

Full Length Research Paper

African yam beans (*Sphenostylis stenocarpa*): A review of a novel tropical food plant for human nutrition, health and food security

Gbenga-Fabusiwa F. J.

University of Medical Sciences, Ondo, Ondo-State, Nigeria.

Received 6 May, 2020; Accepted 31 December, 2020

This review investigated African yam beans (AYB) as a novel tropical food plant for human nutrition. AYB plants food potentials, its nutritional and amino acid compositions were also examined. In the same vein, the health benefits, utilization of AYB in starch and composite flour technology as well as its toxicological analysis were explored. Also, strategies to minimize processing difficulties and antinutritional factors were highlighted. It was revealed that AYB plant products are very rich in protein, minerals and antioxidants with low glycemic index (GI). Furthermore, viable processing techniques like fermentation, boiling and roasting can reduce AYB antinutritional factors and its toxicological effects. The result suggests that AYB plant products can meet dietary needs of people suffering from malnutrition, kwashiorkor, diabetes and other cardiovascular diseases, thus improving food security. Full utilization of AYB plants in food, drugs and health industries should be explored by carrying out further studies on ethno-pharmacological claims of AYB leaves and tubers. The findings revealed that AYB plant products hold great potential in improving food security globally.

Key words: African yam beans, food security, nutritional factors, health benefits, limiting factors.

INTRODUCTION

Plant foods still maintain the greatest possible fountainhead of basic nutrients for major population globally. They are major sources of food for mankind that cannot be replaced. Plant foods are more advantageous over other sources of food due to the fact that they are readily available, cheap, affordable and generally acceptable. In Africa, especially in Nigeria, most of these plant food sources have gone to extinction, ignored and

underutilized (Abdulkareem et al., 2015; Barrett, 2010). African yam beans (AYB) is one of such neglected and underutilized foods. AYB is a tropical leguminous plant cultivated mainly in West African countries (Frank et al., 2016). Above the ground, AYB produces a good yield of edible seeds. It could be found in forests, open wooded grasslands, rocky fields, and marshy grounds as weed and cultivated crops. It grows on wide range of soils

E-mail: fjgbenga@unimed.edu.ng/fjgbenga74@gmail.com. Tel: 08038319220.

Author(s) agree that this article remain permanently open access under the terms of the [Creative Commons Attribution License 4.0 International License](https://creativecommons.org/licenses/by/4.0/)

including acid and highly leached sandy soils at altitudes from sea level to 1950 m (Frank et al., 2016). AYB is cultivated mainly for home consumption and only about 30% of the dry grain produced is sold (Osuagwu and Nwofia, 2014). The noticeable attracting flowers are mauvish-pink, purple or greenish-white in colour, which are about 2.5 cm in length and borne on stout auxiliary peduncles. The smooth, hairless seed pods are linear, flat, with both margins raised, 25 to 30 cm long and 1.0 to 1.5 cm broad, containing 20 to 30 seeds which may be ellipsoid, rounded or truncated, and show considerable distinct in size and colour; the largest are usually about 1.0 cm long and 0.7 cm wide (Adewale et al., 2010). AYB tubers are small and spindle-shaped usually about 5.0 to 7.5 cm in length and weighing on average 50 to 150 g (Adewale et al., 2010). Also, it can weigh up to 0.3 kg under favorable conditions. The tubers are rich in protein, and thus, regarded as an important source of amino acids. AYB dry matter is about 35% in which 14% are protein while 80% are starch (Frank et al., 2016; Ojueoderie and Balogun, 2019). The FAO/WHO (1991) have also reported the AYB amino acid profile to be higher than those in other legumes including soybean, and affirmed that this same amino acid profile compares favorably with whole hen's egg and met the organizations daily requirement of food. It was reported that the tubers can be cooked and eaten in the same manner with other tubers like yams and potatoes. The flavor of the tuber is similar to that of potatoes (Olisa et al., 2010; Okoye et al., 2019). The colour of the seed may differ from creamy-white or brownish-yellow to dark brown, occasionally with black steaky appearance. Previous work done on the AYB seeds showed that the dry matter is approximately (90.50%), which comprise protein (24-28%), fat (1.5-2.0%), total carbohydrate (74.10%), fiber (5.2-5.7%) and ash (2.80-3.20) (Frank et al., 2016; Nwokeke et al., 2013; Osuagwu and Nwofia, 2014; Olisa et al., 2010). The amino acid content of the protein depicted similar value to that of soya bean but richer and higher in histidine and iso-leucine (Frank et al., 2016; Nwokeke et al., 2013; Osuagwu and Nwofia, 2014; Olisa et al., 2010). The energy content of the seeds per 100 g dry matter was reported to be 1.640 kJ. It was reported that the seeds can be eaten without harm, non-toxic to humans, suitable for consumption but must be soaked in water for about 12 h before being cooked or processed (Olasoji et al., 2011; Ajayi and Akande, 2010). The plant has beautiful flowers that are cultivated as ornament in many countries like Europe. There are different varieties of AYB with different sizes, seed coat colors and shades; they include grey, white, black, brown and stripped brown AYB (Gbenga-Fabusiwa, 2019). Nigerian synonyms of AYB are: *Hausa* (Girigiri), *Yoruba* (Sese), *Igbo* (Okpodudu), and *Ibiobio* (Nsama) while the International synonyms of AYBs are: *China* (Fan-ko), *India* (Sankalu), *German* (Knollige Bohne), *Malawi* (Nkhoma), and *Ghana* (Kulege). There

are two edible products of AYB; they include its tuber that grows as the root and the seeds that develop in the pods (Olasoji et al., 2011). Some underutilized legumes similar to AYB including pigeon pea and baobab have been reported to be useful in the dietary management of cardiovascular diseases due to its high protein and fiber contents (Gbenga-Fabusiwa et al., 2019). However, AYB is deficient in sulphur containing amino acids, methionine and cysteine but very rich in lysine and thus could be utilized as a complementary diet (Abioye et al., 2015). The crop is highly underexploited due to the fact that little is known about it. Another reason for its underutilization is due to its relatively low farm yield and long cooking time which is about 140 min (Frank et al., 2016). It is one of the ideal sources of protein supplementation of starchy foods. This will improve the use of this lesser known and underutilized legume in a number of food preparations especially in the developing countries. Supplementation equally has resulted in products with high nutritional values. In line with the aforementioned, the effect of incorporation of AYB on the pasting, proximate and sensory attributes of cassava was studied by Nwokeke et al. (2013). Frank et al. (2015) studied the effect of AYB on serum calcium, inorganic phosphate, alkaline phosphatase and uric acid concentration on male albino rats. It was observed that there were significant reductions of the serum concentration of calcium and uric acid of the test group compared to those of the Baseline and Control groups. The reduction in uric acid level is an indication that AYB consumption could be a good remedy for gout and potential in mopping up urate crystals. Also, some gouty conditions usually led to arthritis. This also means that the AYB can be used as a local analgesic under this condition.

