African Yam Bean: An Under-Utilized Legume with Potential as a Tuber and Pulse Crop

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ABSTRACT. African Yam Bean (*Sphenostylis stenocarpa*) is a legume that provides nutritionally rich seeds, tubers and leaves for human consumption. Production relies upon the cultivation of landraces and, to some extent, the collection of material from the wild. Currently, breeding programs do not exist to improve the genetic composition of this plant. There is an urgent requirement to instigate organized crop management programs, coupled with the genetic improvement of the crop through sexual hybridization. Additionally, *in vitro* genetic manipulation procedures and characterization of germplasms by molecular technologies will provide important adjuncts to conventional breeding approaches. doi:10.1300/J411v20n01_03 *[Article copies available for a fee from The Haworth Document Delivery Service: 1-800-HAWORTH. E-mail address: <docdelivery@haworthpress.com> Website: <http://www.HaworthPress.com> © 2007 by The Haworth Press, Inc. All rights reserved.]*

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INTRODUCTION

African Yam Bean (*Sphenostylis stenocarpa*) is one of seven species of the genus *Sphenostylis* E. Meyer (Leguminosae; Papilionoideae; Phaseoleae) that occur in dry forests and in open or forested savannas in tropical and Southern Africa. It is the most widely distributed and morphologically variable species in the genus and the most important economically (Potter, 1992). The plant is perennial; the stems often have a reddish pigmentation and are glabrous or sparsely puberulus and woody near their bases (Verdcourt and Døygaard, 2001). Roots develop tubers that are rich in starch and serve as organs of perenation when the aerial parts die during the dry season (National Academy of Sciences, 1979; Klu et al., 2001). The plants range from delicate prostrate twiners in some wild populations to robust climbers that reach a height of several meters. The leaves are pinnately trifoliate with linear, lanceolate, ovate or elliptic leaflets, depending on the landrace. The plants bear purple to magenta colored flowers on pseudoracemes. The individual flowers have twisted standard petals (Potter, 1992). Flowers are produced in 100 to 150 days from seed germination and, following pollination and fertilization, yield slightly woody pods, each measuring up to 30 cm in length. The pods each contain 20 to 30 seeds that mature about 30 days after fertilization (Klu et al., 2001). The seeds are brown, white, speckled or marbled in color, have a dark brown hilum border, are ellipsoid or round in shape and approximately 9 by 7 mm in size (Tindall, 1983). Botanical descriptions of African Yam Bean have been published by Potter (1992) and Verdcourt and Døygaard (2004).

African Yam Bean is grown widely in West and Central Africa, especially Nigeria (Tindall, 1983), but its center of origin in Africa is not known with certainty because its domestication cannot be traced to any specific locality (Potter and Doyle, 1992). Thus, because crops such as African Yam Bean are not assignable to a site of origin, they are categorized according to the ecological zones in which they have become domesticated. It is also believed that African Yam Bean may have originated from Ethiopia and spread throughout many areas of tropical Africa. The occurrence of wild races can also be traced to East and Southern African regions. A study of chloroplast DNA and linguistic data (Potter and Doyle, 1992) confirmed that African Yam Bean has West and Central African regions as its areas of domestication, where it is grown for seed and tuberous roots. The plant grows at sea level to elevations of 1800 meters (National Academy of Sciences, 1979). Although collection of plants from the wild for consumption is in decline, there is some evidence of the continuation of this practice, especially in Zaire and Congo, where tubers of a narrow-leaflet landrace are harvested from the wild, cooked and eaten as a vegetable (Potter, 1992).

