Production Practices of Bambara Groundnut

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Chapter 2
Production Practices of Bambara Groundnut

Abe Shegro Gerrano, Ehiokhilen K. Eifediyi, Maryke Labuschagne, Felix O. Ogedegbe, and Ahmed I. Hassen

2.1 Introduction

Bambara groundnut (*Vigna subterranea* (L.) Verdc), a leguminous crop belonging to the family Fabaceae; subfamily *Papilionoideae*, is widely cultivated in sub-Saharan Africa (SSA) because of its economic potential. *Subterranea* is the only cultivated species, while wild forms belong to the progenitor, var. *spontanea*. This crop is thought to have originated in Africa, specifically in the West African sub-region (Begemann 1988). Some scholars believe that Timbuktu in central Mali is the putative center of origin, hence its name Bambara (Goli et al. 1991). However, Linnemann et al. (1995) reported that cultivated Bambara groundnut is believed to have evolved from var. *spontanea,* which has widespread occurrence in West Africa, particularly in Nigeria and Cameroon. Although the Bambara is native to the SSA, it has shown wide adaptation across Southeast Asia, Australia, and in Central and

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South America, suggesting the potential existence of secondary centres of genetic diversity.

Based on the nomenclature, the common name given to the crop is Bambara groundnut and the preferred scientific name of *Vigna subterranea* with the other scientific name of *Voandzeia subterranea* (L.) Thousars, are synonymous. It belongs to the plant kingdom of the family of *Fabaceae* and sub-family of *Faboidea* (Bamshaiye et al. 2011). In different geographical locations and ethnic groups in the world, different names are given to the crop; for example, in Nigeria, the given name by the Igbos in the Southeast is *Okpa*, while the Hausas in the north call it *Gurujia*. In South Africa, it is called *Njugo* bean, *Nzama* in Malawi, and *Ntoyo* (CiBemba or Katoyo) in Zambia (Okonkwo and Opara 2010). Other names in Africa are Congo groundnut, Congo goober, Madagascar groundnut, earth pea, baffin pea, *voandzou*, *indhlubu*, and underground bean (Stephens 2012).

2.2 Botanical Description and Taxonomic Tree for Bambara Groundnut

Bambara groundnut is a herbaceous, intermediate, annual plant, with creeping stems at ground level (Bamshaiye et al. 2011). It is a small legume plant that grows to a height of 0.25–0.37 m with compound leaves of three leaflets (Bamshaiye et al. 2011; Shegro et al. 2013). The plant generally looks like bunched leaves arising from branched stems, which form a crown on the soil surface. After self-fertilization, pale yellow flowers are borne on the freely growing branching stems; these stems then grow downwards into the soil, taking the developing seed within the pods, which makes breeding and development of new cultivars for the traits of interest difficult. The seeds will form pods encasing seeds just below the soil.

The taxonomic tree for Bambara groundnut

Domain: Eukaryota
Kingdom: Plantae
Phylum: Spermatophyta
Subphylum: Angiospermae
Class: Dicotyledonae
Order: Fabales
Family: Fabaceae
Subfamily: Papilionoideae
Genus: *Vigna*
Species: *subterranea*

2.3 Breeding Methods and Focus Traits

One of the main reasons for the decrease in Bambara groundnut production and productivity is the absence of improved agronomic management practices and high yielding cultivars with disease and pest resistance for small-scale and commercial farmers in developing counties, including those in SSA. Bambara groundnut has never benefitted from any breeding programs targeting the development of improved cultivars, mainly because of its complex reproductive system, which is recalcitrant to artificial hybridization. To date, there are no registered or improved cultivars of Bambara groundnut and farmers still use landraces, which have been developed through several generations of mass selection. Although some of these landraces have essential adaptive traits, they are generally low yielding (Massawe et al. 2003a).