The reduction in serum uric acid concentration of AYB compares well with that of soybean (Frank et al., 2016). Sam (2019) stated that the seeds of AYB contribute to nutrient intake by the consuming populations in Nigeria and contain some pharmacological evidence for the treatment of stomach aches and acute drunkenness which can serve as an antimalaria, antidiabetic, fertility agent, anti-ulcer and cardioprotective agent. In Togo, Ghana and Nigeria, the lectin content of AYB seed is used as insecticide. The pastes made from the seeds are used as a cure for stomach ache/antacid. Also, when water is added to this paste, it becomes an anti-alcohol abuse (antabuse) which is natural unlike the drug disulfiram with its adverse drug reaction antecedents (Micheal et al., 2018). An increase in dietary protein has a negative effect on bone calcium level. The proposed mechanism is that increased protein intake (especially proteins with sulfur containing amino acids) leads to an increased glomerular filtration rate, reduced renal reabsorption of calcium, hypercalciuria and thus leaching of calcium out of the bone (Kumar et al., 2013). Food chemists are greatly concerned about oxalate due to its

adverse effect on the availability of minerals. Food having high level of oxalate can result in kidney dysfunction as its high levels tantamount to increased absorption of calcium in the kidneys (Michae, 2018; Okonkwo et al., 2013). Oxalate builds complex if taken by animals and also great amount of oxalate diets can increase the risk of absorbing renal calcium (Sam, 2019). Also, dietary oxalate can form complex with calcium, magnesium and iron resulting in insoluble oxalate salts and oxalate stone. However, polyphenols such as tannins have anticancer properties, so foods such as green tea that contain large amounts of these compounds might be good for the health of some people despite their antinutrient properties. The present unpredictability in the global food supply, the increased demand in searching for other food sources with general accessibility and willingness of weary consumers to consume functional food that will add values to their health prompted this study. A lot of researchers like Adegunwa et al. (2012), Adefegha and Oboh (2013), and Abioye et al. (2015) have investigated the nutritional potentials of plant seeds less known as other food sources. Developing nations' desire to advance in eradicating severe destitution and famine specifically necessitates doing great study in certain under-utilized native crops and tree plants. Due to the transformations all over Africa, wild plants are at risk of going into extinction and might affect the nutrition of the local people. The blood glucose responses of carbohydrate foods can be classified by the glycemic index (GI) and glycemic load (GL), which are considered to be valid indices of the biological value of dietary carbohydrates, and the measure of the potential of carbohydrate to raise blood glucose concentration after a meal (Abioye et al., 2015; Gbenga-Fabusiwa et al., 2019; Okonkwo et al., 2013). In short, carbohydrates that decompose rapidly during digestion have a high glycemic index due to the fact that blood glucose response is fast and high, while those that break down slowly have a low glycemic index (Okonkwo et al., 2013). Many starchy staple foods produced traditionally possess low glycemic indices and they include cracked wheat or barley, parboiled rice, dried peas, beans, pasta and lentils (Oboh et al., 2010). Michael et al. (2018) investigated the antidiabetic activity of seed milk extract in alloxan-induced diabetic rats. The oral glucose tolerance test was also carried out using animal experimental method. The phytochemical analysis of the milk extract revealed the presence of flavonoids, isoflavones, saponin, tannin, phytosterol, lignin and anthocyanidine at moderate concentrations. It was equally reported that the seed milk extract of AYB possessed anti-diabetic activity like the reference drug glibenclamide, and have blood glucose-lowering effect in a time and concentration-dependent manner. AYB is being increasingly consumed by diabetics, hypertensive and cardiovascular patients in some Nigerian communities. However, the processes

involved in making it ready to eat are cumbersome and time consuming, thereby denying vulnerable groups instant consumption access. Therefore, it is of great industrial and commercial importance to develop the technology for its processing into ready-to-eat breakfast cereals, in combination with other local food materials, which will eliminate the associated drudgery and add value to the products. Efforts are being made to promote the use of composite flour in which flour from locally grown crops and high protein seeds replace a portion of wheat flour for use in baking industries, thereby decreasing the demand for imported wheat and producing nutrients enriched flour baked products (Gbenga-Fabusiwa et al., 2018a; Adefegha and Oboh, 2013). Global nutrition survey revealed that the most dietary deficiencies are of protein and of high biological value (Chikwendu et al., 2014; Ajayi, 2011; Christian, 2010). Therefore, the introduction of affordable and readily available plant-derived alternatives to wheat protein could be one of the dietary interventions required to close a nagging nutritional gap in meal planning for diabetic clients. AYB including pigeon pea and baobab have been reported to be of great importance in the management of cardiovascular diseases due to its high protein and fiber contents (Gbenga-Fabusiwa, 2019). It possesses high metabolizable energy, low true protein digestibility and high mineral contents (Abioye et al., 2015). AYB is one of such legumes with a protein, fat and carbohydrate content of 22, 2.5 and 62.5%, respectively (Ikemefuna and Julian, 2010; Okonkwo et al., 2013). Despite its nutritive value and increased production in Akoko area and other South Eastern states of Nigeria, consumption has not increased as with cereal products. Food insecurity is a major challenge to be tackled globally as one billion people are suffering from starvation and malnutrition (Padulosi et al., 2013; Lama, 2017). The trends include the continuing addition of 70 million people per year to the earth's population and the desire of some 4 billion people to move up the food chain and consume livestock products. In China, for instance, annual *per capita* consumption of meat has risen from 20 to 50 kg in less than 30 years (Sasson, 2012, Chikwendu et al., 2014; Frank et al., 2016; Morales, 2011). About half of the grains produced in the world are used to feed the livestock. That is why the increase in cereal and fodder prices has a strong impact on livestock products. For example, milk rose from 80 to 200%, while poultry rose by 10%. Food self-sufficiency is the first challenge developing countries need to tackle and resolve (Sasson, 2012). Africa, where people under 15 years old represent some 45% of the whole population, will have to feed a population that is expected to increase from 832 million in 2002 to more than 1.8 billion by 2050. The agricultural sector, which employs about 60% of the whole population, represents some 20% of the gross domestic product (GDP) and provides more than 10% of the export



Plate 1. Varieties of African yam beans seeds.

revenues. It should become the driving force of economic and social development (Sasson, 2012; Abdulkareem et al., 2015; Ojuederie and Balogun, 2019; Oshomoh and ilodigwe, 2018). Food insecurity and malnutrition is a serious problem in Nigeria, despite all the efforts to combat them. This is because animal food which are rich sources of protein are very expensive and beyond the rich of majority of the population (Morales, 2011; Godfray et al., 2010). There is relatively little information about clinical trials of AYB plant products on kwashiorkor and diabetic clients. Therefore, this study intends to highlight the nutritive composition of AYB, its antioxidants potentials, glycemic response, other health benefits, antinutritional limitation factors, toxicological analysis and suggests viable ways to maximize its utilization in both food and pharmaceutical industries. This could be a veritable way of establishing and maximizing AYB health benefits and its utilization as well as improving food security globally.