POTENTIAL OF AFRICAN YAM BEAN AS A FOOD SUPPLEMENT

African Yam Bean is one of Africa's under-utilized plants with potential to broaden the food base for human consumption. Its tuberous roots contain more protein than sweet potatoes, potatoes or cassava roots and, aboveground, it produces satisfactory yields (2000 kg ha^{-1}) of edible seeds (National Academy of Sciences, 1979). The leaves are also used as a spinach/cooked vegetable (Tindall, 1983). Various nutritional studies (Apata and Ologhobo, 1990; Ene-Obong and Carnovale, 1992; Oshodi et al., 1995; Agunbiade and Longe, 1999) have revealed the potential of African Yam Bean as a food supplement to most diets consumed in the third world that normally lack some essential nutrients, resulting in malnutrition. Most of the literature on the nutritional potential of African Yam Bean has focused more on the seed than on tubers, although the latter are also equally important for their nutritional potential. African Yam Bean, like cowpea (*Vigna unguiculata*) and pigeon pea (*Cajanus cajan*), is rich in both protein and starch (Agunbiade and Longe, 1999). These nutritional components are responsible for the commercial importance of these latter crops.

Protein and Amino Acids of African Yam Bean

Apata and Ologhobo (1990) analyzed the nutritional composition of three varieties of African Yam Bean with grey, purple and mottled seeds. They recorded the mean crude protein of seed to be in excess of 20.9% of the dry weight following the processing procedures used (raw seed and seed cooked by boiling in water or autoclaving). The crude protein content of raw seeds was comparable to that of cashew nut, bambara groundnut, pigeon pea, lima bean, groundnuts and cowpeas. However, although the protein concentration was considerably less than that of soybean, the quality of protein in seeds of African Yam Bean was found to be excellent because of the type and concentration of amino acids in flour produced from dried seeds. The major amino acids recorded were alanine, arginine, aspartic acid, cystine, glutamic acid, glycine, histidine, isoleucine, leucine, lysine, methionine, phenylalanine, proline, serine, threonine, tyrosine, and valine (Oshodi et al., 1995). The concentration of total amino acids ranged from 311 to 603 mg g^{-1}, which is comparable to or exceeds that of soybean (444 mg g^{-1}). Importantly, the observations of Oshodi et al. (1995) placed the amino acid content of African Yam Bean above the 1985 FAO/WHO amino acid reference of cystine, lysine, methionine, phenylalanine, and tyrosine recommended for infants, pre-school and school children. These concentrations were also found to meet the 1973 World Health Organization (WHO) and 1985 FAO/WHO requirements for adults.

Ene-Obong and Carnovale (1992) found seeds of a range of African Yam Bean varieties to have a more acceptable nutritional composition of essential amino acids compared to cowpea and pigeon pea. Indeed, African Yam Bean can make an excellent alternative to cowpea, because some of its processing and preparation procedures are similar to those of cowpea. Evidence suggests that the nutritional value of African Yam Bean, particularly with respect to the composition of protein and amino acids, depends on the genotype and environmental conditions under which the plants are cultivated (Oshodi et al., 1995). Consequently, any difference in amino acid composition recorded by various researchers could be attributed to differences in genotype and cultivation practices.

Minerals

Analysis of African Yam Bean by Ene-Obong and Carnovale (1992) revealed less calcium (46 mg 100 g^{-1}) than cowpea (83.6 mg 100 g^{-1}) or pigeon pea (110 mg 100 g^{-1}). In an analysis of three varieties of African Yam Bean, Apata and Ologhobo (1990) observed slight varietal differences in mineral composition, these differences also being influenced by the processing procedure. Raw seeds gave greater values, followed by seeds that had been autoclaved, or seeds cooked by boiling. Potassium was the most abundant macro-element, followed by phosphorus. The major minerals recorded were potassium (9.7-12.0 g kg^{-1}), phosphorus (3.3-4.2 g kg^{-1}), magnesium (1.3-1.7 g kg^{-1}), calcium (0.70-0.80 g kg^{-1}) and sodium (0.04-0.06 g kg^{-1}), together with the trace elements zinc, manganese, iron and copper. Although African

Yam Bean is relatively rich in minerals, its potential as a source of these elements, like that of any legume, should be based on availability rather than the total concentration. The bioavailability of divalent minerals, such as calcium, phosphorus, magnesium and manganese, is negatively affected by phytic acid (Apata and Ologhobo, 1990), the availability of these minerals being reduced if seed is rich in this acid.