The complex anatomy of the Bambara groundnut reproductive system has been a significant impediment to the improvement of the crop. The crop has tiny florets that are difficult to hand pollinate and emasculate. Nevertheless, the Bambara is amenable to artificial hybridization (Massawe et al. 2003a; Suwanprasert et al. 2006). Several factors are fundamental in enhancing cross-pollination in Bambara and these include a suitable nursery environment which is the first step, short-day lengths (<12 h), and an average temperature of 26 °C which is required for optimum flowering and pod formation and a relative humidity of 90%. These conditions are achievable in Conviron growth chambers (Massawe et al. 2003b). When emasculating and pollinating, great diligence is necessary as the Bambara stamens and pistils are very fragile (Plate 2.1). The female plants should be stress-free soon after pollination. Massawe et al. (2003a) and Suwanprasert et al. (2006) developed several breeding populations in Malaysia, some of which have the potential for release as improved cultivars in Africa. Plant breeders can generate additional genetic variation through mutation breeding. The ability to make crosses, coupled with the elucidation of the annotated Bambara genome, means that careful trait selection can now commence, leading to the development of elite Bambara groundnut cultivars (Mayes et al. 2019) for the traits of interest.

As an underutilised crop, there is a lack of information relating to biotic and abiotic constraints affecting the productivity of Bambara. Hence, breeding priorities for Bambara improvement should be set, following extensive participatory rural appraisals to elucidate farmer trait preferences to stimulate uptake of the improved cultivars. At present, Bambara yields in peasant farm environments rarely surpass 1.00 t ha^{-1}, especially in tropical and subtropical regions, including southern Africa (Mayes et al. 2011). Selection for increased pod number per plant, pod weight, and seeds per pod can be a strategy for yield improvement.

The strict photoperiod requirement of Bambara also limits its productivity in countries further away from the equator. Long day lengths (>12 h) have a negative effect on pod-setting in some accessions, leading to crop failure. For smallholder farmers in various parts of Africa, where the timing of the rains often determines the cropping season, meeting photoperiod requirements of the local growing season can improve crop productivity, yield stability, and adaptation. Some accessions from

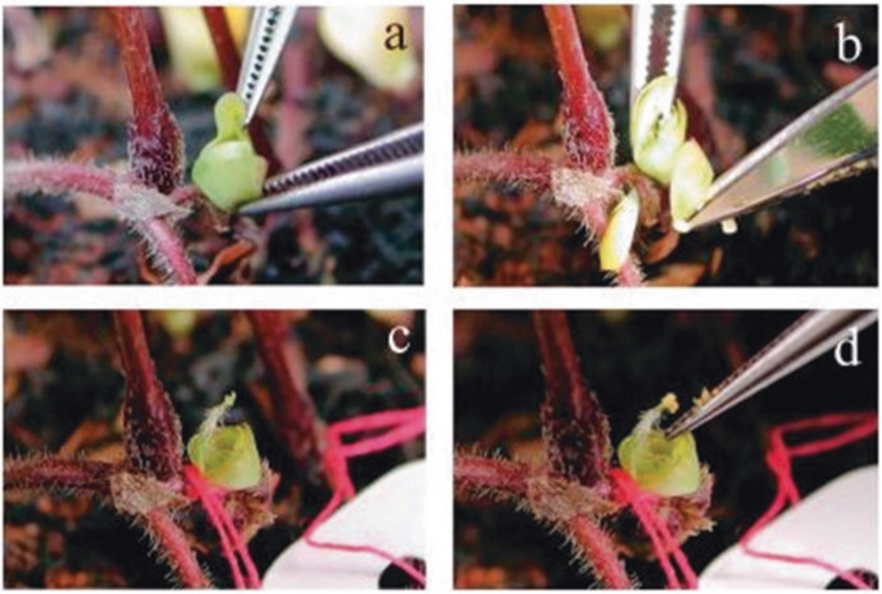

Plate 2.1 Methods of emasculation and pollination of Bambara (**a**) rending half of the keel petal to the top, (**b**) cutting-off the upper half of the petal, (**c**) tagging the emasculated flower at the peduncle level, (**d**) adhesion of pollen to the stigma of the female parent. (Source: Suwanprasert et al. 2006)

Mali, West Africa differ in photoperiod response to flowering time and pod-setting (Linnemann et al. 1995). For example, "TigaNicuru (TN)" is day-neutral in response to flowering time and photoperiod-sensitive for pod-setting. At the same time, the selection "Ankpa-4" is highly photoperiod-sensitive in terms of days to flowering and pod-set. This suggests genetic control of the trait. Hence, these accessions can be used to develop populations for association mapping to identify loci for photoperiod genes to initiate marker-assisted selection.