MATERIALS AND METHODS

AYB samples were procured from interior farm of Oka-Akoko, Ondo-State, Nigeria. The beans were sundried and the picture taken as shown in Plate 1. The tubers of AYB were extracted from the international grain legumes information center (Adebowale IITA, 2010) while the leaves and the flowers pictures were sourced from Wikipedia, the free encyclopedia. These were done for a period of four (4) months. Effect of processing on nutritional composition of AYB was sourced from the reports of Abioye et al. (2015), Adewale et al. (2013), and Ngwu et al. (2014). This spanned for a period of one (1) month. Mineral composition of raw and processed AYB were extracted from the report of Uche et al. (2014) and Adegunwa et al. (2012) for one (1) month. Antinutrients of unprocessed and processed (boiled and roasted) AYBs with their respective permissible limits were reported according to Sam (2019), Chai and Liebman (2004), Uche et al. (2014), and Adegunwa et al. (2012) for

a period of two (2) months. It is worthy of note that amino acids compositions of raw and processed AYBs were extracted from the reports of Esan and Fasasi (2013) for one (1) month. Also, physical and chemical properties of AYB seed milk were obtained from the reports of Michael et al. (2018) and this took place for one (1) month. The gathering of other valuable information and resources took place for a period of four (4) months while the write up of the paper took four (4) months. It took total period of 18 months to complete the study. 78 papers (2010-2020) were reviewed, 10% of which are on AYB plants, 30% on nutritive composition of AYB, 20% on food security, 10% on health benefits, 20% on composite flour technology, 5% on toxicological analysis of AYB 3% on conclusion, 1% on recommendation and 1% on limitation of the study.

RESULTS AND DISCUSSION

African yam beans plants

AYB (*Sphenostylis stenocarpa*) is a perennial climbing bush, 1-3 m high, that is cultivated annually. Its leaves comprise three leaves with oval leaflets (2.7 to 13 cm long and 0.2 to 5.5 cm broad) (Abuldukareem et al., 2011; Chikwendu et al., 2014; Chinedu and Nwonyi, 2012). AYB is cultivated for its edible tubers, which resemble elongated sweet potatoes, and for its seeds, which are contained in hard and tough pods of about 20-30 cm long. It is exclusively utilized as food for feeding livestock (Ajayi et al., 2010; Heuze, 2016; Ikemefuna and Julian, 2010). It grows on deep, loose sandy and loamy soils with good organic content and good drainage. It flourishes better in regions where annual rainfall lies between 800 and 1400 mm, and where temperatures ranged from 19 to 27°C. The plant springs up flowers after 90 days and the pods become mature in 140 to 210 days. The tubers are ready to harvest as from 150 to 240 days after planting (Ohanmu et al., 2018; Heuze, 2016;



Plate 2. African yam beans tubers. Source: Adebowale (2010).

Ikemefuna and Julian, 2010). AYB plant yields small spindle-shaped tubers that are about 5.0 to 7.5 cm tall (Olisa et al., 2010; Okoye et al., 2019; Aremu and Ibirinde, 2012). The seeds are usually ground and substituted to other flour to produce composite flour so as to improve its functional potentials. Seeds can also be used in the preparation of soups, sauces and starch (Olasoji et al., 2011; Ajayi and Akande, 2010, Ajayi et al., 2010). They are important source of calcium and amino acids (Frank et al., 2016; Nwokeke et al., 2013; Osuagwu and Nwofia, 2014; Olisa et al., 2010). Greater attention is being paid by the researchers on the exploitation of starch from under-utilized legumes seeds like pigeon pea and AYB so as to alleviate protein-energy deficiency in food and to improve products diversification of legumes. The picture of two varieties of African yam beans is as shown in Plate 1. They can cause giddiness if consumed in excess; however, it was believed that they can cure drunkenness when mixed with water (Sam, 2019; Yusuf et al., 2013). The high protein content of AYB makes it an important source of protein in the human diets of many tropical countries (Elsie and David, 2016). Furthermore, the high protein bean flour fractions could be substituted for wheat flour to produce good quality biscuits and bread in food industries (Gbenga-Fabusiwa et al., 2018b; Yusuf et al., 2016; Nneoma et al., 2012; Amakoromo et al., 2012). It could also be used in preparing porridge, moimoi and beans cake. The flesh is white and watery, the tubers can be eaten fresh and thus saving the cost of fuel and fire woods (Heuze, 2016; Ojueoderie and Balogun, 2019; Popoola et al., 2011). The researchers that worked on AYB food processing reported that soaking overnight is a vital key to minimize cooking period (Heuze, 2016; Ojueoderie and Balogun, 2019; Popoola et al., 2011). The tubers could be eaten raw or processed, however, the details are still not well

understood, therefore, more work is expected to be carried out on this. Some countries like Mexico process the raw AYB in the following ways: raw tubers are sliced into sticks, sprinkled with lime juice and chill; the sliced tuber could be added to salads for dinner; cooked tuber could be used with or without vegetables for soup preparation; they can also be grated and boiled in milk to create a tasty drink; the tuber could be sliced, diced and pickled with onion and chill to form a popular snack food (Heuze, 2016; Ojueoderie and Balogun, 2019; Okoye et al., 2019).

Furthermore, it was reported that AYB are preserved in vinegar and used as a variety of three-bean salad. The picture of AYB is as shown in Plate 2. AYB should be cultivated industrially to meet the need of people in dearth need of food especially during this corona virus compulsory vacation. AYB leaf and flower are shown in Plates 3 and 4, respectively. The plant is adaptable and can be cultivated anywhere. The plant climbs, twines to heights higher than 3 m, thrives in a region where the rainfall is extremely high and tolerates and grows even in acidic, leached and infertile soil (Heuze, 2016; Osuagwu and Nwofia, 2014). However, there is dire need of information on the health benefits of the AYB leaf and flower. AYB plant has mutual symbiosis with bacteria that fix nitrogen from the atmospheric air and thus adding nutrient such as nitrogenous fertilizer to the soil as well as saving the cost of procuring fertilizers (Osuagwu and Nwofia, 2014; Uwaegbute et al., 2012). In Nigeria, the plant is cultivated from the tropical forests to at least the savanna by the primitive farmers. The plant has great potential feed for livestock and green manure for rejuvenating the soil fertility. It is believed that the leaf is edible but the mode of processing it and the safety of eating it has not been established experimentally. The protein-rich leafy vegetables left-over after harvesting



Plate 3. African yam beans leaf. Source: Wikipedia.