Fats

The fat content of African Yam Bean was found not to be significantly different from that of cowpea and pigeon pea (Ene-Obong and Carnovale, 1992), being 2.10% of dry matter compared with 1.95% and 1.77% for cowpea and pigeon pea, respectively. Oshodi et al. (1995) recorded the percentage of fatty acids in oil extracted from flour of the seeds of six varieties of African Yam Bean with different colored seeds (white, light brown, light brown with black stripes, reddish-brown, reddish brown with black stripes, black with light brown stripes). There was no significant difference in the fatty acid composition of the different varieties in the form of saturated acids (capric, caprylic, lauric, myristic, palmitic, stearic), monounsaturated acids (eicosenoic, erucic, oleic, palmitoleic) and polyunsaturated acids (linoleic, linolenic). Stearic acid had the greatest concentration of 34.4% in some cases, followed by linoleic (29.4%) and palmitic acid (19.9%). Any human health problems normally associated with saturated fatty acids and their induction of coronary disease because of their cholesterol concentrations, is not of concern with the consumption of African Yam Bean because stearic acid, the major saturated fatty acid recorded, is converted to monounsaturated oleic acid (Oshodi et al., 1995). The concentrations of linoleic and linolenic acids, the most important fatty acids essential in the diet for growth, physiological functions and general body maintenance in humans, were found to be acceptable in African Yam Bean at 29.4 and 2.7%, respectively.

Carbohydrates

Depending on the plant species, carbohydrates range from 24 to 68% of seed dry weight for legumes (Ekanayake et al., 2000). Such carbohydrates are monosaccharides, oligosaccharides, starch and other polysaccharides, with starch being the most abundant and also the major source of carbohydrate in the human diet. In addition to protein, African Yam Bean is rich in starch, analysis showing that the starch is non-ionic, with a low water activity and high bulk density (Agunbiade and Longe, 1999). The rate of starch digestion is less both *in vitro* and *in vivo* compared with that of cereals (Hoover and Zhou, 2003). The oligosaccharide concentrations of whole raw, raw dehulled, raw soaked and soaked/cooked seeds of African Yam Bean were, on average, 4.14% (w/w) stachyose, 4.08% sucrose, and 1.08% raffinose, compared with the values for cowpea of 3.06, 2.12, and 2.55%, respectively (Nwinuka et al., 1997).

Anti-Nutritional Properties

In contrast to its nutritional potential, some studies conducted on under-utilized legumes in Nigeria have revealed African Yam Bean to be one of the legumes with traces of anti-nutritional compounds, including α-galactoside, inositol phosphate, lectin, and tannins (Oboh et al., 1998). However, some food processing measures, such as seed dehulling, soaking, and soaking/cooking, have been found to reduce significantly the concentrations of some of these anti-nutritional compounds (Nwinuka et al., 1997), thus making African Yam Bean more acceptable for human consumption. Interestingly, in other studies, anti-nutritional compounds, such as lectin, have been found to confer some insecticidal properties on this legume that can be further exploited to benefit food security by reducing storage losses (Okeola and Machuka, 2000). Additionally, an investigation performed with rats fed on raw and processed seeds revealed a poor nutritive value of raw seeds (Apata and Ologhobo, 1990). The consumption of raw pulse seeds by humans is not common and, consequently, this observation may be an advantage more than a disadvantage in terms of reduction of storage losses normally caused by rodents.