Bambara groundnut also has the "hard to cook" phenomenon (HTC) (Mubaiwa et al. 2017). Prolonged boiling time, often more than 4 h, is required to make the seed edible, and therefore high-energy is expended during cooking compared to other legumes such as cowpea, lentils, and common bean. Given the global energy crisis, there is a need to focus research on reducing cooking time and the overall functional utility of Bambara. This is because hardening of seeds causes a decrease in nutritional quality and extended boiling leads to reduced nutritional quality and digestibility. The hardening of legume seeds causes a decrease in nutritional quality, and extended boiling leads to reduced protein digestibility and further, processors also avoid grain with the HTC as the trait affects hydration during canning. The HTC phenomenon is not unique to Bambara but has been resolved in other legumes and cereals, including the common bean (Guzmán-Maldonado et al. 2003) and pearl-millets (Bouis and Welch 2010).

In legumes such as the common bean and soybean, the leading cause of HTC has been linked to seed coat characteristics such as seed colour and seed shininess. Testa colour influenced seed imbibition, gas diffusion, seed dormancy, and seed quality (Mandizvo and Odindo 2019). Bambara groundnut has a considerable variation for seed coat properties compared to most grain legumes, suggesting the existence of genetic variation in seed imbibition rates (Ntundu et al. 2006). This provides a basis for the need to reveal genetic factors affecting the HTC in Bambara. Following the release of a fully sequenced Bambara genome, QTL (quantitative trait loci) mapping approaches can be used to identify the genetic loci underpinning the HTC trait in Bambara. Such a study will lead to the development of molecular markers to assist in reduction in cooking time, and improvement in functional utility of the legume.

2.4 Economic Importance and Use

Bambara groundnut has huge economic importance to the people who are producing the crop for household use, or for commercial and industrial use of which the production level has remained low, and the processing and storage methods are still traditional (Aviara et al. 2013). This crop is an underutilised legume plant species in SSA and has an unrealised genetic potential to contribute to food security. It is grown for its edible seeds, providing starch and protein content for human food as well as for livestock feed, fodder, and forage. The crop is cultivated for its complementary nutritional advantage when consumed with cereal crops (Olukolu et al. 2012). The crop tolerates drought and has the genetic potential to adapt to adverse environmental growing conditions. It can resist pests and diseases (Sesay et al. 1999). The seeds can also be used as animal feed (Ntundu et al. 2006). Bambara groundnut seeds are usually consumed by the local population cooked or boiled, although in SSA countries the leaves are used for livestock feed. The crop can be eaten in various preparations including use as immature pods or as mature grain in various preparations. Immature pods may be eaten as a fresh snack, roasted, boiled, or crushed for use as a condiment (Bamshaiye et al. 2011).

2.5 Nutrition Benefits

Developing countries, particularly in SSA, are at present confronted with poverty, malnutrition, and current adverse effects of climate change, which directly influence food and nutrition security for rapidly increasing populations. Research in pre-breeding, trait discovery and variety development of legume crops will improve adaptability, the nutritional quality, yield and health potential. Currently, the COVID-19 pandemic is seriously affecting the world population, poor and rich alike, in food, nutritional, health and income security due to the problem of availability, accessibility and utilization of nutrient-rich food crops. This pandemic also significantly affects the agricultural food systems, resulting in decreased availability and accessibility of nutritious foods, and a rise in the global prevalence of micronutrient deficiencies sometimes referred to as hidden hunger.

Bambara groundnut is adapted to diverse environmental conditions and has significant nutritional, functional, and antioxidant potential and is a drought-tolerant crop in tropical and subtropical regions of the world. It is an excellent source of mineral nutrients (macro-and micronutrients) and vitamins. It is a good source of protein, fat and carbohydrate, with sufficient levels to be considered as a complete food (Minka and Bruneteau 2000; Murevanhema and Jideani 2013; Ndidi et al. 2014; Oyeyinka et al. 2015; Yao et al. 2015). The existence of anti-nutritional factors in the seeds of Bambara groundnut greatly limit the absorption of protein and minerals, especially iron and zinc in the body for growth and development (Murevanhema and Jideani 2013; Yao et al. 2015; Unigwe et al. 2018), but dehulling and other preparation methods such as boiling, heating and cooking reduce their activity in the food and body system (Barimalaa and Anoghalu 1997; Frunji et al. 2003). Dark-coloured seeds have been found to contain higher concentrations of tannins, therefore light-coloured seeds may be preferable to improve nutrition and reduce the cooking time needed to break down tannins and increase the bioavailability of nutrients in the body (Ofori et al. 2001; Caldas and Blair 2009). Similarly, it was reported that Bambara groundnut accessions with brown and red seed coats have a high concentration of tannins in the seeds; while the lowest tannin level was present in accessions with cream and light coloured seed coats (Ofori et al. 2001; Mkandawire 2007; Caldas and Blair 2009).