Plate 4. African yam beans flowers. Source: Wikipedia.

serve as useful fodder and are nutritionally beneficial to livestock. However, the utilization of AYB protein-rich-leaf has not been investigated and could be useful in the formulation of dietary supplement.

African yam beans as a solution for the food security problem

Food security occurs when mankind gain access physically, socially and economically to adequate, safe

and nutritious meal to meet their dietary demands and functional food preferences for healthy and active living (Sasson, 2012; Adewale and Dumet, 2010). Sasson (2012), Petrikora et al. (2017) and Adewale and Dumet (2010) identified food availability, access to food, its utilization and stability as the core four pillars of food security. Food insecurity is a major challenge to be tackled globally as one billion people are suffering from starvation and malnutrition (Padulosi et al., 2013; Kandala et al., 2011; Godfray et al., 2010; Lama, 2017). Previous work done revealed that 11.11% people are malnourished, more than 70% of these human beings reside in developing countries. Severe wasting of 52 million children occurs globally due to undernutrition (Hickel, 2019). This results to 45% of deaths in children under five that is 3.1 children die in a year due to malnutrition (Kinyoki et al., 2020). Food and Agricultural Organization of the United Nation (FAO) is expertizing action on attaining sustainable development goals (SDGs) to terminate hunger, accomplish food security and ameliorate sustainable agriculture. Globally, an estimated 155 million children are influenced negatively by acute malnutrition. It also hinders the normal development of children's brain and promotes the risk of death (Fan and Polman, 2014). The International Food Policy Research (2013) reported that emphasis of the SDGs should not be to terminate poverty by 2030, but to abolish hunger and malnutrition by 2025 (Fan and Polman, 2014). Agriculture, social protection and dietary intervention or a combination of any two methods stated are major tracks to eliminate hunger and malnutrition (Fan and Polman, 2014). The number of persons experiencing pains from hunger is estimated at 239 million in sub-Saharan Africa, and this number could shoot up rapidly in the nearest future. The major identified source of food insecurity is insufficient food production. There has been great increase in awareness to cultivate more and better functional foods like AYB to enhance food security since the global food insecurity of 2007 to 2008 (Padulosi et al., 2013). The food insecurity the world is experiencing is motivated by the accumulation of successive confirmed phenomena that influence demand and supply globally (Sasson, 2012; Chikwendu et al., 2014; Frank et al., 2016; Morales, 2011). The phenomena comprise continuing inclusion of 70 million people annually to the world population and the demand for 4 billion populaces to go up the food chain and consume animal products. For example, meat consumption per capital per year in China rose from 20 to 50 kg in less than 30 years (Sasson, 2012; Chikwendu et al., 2014; Frank et al., 2016; Morales, 2011). Livestock are fed with about 50% of the grains produced globally, as a result of this higher prices of cereal and fodder have a strong competitive impact on livestock products. Consequently, the prices of milk rose from 80 to 200%, while poultry rose by 10%. Food self-sufficiency is the

most eminent difficulty task that the developing countries need to tackle and resolve (Sasson, 2012). In Africa, people with less than 15 years old typify 45% of the total population; this is anticipated to rise from 832 million in 2002 to above 1.8 billion by 2050 which have to be fed. The agricultural industry hires about 60% of the total population which exhibits 20% of the gross domestic product (GDP) and furnish with greater than 10% of the export turnovers. This should emerge the driving force for economic and social growth (Sasson, 2012; Abdulkareem et al., 2015; Ojuederie and Balogun, 2019; Oshomoh and Ilogigwe, 2018). Food insecurity and malnutrition is a serious problem in Nigeria, despite all the efforts to combat them. Global nutrition survey displayed that the most dietary inadequacies are protein of high biological value (Chikwendu et al., 2014; Petrikova and Hudson 2017). This is because animal food which are rich sources of protein are very expensive and beyond the reach of majority of the population (Morales, 2011; Godfray et al., 2010). However, vegetable proteins complement each other, for example, a combination of legume and cereal protein will possess a nutritive value as good as animal protein. Chikwendu et al. (2014) and Frank (2015) reported that protein inadequacy cannot be surmounted by using animal products alone. However, it can be improved in combination with vegetable protein consumption, which makes up to 70% of world's protein production. Masika (2014) reported that food insecurity is associated with increased risk of non-adherence to antiretroviral therapy among HIV-infected clients. Mankind are endowed with plant resources for meat before their arrival on earth. Availability of functional plants is not a challenge in developing countries like Nigeria, which is having rich agroclimatic, cultural and ethnic biodiversity. However, full utilization of these functional plants in food, pharmaceutical and health industries is a big challenge. AYB has been reported to have the potential for supplementing the protein requirement of many families throughout the year (Ikemefuna and Julian, 2010; Okonkwo et al., 2013). Several processing methods have been used to enhance its acceptability and nutritional values (Uwaegbute et al., 2012; Abioye et al., 2015). The blood glucose responses of carbohydrate foods can be classified by the glycemic index (GI) and glycemic load (GL), which are considered to be valid indices of the biological value of dietary carbohydrates, and the measure of the potential of carbohydrate to raise blood glucose concentration after a meal (Abioye et al., 2015; Gbenga-Fabusiwa et al., 2019; Okonkwo et al., 2013). AYB potential to scavenge free radicals and to act as a chelating agent of metal ions, or act as hydrogen donor enable it to neutralize the effect of free radical in the body. AYB is usually cooked and eaten either alone or with yam, maize and rice. It can be used to replace cowpea in food preparation especially during the lean period when food is scarce among rural farmers