AFRICAN YAM BEAN IN CROPPING SYSTEMS AND SUSTAINABLE PRODUCTION

Nitrogen Fixing Ability

African Yam Bean is a highly adaptable crop capable of growing even on acid and highly leached sandy soils of the humid lowland tropics (Potter, 1992), an attribute common to most under-utilized food plants known to flourish with little input in areas too marginal for conventional crops. An important reason for its success on marginal lands is that it develops nitrogen-fixing nodules, although attempts have not been made to isolate the endosymbiont(s). Obiagwu (1995a) recorded the formation of nodules on African Yam Bean plants that did not receive any fertilizer and those that received phosphorus, but none on plants treated with nitrogenous fertilizer. The contribution of African Yam Bean to soil productivity was attributed to nitrogen fixation and also to its low nitrogen harvest index, since substantial quantities of nitrogen remain in its residues and are available to other crops. In a screening experiment for a suitable cover crop, Obiagwu (1997) observed that the nitrogen-fixing ability of African Yam Bean was low in phosphorus deficient soils, but could be improved significantly with the application of this element. Tissue nitrogen content increased significantly from 26 to 203 mg kg^{-1} with phosphorus treatment.

Assefa and Kleiner (1997) showed the plant to nodulate following inoculation with the slow growing *Bradyrhizobium* sp. AUEB20, the latter being isolated from the Ethiopian leguminous tree *Erythrina brucei*. In more recent work, African Yam Bean also nodulated profusely with both the slow-growing *Bradyrhizbium* sp. CP279 and with the fast-growing *Rhizobium* strains NGR234 and ORS302, 79.0-97.6% of the nitrogen in the plants being derived from atmospheric nitrogen and increasing the growth of inoculated plants by up to 1547% compared to their uninoculated, non-nodulated counterparts (Oagile, 2005). Such plants were grown in pots in vermiculite, watered with a nitrogen-free solution and maintained under glasshouse conditions with a 12-hour photoperiod during the months of June to August in the UK. These results compare favorably to most tropical grain legumes mentioned by Giller (2001) and show that it is possible to grow African Yam Bean without the addition of any supplementary nitrogenous fertilizer, if inoculated with compatible *Rhizobium* strains. Nitrogen-fixing capacity of up to 7.04 μmoles g^{-1} h^{-1}, as estimated by the acetylene reduction assay compared favorably with 1.02 μmoles g^{-1} h^{-1} reported by Assefa and Kleiner (1997) on African Yam Bean inoculated with strain AUEB20.

This ability to fix symbiotically atmospheric nitrogen means that African Yam Bean does not require large amounts of nitrogenous fertilizer to meet its growth demands, thus making its production affordable to resource-poor farmers unable to purchase chemical fertilizers. Although constrained by various environmental and nutritional factors, including cropping patterns used in Africa, grain legumes still fix 15-210 kg N ha^{-1} annually, which benefits succeeding crops (Giller, 2001), thus making rapidly growing legumes, such as African Yam Bean, an important component of traditional cropping systems (Dakora and Keya, 1997; Pretty et al., 2003). The use of African Yam Bean and other legumes as cover crops has been shown not only to increase soil nitrogen content, but also to increase the amount of organic matter for maintenance of high soil productivity (Obiagwu, 1995b). Indeed, the contribution of nodulating legumes to soil and crop productivity has been widely documented, as in a recent article (Fening and Danso, 2002). Okpara and Omaliko (1995) reported yield increases of yellow yam (*Dioscorea cayensis*) as an intercrop with African Yam Bean, while Obiagwu (1995b) demonstrated that African Yam Bean increased the yields of maize, yam and cassava. In all cases, this increased growth was attributed to the ability of African Yam Bean to form a nitrogen-fixing symbiosis with *Rhizobium*. The climbing habit of African Yam Bean is also exploited, as it can form a living fence when grown on stakes around fields of cocoyam (Potter, 1992).