Food crops with high nutritional value in tropical and sub-tropical regions of the world remain one of the main thematic areas in achieving nutritional and health security through the subsequent selection of nutrient-dense cultivars in the breeding programmes and for the application of industrial uses. Bambara groundnut is a legume crop species, underutilised and indigenous to the African continent, which constitutes a rich source of protein, vitamins, and carbohydrates (Belewu et al. 2008) and has medicinal properties. The availability of adequate dietary protein in food is crucial to ensure healthy human development and growth (Moradi et al. 2019). Bambara groundnut is an excellent source of proteins and essential amino acids among legume crops, which varies from 22 to 35 g of proteins per 100 g (van Jaarsveld et al. 2014). Therefore, improving the cultivation and biodiversity of Bambara groundnut for food and nutrition security is important in addition to the important role it plays as a source of household income (Padulsi 2015).

2.6 Biological Nitrogen Fixation as a Tool for Enhanced Production in Bambara Groundnut

Like many other legumes, Bambara groundnut fixes atmospheric nitrogen through the process of Biological Nitrogen Fixation (BNF), the conversion of atmospheric nitrogen (N_2) into ammonia, which is regarded as the major supply of nitrogen to crops. Its potential to be used as an alternative to chemical fertiliser in agriculture has been investigated for many years (N'cho et al. 2013). The process is also very important to improve soil fertility and to supply other non-leguminous crops with the nitrogen left in the soil after the legume is harvested. This BNF process in legumes is executed by forming a symbiotic association with a group of soil bacteria, commonly known as rhizobia which fix atmospheric nitrogen naturally by forming specialized cells on roots, known as nodules (Kiers et al. 2003; Denison and Kiers 2004). However, not all bacteria in the soil form nodules on the roots and fix nitrogen, since most of the rhizobia are host specific to the legumes they infect (Lupwayi and Kennedy 2007). Rhizobia generally belong to the α-sub class of Proteobacteria that includes the genera *Rhizobium*, *Bradyrhizobium*, *Mesorhizobium*, *Sinorhizobium*, *Azorhizobium* and *Methylobacterium* and recently members of the genus *Burkholderia* belonging to the β-proteobacteria group have been reported to form nodules in legumes (Moulin et al. 2001; Hassen et al. 2020).

Rhizobia have been successfully used in the past as inoculants (bio-fertilizers) of various food legumes to minimize the application of artificially produced chemical fertilizers (Ngakou et al. 2009). The use of rhizobium inoculants in the cultivation of legumes has huge advantages not only in terms of attaining significant crop yield and improved protein content, but they are also less expensive than chemical fertilizers and harmless to the environment (Franks et al. 2006). For instance, when chemical fertilisers are used, most of the unused nitrogen and phosphorus remain in the soil, thereby causing environmental pollution (Adesemoye and Kloepper 2009). In the past several decades, many studies reported the symbiotic relationship and the specific rhizobia that nodulate and fix atmospheric nitrogen in legumes such as soybean, cowpea, chickpea, common beans, pea and clover (Keyser and Cregan 1987; Senanayake et al. 1987; Ndungu et al. 2018). This has, however, not been the case for Bambara groundnut, and many concerned stakeholders believe that this legume has been undermined and forgotten by researchers in the field. One of the reasons could be the fact that the legume is used mainly by peasant farmers, the majority of whom do not use rhizobia inoculant or other bio-fertilizers in the cultivation of their legumes (Amos et al. 2001). Since Bambara groundnut is the most under-researched and underutilized food legume in Africa, there exist neither sufficient improved varieties of this legume nor recommended agronomic practices for its sustainable cultivation (Ntundu et al. 2006).