(Frank et al., 2016; Nwokeke et al., 2013; Osuagwu and Nwofia, 2014; Olisa et al., 2010; Kandala et al., 2011). It is one of the ideal sources of protein supplementation of starchy foods. This will improve the use of this lesser known and underutilized legume in a number of food preparations especially in the developing countries. Supplementation equally has resulted in products with high nutritional values. In line with the aforementioned, the effect of incorporation of AYB on the pasting, proximate and sensory attributes of cassava was studied by Nwokeke et al. (2013). It was reported that incorporation of AYB into cassava gives the product referred to as AYB fufu flour. The feasibility of using the legume (AYB) and guinea corn to produce a weaning food formulation has also been investigated (Chikwendu et al., 2016). Michael et al. (2018) and Yusufu et al. (2016) produced cookies from maize, AYB and plantain composite flour and reported that cookies had higher levels of proteins, fat, moisture, beta-carotene (provitamin A), vitamin C, and iron but reduced carbohydrate when compared with the control (100% Wheat). Cookies produced from 70% maize, 20% AYB and 10% plantain composite flour had the highest score for general acceptability and compared favorably with the control cookies for almost all sensory attributes. Microbiological analysis revealed that all the cookies produced were free of microorganisms for up to two months of storage under ambient conditions. Uche et al. (2014) studied the level of anti-nutrients composition of raw and processed AYB. It was observed that the processed AYB registered significant reduction in levels of hydrogen cyanide, trypsin inhibitor, phytate, oxalate, and tannins compared to the unprocessed. AYB is being increasingly consumed by diabetics, hypertensive and cardiovascular patients in some Nigerian communities. However, the processes involved in making it ready to eat are cumbersome and time consuming, thereby denying vulnerable groups instant consumption access. Therefore, it is of great industrial and commercial importance to develop the technology for its processing into ready-to-eat breakfast cereals, in combination with other local food materials, which will eliminate the associated drudgery and add value to the products. Researchers who did a nutritional evaluation of 44 genotypes of AYB reported that the crop is well balanced in essential amino acids and has higher amino acid content than pigeon pea, cowpea, and bambara groundnut (Chikwendu et al., 2014; Ajayi, 2011; Magdi, 2010). Apart from the use of soybean as an alternative to animal protein, protein from other plant sources is not often exploited. Thus, AYB incorporation in formulating new food products may suggest a viable way of food security. Another researcher reported on positive contribution of AYB to food security due to presence of lectin identified in the seeds, which could be a potent biological control for most leguminous pests (Chikwendu et al., 2014; Ajayi, 2011; Magdi, 2010). AYB farming is

Table 1. Effect of processing on nutritional composition of AYB (g/100 g).

Sample	Moisture	Ash	C. Fiber	Fat	C. Protein	Carb
UAYB	10.58±2.01 ^{ab}	2.79±0.30 ^a	9.40±0.24 ^a	2.84±0.05 ^a	21.54±1.51 ^a	62.92±1.05 ^d
AYBB	12.61±0.01 ^{ab}	2.64±0.04 ^a	7.98±0.00 ^a	1.88±0.00 ^a	18.95±1.06 ^a	64.90±1.06 ^c
AYBR	9.83±2.62 ^{ab}	2.64±0.01 ^a	8.84±0.50 ^{ab}	2.41±0.03 ^a	20.47±0.00 ^b	68.62±1.52 ^{bc}

Source: Abioye et al. (2015), Adewale et al. (2013), and Ngwu et al. (2014).

Table 2. Mineral composition of raw and processed AYB (mg/100 g).

Sample	UAYB	AYBB	AYBR
Ca	245.00±5.0 ^b	220.95±0.30 ^a	249.40±6.24 ^c
P	252.61±0.0 ^b	226.40±0.04 ^a	257.98±0.00 ^c
Mg	89.83±2.62 ^a	91.84±0.50 ^b	90.41±0.03 ^b
K	478.47±0.00 ^b	452.62±1.52 ^a	580.62±1.52 ^c
Na	352.47±0.00 ^a	392.62±1.52 ^c	389.62±1.52 ^b
Mn	3.57±0.00 ^b	3.26±1.52 ^a	6.0062±1.52 ^c
Fe	19.47±0.00 ^a	19.22±1.52 ^a	19.62±1.52 ^a
Cu	2.28±0.00 ^a	2.42±1.52 ^a	2.49±1.52 ^a
Zn	6.05±0.00 ^b	3.75±1.52 ^a	3.79±1.52 ^a

Source: Uche et al. (2014) and Adegunwa et al. (2012).

not capital intensive; hence, it could provide new vista of opportunities for farmers. It is a remarkable wholesome quality crop, since is mostly cultivated by primitive farmers which constitute about 70% of African population. It provides a functional way to economically empower the poor farmers, thus improve the standard of living of mankind. The seeds are drought resistant and perfect for intercropping and crop rotation; they do not require huge land space but do enhance nitrogen fixation and consequently soil fertility. Food insecurity and malnutrition is a serious problem in Nigeria and the globe at large, despite all the effort to combat them. The food industries should subscribe to the production, processing and utilization of this under exploited AYB leguminous plant as they could be valuable in the persistent fight against hunger, malnutrition, diabetes and food insecurity.

Nutritional composition of AYB

Animal food which are rich sources of protein are very expensive and beyond the rich of majority of the population (Chikwendu et al., 2014; Ajayi, 2011). However, vegetable proteins complement each other, a combination of legume and cereal protein will have a nutritive value as good as animal protein. According to Ajayi (2011) protein deficiency cannot be overcome by using animal products alone. He maintained that the only

alternative is to push up the vegetable protein intake, which already makes up 70% of world's protein production. This study revealed that AYB have many nutritional benefits which could improve the level of malnutrition, boost food security and serve as a good functional food in formulating composite flour that possess some health benefits. Tables 1, 2, and 3 depicted the proximate, mineral and antinutrient compositions of processed and unprocessed AYB. It was revealed that the nutritional composition of AYB consists of carbohydrate (63.39), ash (3.41), fat (0.54), protein (20.37) and crude fiber (1.54). The average mineral composition comprised Na (496), K (620), Ca (92), Mg (103), P (251), Zn (6), Fe (53), Mn (12), Cu (1.3), Cd (2.1) but Hg, As, Ni were found below detection limit (Abioye et al., 2015; Adewale et al., 2013; Ajayi et al., 2010; Ngwu et al., 2014). Yusufu et al. (2013) evaluated complementary food produced from sorghum, AYB and mango mesocarp flour blends and reported an increase in the protein and fat level of the formulated complementary food from 8.90 to 17.40 and 1.50 to 3.50, respectively. However, a significant decrease in the carbohydrate level (78.00 to 67.59%) was observed. The sensory evaluation revealed that the formulated complementary food had good overall acceptability. In addition to this, it is revealed that the food produced is a protein-rich product with good functional potentials. Yusufu et al. (2016) produced cookies from maize, AYB

Table 3. Antinutrients of unprocessed and processed AYB.