Regions of Cultivation and Cropping Systems

African Yam Bean is cultivated widely in most countries in West Africa, particularly in Guinea, the Ivory Coast, Nigeria and Togo, extending to parts of central and equatorial Africa (Tindall, 1983). In all areas of its cultivation, it is grown mainly as a minor intercrop with major crops, such as maize (*Zea mays* L.) and cassava (*Manihot esculenta* Crantz), especially in some areas of Ghana, where it twines around their stems for support (Klu et al., 2001). Potter (1992) made several observations in an extensive study of the species. In major areas of production in Zaire, African Yam Bean is grown as an annual where it is propagated by seed planted in September and October for tubers to be harvested during the following March to April. Similarly, for seed production and consumption, African Yam Bean is grown as an annual in most parts of Nigeria. However, in these areas, plants have also been observed to exhibit a perennial habit by re-growing from rootstocks every year after the dry season, with some plants being maintained for more than 20 years. Plants grown from seeds also take the same time to develop as tubers from planting to harvest, normally from April to July until December. In these mixed cropping systems, special attention is not given to African Yam Bean, because it benefits from the occasional cultural practices applied to the major crops. Unfortunately, Klu et al. (2001) noted a decline in production of African Yam Bean, with only limited quantities of the product being offered for sale in local markets, even though its price compared favorably with those of cowpea or groundnut. At present, improved varieties are not available in African Yam Bean and crop establishment is usually achieved through the use of landraces that farmers retain from previous harvests or, in some cases, from seed collected in the local markets. Lack of improved varieties with a dwarf erect stature, shorter growth period and seeds with testas that are easier to cook, have been identified as constraints to large-scale commercial cultivation of African Yam Bean (Klu et al., 2001).

The tuberous roots and seeds of African Yam Bean are the main organs consumed in its areas of cultivation. However, 7 to 8 months are required before seeds and tubers are ready for harvest (Potter, 1992). In addition, the yield, particularly of tubers, is usually limited (National Academy of Sciences, 1979). Therefore, it is important to investigate factors that control the formation and growth of tubers to improve their yield, as well as reducing the time to maturity.

African Yam Bean is thought to be sensitive to photoperiod and does not flower during the wet season (Tindall, 1983); a short-day photoperiodic response to flowering has been observed (Okpara and Omaliko, 1997). In an evaluation of the response of plants to fertilizer and planting time in Nigeria, grain yield was not affected by the time of planting, but other components, such as the development of nitrogen fixing root nodules, biomass and root yield, had a 20-30% reduction due to late planting (Obiagwu, 1995a).

Temperature may also affect the time of flowering. For example, plants of African Yam Bean failed to flower when maintained in pots with a mixture of equal volumes of John Innes No. 3 and Levington M3 composts, in growth rooms at 30°C with a 12-hour photoperiod provided by 400 W high pressure mercury vapor lamps giving an irradiance of 450 ± 25 mmol m^{-2} s^{-1}. In contrast, flowering was observed within 7 months in plants grown in a similar room with the temperature reduced to 25°C and the same photoperiod (Oagile, 2005). The photoperiod in the tropics is relatively short and, consequently, some legumes adapted to the tropics, including *Phaseolus* spp. (Davies, 1997) and *Vigna subterranea* (Linnemann and Azam-Ali, 1993), have been found to flower only at specific relatively lower temperatures. The period of development to flowering in yam bean (*Pachyrhizus* spp.) is reported to vary with the photoperiod, flower initiation being delayed by long days and occurring only when the photoperiod approached 12.5 hours (Sørensen et al., 1993). Because photoperiodic change is concomitant with temperature, it is likely that a lower temperature may play a role in flower induction not only in *Pachyrhizus*, but also in African Yam Bean.

As tubers of African Yam Bean develop underground, it has not been possible to identify the precise time of their initiation. However, the report that tubers are harvested about the same time as seeds (Potter, 1992) supports the possibility that tuber development follows the same pattern as that reported in yam bean (Sørensen et al., 1993). In the latter case, tuber initiation occurs within 4-6 weeks after plant establishment, irrespective of the photothermo period. However, growth under long days appears to be important only for vegetative development, linked to photosyntheic ability, required for tuber enlargement (Sørensen et al., 1993).