There are a few studies that have been undertaken on the symbiotic performance and the rhizobia that nodulate and fix atmospheric nitrogen in Bambara groundnut for improved growth and yield. Some of these studies reported on the use and application of rhizobia by local farmers and their effectiveness in agronomic practices in improving and increasing nodulation, biomass production, and nitrogen fixation (Uguru and Ezeh 1997; Seneviratne et al. 2000; Mohale et al. 2014; Allito et al. 2015; Gnangui et al. 2019). These studies reported that the use of rhizobium as an inoculant in many legumes, including *Vigna subterranea,* has provided positive results by enhancing nodulation and nitrogen fixation and hence improving yield. A study conducted in South Africa and Ghana on the African origin of *Bradyrhizobium* populations gives a good assessment of the diversity of rhizobia that nodulate Bambara groundnut (Puozaa et al. 2017). According to this study, which used phylogenetic analysis of the sequences of 16S ribosomal RNA and other housekeeping genes, *Vigna subterranea* is nodulated specifically by a diverse group of *Bradyrhizobium* species including *Bradyrhizobium vignae*, and a novel group of Bradyrhizobium spp. In a separate study, screening studies on the nodulation of various Bambara groundnut cultivars by selected *Bradyrhizobium* strains in South Africa indicated promising results that might promote similar in-depth studies and the application of Bambara groundnut inoculants for use in agriculture (Plate 2.2) (Hassen et al. 2018).

In summary, there is a paucity of information about the symbiotic properties of Bambara groundnut that involve its nodulation and nitrogen fixation efficiency and the microsymbionts associated with it. As a result, no improvement and recommendation have been made so far for this legume in terms of its sustainable cultivation using formulated products of rhizobium inoculants. More research is thus needed to examine the detailed properties of the specific rhizobia that form a symbiotic interaction with this legume. Based on this, further laboratory and field screening trials will facilitate future selection and development of the most effective rhizobia for sustainable production of Bambara groundnut in Africa.

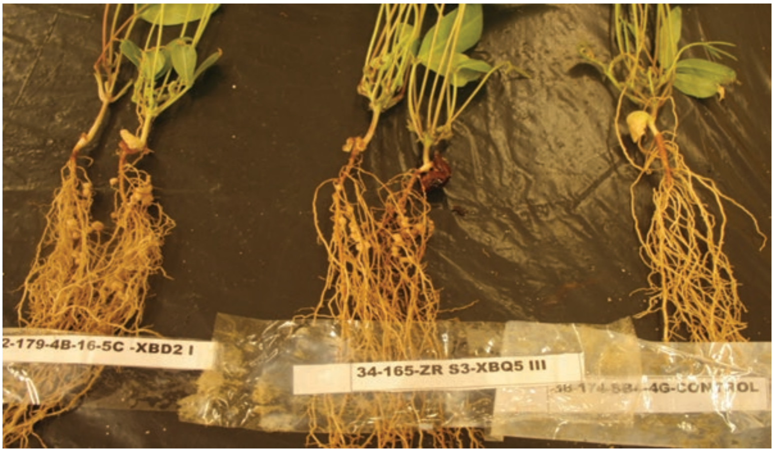

Plate 2.2 Conspicuous and pink nodules of Bambara groundnut cultivars inoculated with *Bradyrhizobium* sp. XBD2 (left) and *Bradyrhizobium* sp. XBQ5 (middle) compared with an uninoculated control with no nodules (right) in a glasshouse pot experiment. (Source: Hassen et al. 2018)

2.7 Bambara Groundnut Cultivation Practices

2.7.1 Choice of a Site for Bambara Groundnut Cultivation

Agricultural production takes place on land, hence the choice of land for Bambara groundnut cultivation (Plate 2.3) is very important as this can have profound effects on growth and yield of the crop. The best site should be fairly level to avoid a run-off. A well-drained site to avoid water logging because of rotting of the pods and stony areas should be avoided to prevent damage to pods or impede pod development. The soil should be of moderate fertility, where other leguminous crops cannot thrive (Yamaguchi 1983). Sandy loam soils are the best for the cultivation of Bambara groundnut (FAO 2007) which makes the development of the pod in the soil and harvesting easy (Anonymous 2016).