Antinutrient	UAYB	AYBB	AYBR	PL
Hydro cyanide (mg/kg)	18.58±2.01 ^a	44.29±1.30 ^b	49.40±1.24 ^c	50
Tannin (mg/g)	16.40±0.01 ^b	3.64±0.04 ^a	3.45±0.00 ^a	20
Phytate (mg/100 g)	429.30±2.62 ^b	125.34±0.01 ^a	122.84±1.50 ^a	50
Oxalate (mg/kg)	8.41±0.03 ^b	2.22±0.00 ^a	3.17±1.52 ^a	3-5
Trypsin Inhibitor (mg/100 g)	6.67±0.03 ^b	1.10±0.00 ^a	1.64±0.00 ^a	0.7-3

Unprocessed African yam beans (UAYB), African yam beans boiled and African yam beans roasted ($P < 0.05$). PL-Permissible limits. Source: Sam (2019), Chai and Liebman (2004), Uche et al. (2014), Adegunwa et al. (2012), and Hession et al. (2009).

and plantain composite flour and reported that cookies had higher levels of proteins, fat, moisture, beta-carotene (pro-vitamin A), vitamin C, and iron but reduced carbohydrate when compared to the control (100% Wheat). Cookies produced from 70% maize, 20% AYB and 10% plantain composite flour had the highest score for general acceptability and compared favorably with the control cookies for almost all sensory attributes. Microbiological analysis revealed that all the cookies produced were free of microorganisms for up to two months of storage under ambient conditions. The use of plant protein sources in local food formulations could be vital in upgrading their nutritional, functional and sensory properties. Previous work done on the effect of processing on the nutritional levels of AYB depicted that protein content, crude fiber and lipid are significantly higher in raw, unprocessed than the processed AYB (Uche et al., 2014; Adegunwa et al., 2012; Sam, 2019). The level of crude protein and crude fiber for the processed AYB were lower than that of unprocessed AYB (Uche et al., 2014; Adegunwa et al., 2012). The loss in protein content could be due to denaturation that took place during roasting process. Contrary to this, Chikwendu et al. (2014) reported that fermentation process improved protein (24.70-28.70) and ash levels of AYB flour. However, carbohydrate content of the flour sample was decreased by fermentation process. Roasting increased the % levels of Ca, K, Cu, Fe, Mn, Mg, P but Zn level was reduced (Uche et al., 2014; Adegunwa et al., 2012). Boiling processing resulted in reduction in Ca, K, Fe, Mn and Zn, however there was increased in moisture and carbohydrate levels of AYB (Uche et al., 2014). This assertion could be attributed to the dehydration that took place during roasting process, hence, improve the concentration of the mineral content in the raw or unprocessed AYB. The presence of water during boiling will definitely increase moisture content of AYB, enhance hydration, hydrolysis, thus the conversion of some mineral to other compounds which may likely result to the reduction in mineral levels of processed AYB when compared to raw AYB. Antinutrient compounds are toxic, harmful and may impair digestibility of protein and some

vital minerals into the body system. However, the good news is that they are labile and thus may be reduced or inactivated by processing methods such as boiling, roasting and frying (Nwosu, 2010). The antinutrient contents of AYB were significantly reduced by processing methods such as roasting, baking and boiling (Uche et al., 2014; Adegunwa et al., 2012). It was revealed that roasting process is more effective and efficient in the reduction of phytate levels in AYB than boiling process. However, boiling process reduced oxalate better than roasting (Uche et al., 2014). Table 4 reveals that roasting and boiling process increase the hydro cyanide content of AYB. However, the increment is still below the permissible limit recommended by FAO/WHO. Conversely, the processes lower the tannin, phytate, oxalate and trypsin inhibitor. This is in agreement with the report of Chikwendu et al. (2014) where fermentation reduced the tannin levels in both flours as against the control from 0.51 to 0.31 and 0.16 to 0.02 mg, respectively. The phytate content was also reduced from 0.49 to 0.25 and 0.26 to 0.06 mg. It has been reported that AYB processing has both positive and negative correlation with its nutritional potentials. For example, it was reported that roasting increased the % of mineral levels of AYB and decreased its Zn content. Boiling had negative correlation with AYB mineral levels but resulted to positive correlation with the levels of Cu, Mg, P and Na (Uche et al., 2014). The levels of oxalate in unprocessed AYB (16.40) were higher than the boiled AYB (3.64) and roasted AYB (3.45) (Sam, 2019). Ikemefuna and Julian (2010) reported that AYB has high quality protein and minerals which could be much improved by adequate preparation and supplementation for incorporation into various traditional dishes for both children and adults. All the articles reviewed pointed to the fact that, adequate processing like soaking, parboiling, boiling, cooking and roasting is required to improve antinutrient content of AYB seeds. Table 4 depicted the basic amino acids present in unprocessed AYB and FAO/WHO suggested amino acid contents for children and adults. It was also revealed that processing like boiling, cooking and roasting increase the Alanine, Glycine and Valine

Table 4. Amino acids composition of raw and processed AYB (mg/100 g).

Amino acid	UAYB	AYBB	AYBR	FAO/WHO
Morlencine	4.00	6.86	6.63	-
Glutamic acid	12.10	10.44	10.64	-
Aspartic acid	10.00	9.89	7.87	-
Serine	5.04	4.48	3.52	0.5
Threonine	4.58	5.00	4.27	-
Alanine	3.85	5.35	5.53	-
Glycine	4.11	6.65	6.31	-
Valine	-	4.92	4.04	-
Cystine	5.44	1.79	1.69	-
Methionine	5.44	0.97	1.12	1.90
Isoleucine	4.89	2.81	2.28	13.00
Leucine	7.90	5.07	4.34	19.00
Tyrosine	3.80	2.19	2.88	-
Phenylalanine	6.13	1.78	2.72	-
Histidine	5.51	3.41	3.58	1.60
Lysine	8.80	6.95	7.09	1.60
Arginine	6.39	3.41	3.49	-

Unprocessed African yam beans (UAYB), African yam beans boiled and African yam beans roasted (P<0.05). Source: Esan and Fasasi (2013).

contents of AYB. Esan and Fasasi (2013) reported that AYB raw flour (unprocessed) had threonine (4.58 g/100 g) which was far above (0.9 g/100 g) required by FAO/WHO for adult. Amino acids are essential components for wound healing and protein production. Lack or deficiency in these vital essential amino acid components will inhibit the healing and recovery processes (Michael et al., 2018; Okonkwo et al., 2013). Polypeptide that enhance growth and wound healing are produced from glycine and other essential amino acids such as alanine, proline, arginine, serine, isoleucine and phenylalanine (Esan and Fasasi, 2013; Sarwar et al. 2010). AYB contains all the essential amino acids in higher proportion compared with FAO requirement for adults (Rajapakse et al., 2005), and contains sulphur amino acid found to be deficient in other legumes (Ikemefua et al., 2010). AYB may contribute adequate proportions of total essential amino acid since the value obtained is similar to the recommended (39%) considered to be adequate for ideal protein food for infants above that recommended (26%), and considered to be adequate for ideal protein for children and (11%) for adults (FAO/WHO/UNU, 1985). Amino acid composition of AYB suggests that it has adequate protein content and are excellent for mankind consumption. However, there is dire need of information on how to improve the hygroscopic nature of AYB protein concentrate and its production as a dietary supplement or tablet. Improvement of the palatability of protein hydrolysates,

while maintaining nutritional value and safety is required.