CLONAL PROPAGATION OF AFRICAN YAM BEAN FOR CROP IMPROVEMENT

Most legumes are propagated easily from seed. However, in certain cases, shortage and lack of availability of viable seed make it difficult to obtain enough plants for field trials in crop-improvement programs. In addition, seed-derived progeny may be highly heterogenous. Consequently, vegetative propagation by cuttings, or by *in vitro* approaches, is important in the rapid multiplication of elite plants to generate clonal lines, and to provide uniform source material for breeding/crop improvement programs. Additionally, *in vitro* propagation plays an important role in multiplying germplasm that can be conserved in gene banks through cryopreservation, the latter being a very relevant adjunct to conventional storage in seed banks, or in living plant collections.

Propagation of African Yam Bean by Stem Cuttings

The taking of cuttings of easy-to-root species is usually exploited as a method of asexual propagation to achieve genetically identical plants. A simple and rapid technique is required for the induction of a root system to maximize propagule survival resulting in vigorous plants (Vesperinas, 1998). The formation of adventitious roots on stem cuttings is influenced by several factors, including the relative balance of plant growth regulators, such as auxins, the physiological condition of propagules and the interactive effects of these factors. Day and Loveys (1998) observed that the response of cuttings of woody plants may be species-specific and that seasonal variation in the success of propagation may be mediated through changes in the concentrations of endogenous plant growth regulators or carbohydrates.

Experiments to multiply clonal material of African Yam Bean have shown that stem cuttings root readily without the application of auxin (Oagile, 2005). Indeed, auxins are unnecessary for the rooting of leafy, single node stem cuttings taken from 12 months-old plants, although root formation per cutting was enhanced and more synchronized in those cuttings treated with a low concentration of auxin (e.g., 1.0-5.0 g l^{-1} of indolebutyric acid; IBA). In these experiments, the ends of the stems were immersed for 60 seconds in an aqueous solution of the potassium salt of IBA, prior to placing the treated cuttings in a mixture of equal volumes of Perlite and peat in unheated trays with propagator lids. These findings are in agreement with the results from studies with other species, in which application of exogenous auxin stimulated rooting and increased the number of roots, although in some cases, relatively high auxin concentrations inhibited root formation and growth, reduced bud/shoot growth and even led to mortality (Ercisli et al., 2003). The presence of leaves on cuttings may be beneficial to rooting (Nketiah et al., 1998) due to their ability to produce endogenous auxins (Hartmann et al., 1997) as well as ensuring essential metabolic functions (Badji et al., 1991). However, rooting sometimes decreases with leaf area because of increased water loss through transpiration (Aminah et al., 1997).

In Vitro *Propagation of African Yam Bean*

In vitro propagation, generally termed micropropagation, is exploited extensively not only as a means of generating large populations of elite plants, but also as a procedure fundamental to plant genetic manipulation by somatic cell techniques. The latter involve exposure of somaclonal variation, somatic hybridization and cybridization, and transformation. Micropropagation enables clones to be generated under uniform laboratory conditions through manipulation of the culture environment and nutrient media. Several *in vitro* procedures have been described, including the culture of intact plants and shoots, isolated embryos, organs and parts of organs (explants), callus, single cells and isolated protoplasts (naked cells). Micropropagation involves shoot multiplication from meristematic tissues, such as apical and axillary buds, and the formation of adventitious shoots, either directly or indirectly by organogenesis on explants or callus. The pathway of shoot regeneration may also occur by somatic embryogenesis in both cases. Several of these approaches have been reviewed, including the application of protoplasts to genetic manipulation, physiology and plant-pathogen interactions in grain and forage legumes (Davey et al., 2003).

In vitro propagation is not always easily achieved in all plant families, including the Papilionaceae, because some genotypes have less inherent ability to regenerate than others. Nevertheless, several examples of legumes have been reported in the literature, with plants being regenerated from cultured tissues of black gram (*Vigna mungo*; Das et al., 1998), soybean (*Glycine max*; Samoylov et al., 1998), cowpea (*Vigna unguiculata*; Brar et al., 1999), peanut (*Arachis hypogea*; Akasaka et al., 2000), pigeon pea (*Cajanus cajan;* Singh et al., 2003), adzuki bean (*Vigna angularis;* Avenido and Hattori, 2000), mung bean (*Vigna radiate;* Devi et al., 2004), common bean (*Phaseolus vulgaris*; Santalla et al., 1998), and tepary bean (*P. acutifolius*; Zambre et al., 1998). Indeed, these reports emphasize the importance of *in vitro* approaches for the genetic manipulation of such target leguminous species.