2.7.2 Soil and Climatic Requirements

Bambara is a fast-growing crop and requires about 110–150 days to complete its life cycle. The crop can tolerate drought and survive in areas where other leguminous crops such as groundnut and cowpea will fail (Tsoata et al. 2017), hence can be used to mitigate food insecurity. The crop is known for its tolerance to poor soils. Cultivating the crop under optimal environmental conditions will also result in good growth and yield. The drought tolerance of Bambara groundnut is brought about by the plant's ability to maintain leaf turgor pressure through a combination of osmotic adjustment, reduction in leaf area and effective stomatal control (Collinson et al.

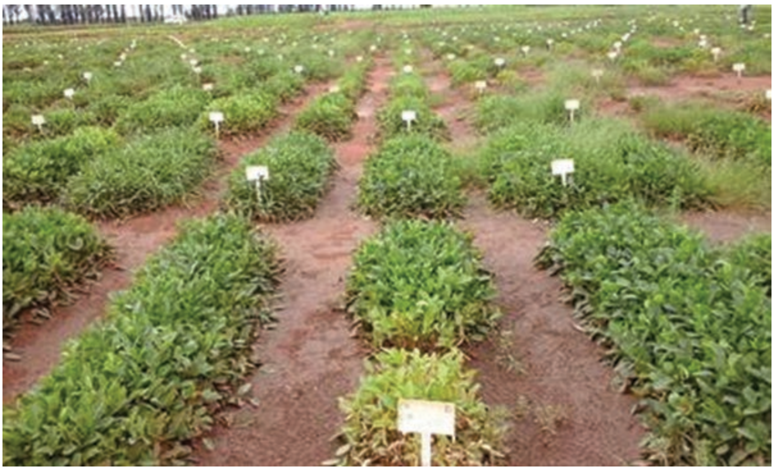

Plate 2.3 Bambara groundnut plants in the field. (Photo by Dr. Abe Gerrano, ARC, South Africa)

1997; Jorgensen et al. 2010). An optimum rainfall of 500–1200 mm which is evenly distributed, is the best rainfall regime for growing the crop (Anonymous 2016). However, the crop is tolerant to heavy rainfall, but too much rainfall at harvest time may result in yield reduction (Anonymous 2016). The optimum temperature for seed germination is between 30 and 35 °C and a day temperature of 20–28 °C. Very low temperature can cause chilling injury. Although the crop is resistant to high temperature, very high temperatures of above 38 °C during the growing season result in arrested development (FAO 2007). The optimum pH for Bambara groundnut cultivation is between 5.0 and 6.5, and a pH of less than 4.3 and above 7.0 is not ideal for its cultivation (FAO 2007). The optimal depth of the soil is between 50 and 100 cm (FAO 2007).

Bambara groundnut responds to day length. Long photoperiod favours vegetative production at the expense of pod production compared to those cultivated under short photoperiod (Brink 1999; Berchie et al. 2010a). Azam-Ali (1998) also reported that long photoperiods result in increased leaf production and a decrease in pod formation while Linneman (1993) observed that floral initiation with subsequent flowering, podding and increase in pod length were all affected by a day length exceeding 14 h.

Bambara groundnut is tolerant to salinity, but at high sodium chloride concentration in the soil, there will be competition between Na^+ and K^+ absorption resulting in Na/K antagonism which will lead to yield reduction (Mezni et al. 2002; Taffouo et al. 2010). Ambede et al. (2012) also reported the negative effect of salinity on seed germination, root length and leaf area of Bambara groundnut in Kenya.

2.7.3 Land Preparation

The land is cleared of existing vegetation, ploughed, harrowed twice to get a level seedbed and in some cases, ridges are constructed in areas prone to waterlogging. Oseghale et al. (1991) observed that the use of traditional hoes for soil preparation increased the growth and yield attributes of Bambara groundnut in Nsukka, South-East Nigeria whereas Eifediyi et al. (2020) reported economic advantage of zero tillage over other tillage methods in Bambara groundnut cultivation in Ilorin, north-central Nigeria. However, land preparation is an important cultural practice for the cultivation of Bambara groundnut because the pods are formed underground. In addition, a pulverized soil will assist the penetration of pod during podding.