Health benefits of African yam beans

Consumption of legume seeds such as AYB, pigeon pea and soya beans have many health benefits in that they are rich in food components such as vitamins, flavonoids, total polyphenols, fibers and lipids (Esan and Fasasi, 2013; Chikwendu et al., 2014; Ajayi, 2011; Magdi, 2010; Antangwo et al., 2013; Amakoromo et al., 2012). Legumes ability to prevent disease is based on its antioxidant, anti-inflammatory, anti-ageing and detoxification potentials (Esan and Fasasi, 2013; Atangwho et al., 2013). Natural antioxidants are more desirable because they do not have harmful side effect associated with the use of synthetic equivalent even at higher concentration (Soetan et al., 2018). The following phytochemicals are reported: total phenolic (0.925 mgGAE/ml); DPPH scavenging ability of AYB (69.16-87.83), total antioxidant capacity (3.9795 mgAsAE/ml); reducing capacity (1.4985) (Soetan et al., 2018). The antioxidant activities observed in aqueous extract are generally low (Soetan et al., 2018; Enujiugha et al., 2012). Phenolic compounds play vital roles in human pathogenic infections (Doughari, 2012). Nwankwo and Ekeanyanwu (2011) reported that the phytochemicals present in AYB such as flavonoids, isoflavones, anthocyanides, saponins, phytosterols, and lignin have

the potential health benefits functioning as anti-cancer, and heart disease, lower blood cholesterol, reduce risk of heart disease, anti-hypertensive, anti-diabetic, anti-osteoporosis as well as anti-inflammatory agent. In 2016, an estimated 1.6 million deaths were directly caused by diabetes. Another 2.2 million deaths were attributable to high blood glucose levels in 2012 (Sarwar et al., 2010). The dietary glycemic index (GI) and glycemic load (GL) concepts indicate an expected behavior for the rate of carbohydrate assimilation in the prevention, management and treatment of chronic disease such as diabetes and high blood pressure. Diabetes mellitus (DM) is a complex metabolic disorder affecting 171 million people worldwide, and this number is projected to reach 366 million by 2030. About 50 to 70% diabetic wound resulted to limb amputation globally. WHO report that diabetes will be 7th foremost reason for death in 2030. In 2014, 9% adults had diabetes and resulted to 1.5 million death in 2012. The number of people with diabetes has increased from 108 million in 1980 to 422 million in 2014. The global prevalence of diabetes among adults over 18 years of age has increased from 4.7% in 1980 to 8.5% in 2014 (Basith et al., 2020). Diabetes prevalence has been rising more rapidly in middle-and low-income countries. Diabetes is a major cause of blindness, kidney failure, heart attacks, and stroke. The good news is that diabetes can be treated and its consequences avoided or delayed with diet, physical exercise, medication, regular screening and treatment for complication (Sarwar et al., 2010). Oboh et al. (2010) worked on the glycemic response of some boiled legumes commonly eaten in Nigeria and reported that AYB had the lowest GI (17). The GI of AYB is very low when compared with cow pea (41), pigeon pea (24), and groundnut nut (24) (Oboh et al., 2010). Legumes produce relatively low glycemic responses in both healthy individuals and diabetic clients (Gbenga-Fabusiwa et al., 2018a, 2019). The components present in legumes, particularly the dietary fiber, the protein contents and the type of starch can influence the rate by which glucose is released from starch and rate at which it is absorbed from the small intestine. This makes legumes especially the one with low GI like AYB suitable as functional meal in regulating postprandial rise in blood glucose levels. Many researchers have reported epidemiological importance of AYB in the management and prevention of several diseases. The medicinal properties of plants secondary metabolites are many and well documented (Frank et al., 2016; Michael et al., 2018; Okonkwo et al., 2013; Sarwar et al., 2010; Akpan et al., 2012). AYB are very nutritious in that they contain vital nutrients and if well utilized can reduce the number of people suffering from diabetes due to its low GI. AYBs are very high in antioxidants such as vitamin C at 44% of the RDI (Soetan et al., 2018). Tables 5 and 6 reveal the physical and chemical properties of AYB milk.

Antioxidants fight against free radicals and the release

of oxidative stress which is responsible for ill-health like cancer and cardiovascular diseases. They therefore, help protecting cell damage. AYBs are very rich in dietary fiber, potassium, iron and nitrate which exchanges LDL (bad cholesterol) to HDL cholesterol (good cholesterol) improves heart health, blood pressure and red blood cells. The presence of antioxidant and dietary fiber in AYB helps prevent colon cancer (Michael et al., 2018). AYB are very rich in dietary fiber which helps to improve bowel movements by 31% while the moisture content of the beans ease constipation thus, aids and boost digestion (Michael et al., 2018). They contain inulin (a prebiotic fiber) which may not be absorbed by the digestive system but can be fermented into good bacteria for the gut. The presence of many good bacteria in the gut could help reduce the risk of cardiovascular diseases. AYB contains low carbohydrate contents, low calories, high fiber content and water content. Previous work done revealed that regular consumption of legumes leads to decrease blood sugar levels (Gbenga-Fabusiwa et al., 2019), improve insulin sensitivity and it makes stomach feel full longer (Michael et al., 2018). AYB is an important source of protein rich diet which can help to fight ill-health resulted from malnutrition such as kwashiorkor.

African yam beans, starch and composite flour technology

Composite flour can be defined as a mixture of two or more flours obtained from roots, tubers, cereals and legumes with or without the addition of wheat flour with the sole aim of improving its nutritional values. In the tropic sub-Saharan region where protein inadequate and deficiency in diet is common leading to endemic protein malnutrition with its attendant health challenges in mankind especially in children. Therefore, production of complementary food from protein-rich legumes like AYB is inevitable. Complementary food are foods consumed other than breast milk introduced to an infant or ill-health clients in order to meet or supply basic nutrients needed in the body. In developing countries like Nigeria, Algeria, Ghana, and Cameroun, complementary foods are majorly based on carbohydrate-rich tubers and grains like yam, potatoes, maize, millet and sorghum. Children and ill-health clients are normally given this staple food in form of pap by mixing the gruels in boiled water or boiled with water (Igyor et al., 2011). Gbenga-Fabusiwa (2019) investigated starch extracted from pigeon pea and African yam beans. It was reported that the flour was rich in minerals, but no fiber was detected in the starch samples. Iwe et al. (2016) investigated composite flour produced from FARO 44 rice, AYB and brown cowpea seeds and reported that incorporation of AYB increases the protein, fiber and ash contents of the composite flour. The composite flours were used in the production of

Table 5. Physical properties of African Yam Bean (AYB) seed milk.