In contrast to the reports presented for other grain legumes, information is not available in the literature on the application of *in vitro* techniques for the multiplication and genetic improvement of African Yam Bean. However, in preliminary studies, axenic shoot cultures were established from nodal explants taken from the stems of mature plants. Following surface sterilization of source material by immersion in a dilute solution of commercial bleach, explants were incubated on a semi-solid culture medium (Oagile, 2005). A medium based on the formulation of Murashige and Skoog (MS; 1962) was more suitable than a B5 (Gamborg et al., 1968) or Woody Plant medium (McCown and Lloyd, 1981). A cytokinin in the culture medium was essential for shoot initiation, with 6-benzylaminopurine (BAP) being preferable to 2-isopentenyladenine (2iP) or thidiazuron (TDZ). Most shoots were produced at a BAP concentration of 2.5 mg l^{-1}, whereas at concentrations of 0.25-1.0 mg l^{-1}, the shoots produced were taller. Increase in shoot number with BAP concentration, with shoot elongation being inversely proportional to BAP concentration, was in agreement with the observations of Polisetty et al. (1997) in chickpea (*Cicer arietinum*) and Girija et al. (1999) in *Crossandra infundibuliformis*. Future work with African Yam Bean should focus on optimizing the concentrations and combinations of growth regulators in MS-based medium that stimulate shoot regeneration from explants, and to reduce the extent of callus proliferation, since callus generally develops at the expense of shoots. Regenerated shoots of African Yam Bean were excised from the parental explants and rooted. Root induction necessitated the presence of auxin in the culture medium, with IBA being preferable to α-naphthaleneacetic acid, in agreement with reports for other species. Because root initiation was erratic, this aspect of micropropagation also necessitates additional investigation.

CONCLUSIONS AND FUTURE RESEARCH

The food and soil improvement potentials of African Yam Bean cannot be over-emphaszed. However, like many other third world crops, it is under-utilized because of inadequate information relating to its physiology and agronomy, together with lack of uniform planting material and agronomically improved varieties. It is also becoming over-shadowed by legumes, such as cowpea, and tuber crops, like potato (*Solanum tuberosum*), that have been improved with respect to their yield, quality, disease and pest resistance. As in the case of many other under-exploited species, the survival of African Yam Bean as a crop has been sustained mainly through tradition and the knowledge of local growers. This is evident from the general paucity of documented information on its cultivation.

The current pattern of exploitation, in which African Yam Bean is collected from the wild and its production is based on indigenous knowledge, is not sustainable and the crop faces genetic erosion if measures are not instigated to address the problem. Consequently, it is essential to focus research and to document information that will enhance the status of the plant and its potential as a food crop of considerable economic and nutritional value. For example, there is a requirement to characterize its growth and development under different environmental conditions to facilitate the formulation of decisions relating to its production. Focus should also be placed on genetic improvement through both conventional breeding and biotechnological approaches, with the aim of developing cultivars with increased yields compared to the landraces currently in use.

Genotypic variation exists in the growth of African Yam Bean landraces, particularly with respect to characteristics such as seed pigmentation, leaf size and number per plant. Morphological characteristics of existing landraces need to be correlated with detailed studies using state-of-the-art molecular approaches, as applied to other grain legumes. In bambara groundnut (*Vigna subterranea*), another under-utilized grain legumes of African origin, with food potential, Randomly

Amplified Polymorphic DNA and Amplified Fragment Length Polymorphism analyses have revealed variation between landraces. These techniques offer an opportunity to develop landrace-specific markers for purposes of identification as well as linking molecular markers to agronomic traits (Massawe et al., 2005). Using DNA primers designed for cowpea, Phansak et al. (2005) revealed more genetic diversity between accessions of yardlong bean (*Vigna unguiculata* ssp. *sesquipedalis*) using Sequence Tagged Microsatellite Site (STMS) analysis than variation based solely on plant morphology.