2.7.4 Seed Treatment and Sowing

The seeds are treated with chemicals such as insecticide (chloropyriphos at 3 g kg^{-1} of seed) and fungicides such as Dithane at the rate of 1.1 kg ha^{-1} to prevent insect and fungal attack. These chemicals also prevent the seeds from being eaten by bush fowl (*Numida meleagris*). For even establishment, seeds are primed using water. Seed priming is done due to the variation in seed germination which is 7–21 days (Swanevelder 1998). Seed treatment is an important factor in Bambara groundnut cultivation, as this improves seed germination and stand establishment of the crop (Mabhaudhi and Modi 2011). Berchie et al. (2010b) reported that seed priming by soaking seeds in water overnight, followed by drying before sowing, improved seedling emergence, plant stand establishment, vigour and yield. Delayed germination/emergence is even more worrisome due to the area of cultivation, which is the semi-arid environment where there is low soil moisture. The semi-arid regions where Bambara groundnut is a dominant crop require that seeds be treated before sowing to improve germination and seedling establishment (Azam-Ali et al. 2001). The sowing time depends on the importance of the crop in the locality (Linneman 1990). In some locations, the crop is often intercropped with cereal crops such as millet, sorghum, maize and introduced after these cereal crops are established while in other areas, it is cultivated as a sole crop. Sesay et al. (2004) reported delayed emergence in Bambara groundnut due to drought in Swaziland.

2.7.5 Sowing Depth

Sowing depth is an important factor in the sowing of Bambara groundnut. Sowing depth will influence germination, seedling emergence and establishment (Ali and Idris 2015). When sown too shallow, the seeds will be exposed to desiccation by the sun and eaten by birds and mammals, and this can result in poor germination due to inadequate soil moisture in the topsoil layer (Desbiolles 2002). When sown too deep, some seeds will germinate without emerging due to pre-emergence mortality; also some seedlings will die due to lack of oxygen, light or temperature fluctuation (Vleeshouwers 1997; Aikins et al. 2006), and when it germinates in some cases, the seedlings will be less vigorous with poor leaf development due to the exhaustion of food reserves in the cotyledons before the commencement of photosynthesis by the leaves. So 3–5 cm is the appropriate sowing depth for even establishment and high yield. It has been reported in other crops like the fluted gourd (*Telfairia occidentalis)* that increasing sowing depth significantly reduced cumulative growth over time (Umeoka and Ogbonnaya 2016). Moreover, Fredrick et al. (2018) also reported that an increase in the depth of sowing will result in plants with thinner stems and poor vigour.

2.7.6 Spacing

Traditional farmers often intercrop Bambara groundnut with cereals such as sorghum, maize and millet. Sometimes the crop is sown simultaneously or introduced in the middle of the cropping season with these cereals. This often results in low yield due to suboptimal plant population density. Planting density of Bambara groundnut is often low (<100,000 plants ha^{-1}) in farmers' fields (Egbe et al. 2009) and especially when the crop is not grown in rows (Ngugi 1995), and this results in low yields. Planting density varies from one location to another in different parts of Africa. Mkandawire and Sibuga (2002) reported a spacing of 30 × 80 cm in Tanzania and a spacing of 60 × 30 cm in West Africa.

2.7.7 Sowing

In some locations, the crop is a major source of income, while in others, it is a minor crop, which is sown by women. Sowing by peasant farmers in tropical Africa is done by using manual methods, while mechanical sowing is possible by using modified soya bean planters due to its seed size, on commercial farms. Time of sowing in Africa varies from one country to another. In Northern Nigeria, sowing is done when the rains have regularised in June, while in Southern Nigeria, sowing is done in April – May. In South Africa, planting usually starts in summer from mid of October to end of December. In some provinces such as Limpopo, planting of Bambara groundnut starts in January due to the cultural beliefs. Sowing is usually done by a hoe or a cutlass, the soil is opened with a hoe and one seed is placed in the hole and closed. Seeds are not sown by broadcasting, as this will predispose the seeds to birds and small mammals.

2.7.8 Seed Rate

Bambara seed rate varies from 25 to 75 kg ha^{-1} (Anonymous 2016). The lower rate is usually the rate when the crop is intercropped while the higher rate is for sole cropping.

