimed at inceasing BG production should consider cultivar selection for effective symbiosis, preferably with native bradyrhizobial strains (Dakora and Muofhe, 1997).

Pests and diseases. At least in drier areas, BG seems to be remarkably free of serious pest and disease problems, and this may be due to two factors. Firstly, the small and scattered scale of production has avoided iatrogenic effects. Secondly, crop biodiversity and the presence in the plant tissues of secondary metabolites which may act as biocides and contribute to yield stability. The tough shell of the nut may protect against most insects but stored BG seed is particularly prone to attack by bruchids. Crop improvement activity to increase yield and palatability, and shorten cooking times, may also decrease yield stability through loss of resilience to a range of environmental and biotic stress factors and, increased susceptibility to pests and diseases, through a decrease in biocidal metabolites.

In Nigeria, virus diseases are widespread on BG in most environments, especially in areas where other grain legumes such as cowpea are grown. Two of the common virus diseases are cowpea mottle virus (CMeV) and cowpea aphid-borne mosaic virus (AbMV) (Ng *et al.* 1985). BG was artificially infected with eight sap-transmissible virus diseases (Thottappilly and Rossel, 1997). No information was presented on the effect of these virus diseases on crop yield.

Fungal diseases are common in humid conditions, such as leafspots (CLS) (e.g. *Cercospora* sp.), a wilt caused by *Fusarium* sp. and stem rot (*Sclerotium rolfsii*) (Begemann, 1986). A combination of unusually heavy virus attacks and CLS on one particular accession (TVSU 218), resulted in complete crop failure, during a trial conducted in Burkina Faso (Goli *et al.* 1991).

In Botswana, the main diseases are a *Fusarium* wilt, which attacks young seedlings in wet weather, particularly under waterlogged conditions, and CLS, during humid conditions but also, in dry conditions under irrigation.

In dry weather, pods may be attacked by termites and in one particular year, 1994-95, a severe attack resulted in the loss of an entire crop. Root knot nematode (*Meloidogyne javanica*) also attacks BG in sandy soils. In storage, shelled bambara groundnut seeds are extremely susceptible to attack by bruchids (*C. maculatus*). All landraces tested in Botswana were attacked by this pest, but the black-seeded landrace was affected less severely. The unshelled seed was extremely resistant to bruchid attack (Karikari *et al.*, 1995). According to Golob *et al.* (1998) the main bruchid species attacking the seed in northern Ghana was *C. subinnotatus* (Pic.).

The pests and diseases affecting BG in Namibia have not been identified but photos of the symptoms were presented by Fleissner (undated).The insect pests were aphids, harvester termites, leaf miner and a lepidopteran pest. Nematodes were a problem on sandy soils and the main disease was a powdery mildew.

In Nigeria, because BG is grown during the period of high temperatures and humidity, its leaves are often attacked by rust caused by *Puccinia* sp. and leaf blight caused by *Colletotrichum* sp. Rosette virus disease has also been observed on BG in Nigeria (Tanimu and Aliyu, 1995).

In Tanzania, the most common disease on BG is a leaf spot, caused by *Cercospora canescens*, producing severe premature defoliation. Virus rosette disease and powdery mildew diseases are also present. Two virus races which had been found to be latent in peanuts (*Arachis hypogaea*) were shown to cause the rosetting effect on BG. One variety from Bukoba (BA/30) and another from Mwanza (BA/25) showed high resistance to both CLS and virus rosette diseases. Kindale, a local variety from Ukiriguru Research Institute, was among the most resistant to rosetting. Powdery mildew, although widespread, occurred late in the season and was economically unimportant (Ntundu, 1995).

In Zimbabwe, aphids represent 65% of the insect pests on BG. The aphid problem is encouraged by late planting, and by periods of heavy rainfall, followed by days of sunshine. The main diseases are die-back, rosette and a virus disease, spread by aphids. The sap-sucking leafhopper, *Hilda patruelis* and termite damage have been recorded on BG in Zimbabwe. The root-knot nematode *Meloidogyne javanica* can seriously affect the crop in Zimbabwe (Gwekwerere, 1995).

In high moisture environments, for example in Sierra Leone and Morogoro in Tanzania. The most prevalent fungal diseases appear to be CLS, *Rhizoctonia solani* and downy mildew. Collinson (1997) noted that in some cases, whole experiments have been destroyed by diseases and states and concluded that BG was not as resistant to pests and diseases as was previously reported. The IITA BG collection was screened for resistance to CLS and 27% of accessions were found to be resistant (Goli *et al*., 1997).

ACKNOWLEDGEMENT

The Collaborative Crop Research Programme of the McKnight Foundation funded this research.

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