Flowering is likely to be photothermally controlled in African Yam Bean. The growth and development of plants should be investigated in different environments to characterize developmental patterns, the production of assimilates and their partitioning. An integrated study of the phenology and physiology of the species is essential to characterize developmental patterns that will provide guidelines for sustainable production of African Yam Bean as a long-term crop.

The nitrogen-fixing ability of African Yam Bean is an area in which research should be intensified, because its symbiotic association with *Rhizobium* will not only influence the performance of the plant itself, but will also contribute naturally to the soil nitrogen available to subsequent crops, negating the need for resource-poor farmers to purchase artificial fertilizers. Clearly, there is a requirement to evaluate indigenous bacterial strains that have an ability to form nitrogen-fixing nodules in existing and potential areas of African Yam Bean cultivation and to select the most efficient strains to be used as inoculants, following the approach in routine use for other leguminous crop species (Zahran, 2001). Selecting indigenous strains as inoculants could be the most efficient approach, as such bacteria are likely to be more persistent than any that are introduced (Fening and Danso, 2002). Thus, there is a need to search for specific bacterial strain-plant cultivar combinations to maximize nitrogen-fixation capacity. Occasionally, nodulation and nitrogen fixation in legumes may be stimulated by enhancing root growth through co-inoculation with other micro-organisms, as in the case of soybean with *Azospirillum* and *Bradyrhizobium* (Molla et al., 2001). Such an approach may be worthwhile to evaluate in African Yam Bean.

Clonal propagation techniques provide simple procedures for the rapid multiplication of elite germplasms and, importantly, such procedures are not dependent on regular seed production. The facts that cuttings of African Yam Bean taken from mature plants root readily without auxin treatment, that leaf area does not appear to affect the rooting ability of cuttings, and that cuttings of different size can serve as propagules, should make this approach readily adaptable to field conditions. Similarly, *in vitro* procedures provide a more sophisticated means of propagation. The establishment of shoot cultures, with regular transfer to new medium, enables germplasm to be maintained indefinitely under axenic conditions. Techniques need to be established for anther and ovule culture to generate haploid plants for use in conventional breeding programs. Likewise, robust protocols need to be developed for shoot regeneration by organogenesis and/or somatic embryogenesis from explants, callus, cell suspensions and isolated protoplasts, because these will be essential for the generation of somaclonal variant plants and those manipulated genetically through somatic hybridization, cybridization and transformation (Davey et al., 2005). Long-term targets for the genetic manipulation of African Yam Bean may focus, as in other major crops, on increased disease and pest resistances, and tolerance to drought and salinity.

In crops such as potato, tuber formation has been studied extensively *in vitro* (Smith, 2000), revealing the importance of cytokinin in the medium and certain environmental requirements for tuberization. *In vitro* microtuberization has been reported in three food yam (*Dioscorea*) species, through addition of jasmonic acid to the medium, or its methylester applied either to the medium or as vapor (Jasik and Mantell, 2000). Significant stimulatory effects were observed only when the photoperiod, salt composition and sucrose concentration of the medium were optimal for microtuberisation. This background knowledge affords the opportunity to conduct similar morphogenetical studies on African Yam Bean and to investigate the physiological control of tuberization of the roots both *in vivo* and *in vitro*.

Although it is generally considered a minor crop in most areas of its cultivation, farmers in some regions of Eastern Nigeria grow African Yam Bean as an important source of income and, indeed, it is the most important legume that they cultivate (Potter, 1992). There is a requirement to raise the profile of this plant, which is currently underexploited. Several food products available to the world's poor are lacking in dietary nutrients. Clearly, African Yam Bean has enormous nutritional potential to assist in the fight against malnutrition, provided specific parameters as outlined in this review are addressed and efforts are made to introduce crop management programs.

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