2.7.9 Weeding

Weeding is done twice or thrice during the growing season. If deep ploughing and harrowing were properly carried out, the first weeding is done at 3 weeks after sowing. However, manual weeding is carried out by peasant farmers by the use of handheld tools such as hoes and cutlasses. Hand pulling can also be done close to the seedlings. Furthermore, the use of herbicide supplemented by hand weeding can be also effective in weed management. Banta and Sodangi (2016) reported that the application of pendimethalin herbicide followed by one hoe weeding was effective in weed control for Bambara groundnut.

2.8 Fertiliser Application and Management

Bambara groundnut is a leguminous crop and fixes atmospheric nitrogen. The nitrogen needs of the crop are usually supplied by natural nitrogen fixation by Rhizobium bacteria (Baudoin and Mergeai 2001). Musa et al. (2016) reported that Bambara groundnut fixes about 32–82 kg N ha^{-1} while Yakubu et al. (2010) reported that Bambara groundnut can fix up to 28.42 kg N ha^{-1} in the Sudan and Sahel zones of Nigeria. However, Tweneboah (2000) reported that a high nitrogen level in the soil leads to excessive vegetative growth at the expense of pod and seed formation and subsequent low yield. It has been reported that when N is added late in the season, it will result in poor nodulation (Temegne et al. 2018). Nweke and Emeh (2013) advocated the use of single superphosphate fertilizer of 165 kg ha^{-1} for improved growth and yield in Igbariam, Southeast Nigeria while Toungos et al. (2009) suggested an application rate of 60 kg ha^{-1} of single superphosphate in Yola, North-East Nigeria. Eifediyi et al. (2020) reported an increase in growth and yield components of Bambara groundnut in Ilorin Northcentral Nigeria by using 40 kg ha^{-1} of single phosphate. In the centre region of Cameroon, an increase in growth and yield of Bambara groundnut was reported by Temegne et al. (2018) by using 150 kg ha^{-1} of single superphosphate. However, traditional farmers use organic manure from farm animals such as cattle, goats, sheep, poultry manure and other organic manures in very poor soils. Reported that using poultry manure at 10 t ha^{-1} improved the growth and yield components of Bambara groundnut in Wukari, Northern Nigeria. Wamba et al. (2012) reported that growth and yield of Bambara groundnut were improved by the application of water lettuce as green manure and poultry manure in Cameroon. Before any fertiliser is applied, soil analysis must be carried out to ensure the proper rate of application. Earthening-up is also an important cultural practice in Bambara groundnut cultivation. This is the heaping of the soil around the base of the plant. It is best done after flowering and this will ease harvesting and will have a positive effect on yield. However, it may predispose the plant to the effect of *Scelrotium rofsii,* a fungal disease.

2.8.1 Maturity Index

In dry environments, harvesting is done when the entire foliage dries up while in wet environments, harvesting may take place when the foliage is still green. Care should be taken because pod rotting or early seed germination is common when the leaves are still green.

2.8.2 Post-Harvest Handling

Bambara groundnut after harvesting is sun-dried to a safe moisture content of 12–14%. Over-drying leads to shrinking and warping of the seed; and sometimes death of the embryo, while too little drying leads to the proliferation of microbes during storage because of high moisture content. After drying, the seed pods are shelled either by hand or by pounding lightly in a mortar and pestle. Moreover, mechanical shelling can be done by using modified groundnut shellers to get a shelling percentage of 70–77 (PROTA 2010). The grains are then stored in bags or drums in granaries.

2.9 Conclusion and Research Needs

This chapter has examined Bambara groundnut as an important crop cultivated by peasant farmers in the developing countries of the world. The review confirmed that the crop has a high nutritional composition and that it can play a major role in the improvement of impoverished soils due to its nitrogen-fixing ability and hence reduce the fertiliser needs of the succeeding crop. This underpins the importance of the crop and could change scientists' perception of the crop as a poor man's food and take advantage of the crop's ability to tolerate drought and salinity in this era of climate change. In addition, the crop's ability to survive in hostile environments where other legumes cannot survive necessitates the carrying out of research in areas of shortcomings in the future which include:

1. Breeding of high yielding varieties; breeding of varieties which are easy to cook and have low anti-nutritional contents.
2. Breeding of varieties which have soft seed coats and take 5–6 days to germinate instead of the present 7–21 days.
3. Carrying out studies on the herbicide recommendations for the crop.
4. Studies on the intercropping with other crops apart from the cereals to find the appropriate seed rate for the crop under sole and intercrop conditions.

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