Parameter	Results
Color	Milk color
Aroma	5.8
Taste	6.4
Mouth feel	6.2
Overall acceptability	6.8

Source: Michael et al. (2018).

Table 6. Chemical properties of African Yam Bean (AYB) seed milk.

Parameter	Results
Titration acidity	25.24
pH	4.76
Ca	0.12605 ppm
Fe	0.05605 ppm
Cu	0.0009 ppm
Pb & Cd	Not detected

Source: Michael et al. (2018).

functional bakery food products like bread, biscuits and enriched pap (Atinuke, 2015). Obasi et al. (2012) evaluated biscuits produced from AYBs and wheat composite flour and stated that the biscuit had 0.88-2.28% crude fiber, 12.75-22.00% protein, and 63.30-73.01% carbohydrate. Sensory evaluation showed that all the biscuits had high rating for general acceptability. AYB proportions at 75:25% and 50:50 compared favorably with 100% wheat flour (control). Anoshirike et al. (2018) made biscuits from wheat, AYB and cocoyam composite flours and reported that the biscuit produced had higher energy, protein and fiber contents than the control (100% wheat flour). The biscuits were higher in calcium (0.19%), magnesium (0.22%), zinc (1.91 mg) and iron (5.98 mg), richer in nutrients and had high general acceptability. Ogbonnaya et al. (2018) and Aniedu and Aniedu (2014) examined the blends of cassava fufu, cooking banana, and AYB, with the sensory. It was reported that overall protein content and fat content of the blended flour samples increased with increase in the AYB component of the blended samples. Also, the fibre contents of blended samples significantly increased with increase in both cooking banana and AYB. The sensory evaluation revealed that sample that contains 33.3% CF, 33.3% CB, and 33.4% AYB scored the highest in texture (7.08) and aroma (7.00) but did not carry out the glycemic index and texture profile analysis of the work. Ukegbu et al. (2015) reported nutritional potential of AYB flour enriched

complementary foods. It was revealed that enrichment of complementary foods with AYB had good acceptable organoleptic attributes when incorporated in infant formulations (Okafor and Usman, 2010; Nwosu, 2010). The results in this study suggest that utilization of AYB in starch and composite flour formulation technology could be a viable way of overcoming the hard to cook utilization limiting factor.

Toxicological analysis of AYB

Toxicity is referred to the effect on a whole organism (humans, animal, bacterium, or plant), as well as the effect on a substructure of the organism, such as a cell or an organ like liver and kidney. It is the degree to which a chemical substance (toxin, poison) or a particular mixture of substances can damage an organism. The distribution of heavy metal in soils and sediments indicates the potential harm to the environment through their chemical associations since a buildup of heavy metals at high concentration can cause serious risk to human health when food plants are consumed. Cadmium (Cd) is one of the most toxic pollutants found in the air, water, and soil, and is nonessential for plants (Gallego et al., 2012). Cd has a negative influence on photosynthetic, respiratory, and nitrogen (N) metabolism in plants, resulting in a poor growth and low biomass (Gallego et al., 2012). AYB have provided a good source of anti-infective agents and phyto-medicines that have shown great promise in the treatment and management of numerous kinds of infections and diseases. Most people in rural areas utilize AYB to bring about cure and relief to disease conditions with little or no knowledge about the safety and toxicity of AYB. Okonkwo et al. (2013) investigated acute toxicity (LD50) test and hematological parameters of anaemic rats treated with the methanol extract of the plant seeds and stated that the extract was not toxic up to 5000 mg/kg, indicating the safety of the plant for both human and animal consumption. Oshomoh and Ildigwe (2018) studied ameliorative potential of biocharcoal on sodium azide toxicity in AYB. It was reported that the growth of AYB was significantly improved by the application of the biocharcoal as higher plant height, number of leaves, percentage seedling emergence and number of branches were observed when compared with control. Biocharcoal proved to have ameliorative potential on AYB, however, more work is needed to understand the mechanism by which it operates. Ohanmu et al. (2018) examined the nitrogen assimilation and distribution pattern of AYB exposed to cadmium stress by partitioning the plant accessions into root and leaf, and N-nitrate and N-ammonia analysis was carried out during the seedling and flowering stage. It was reported that Cd toxicity reduced the total nitrogen assimilation of AYB accessions. Okoye et al. (2019) reported the growth responses of

AYB (*Hochst. ex A. Rich.*) harms to cadmium pollution. It was observed that cadmium pollution significantly delayed seedling emergence in all tested AYB accessions by at least one day. Overall, decrease in total chlorophyll content seems to be the major reason of injury in Cd-exposed plants. Michael et al. (2018) reported the acute toxicity test showed there was no lethality in AYB seed milk up to a concentration of 5000 kg/body weight. The reviewed studies revealed that raw AYB possess some levels of hydrogen cyanide, trypsin inhibitor and oxalate which can be reduced below detection limit when it undergoes certain process techniques such as parboiling, cooking, fermentation, boiling and roasting.

Strategies to eliminate or minimize the processing difficulties of AYB

The major challenge in the utilization of AYB is the fact that it is very hard to cook. Therefore, different dehulling methods are required to remove the hulls. Locally, the dehulling process is done by soaking the beans and dehulling manually. This process is time consuming, labor-intensive and thus inhibits the effective utilization of AYB. Under cooked AYB seeds may cause diarrhea and when it is over-done results to constipation (Oyedele et al., 2019). Steeping may improve the dehulling process of AYB. In addition to this, processing of AYB into flour and composite flour will be a viable way of improving AYB utilization. Another limitation to the utilization of AYB is poor storage capacity as result of adverse effect of seed-borne fungi. Oyedele et al. (2019) reported that the Jute bag is the most effective method of preserving AYB seeds. Anti-nutritional factors like flavonoids and phytate, contributed greatly to underutilization of AYB in that they reduce beans' digestibility, swelling bellies and causing flatulence when they are not properly processed. However, studies revealed that roasting, cooking, formulation of flour, composite flour, pre-cooking treatments and fermentation could reduce the processing difficulties of AYB (Olisa et al., 2010; Chikwendu et al., 2014; Ajayi, 2011; Magdi, 2010). Uche et al. (2014) studied the level of anti-nutrients composition of raw and processed AYB. It was observed that the processed AYB registered significant reduction in levels of hydrogen cyanide, trypsin inhibitor, phytate, oxalate, and tannins compared to the unprocessed.

CONCLUSION

African yam bean is going to extinction and reported as one of the underutilized legumes in Africa. However, AYB holds great potentials in improving food security globally. The results obtained in this study indicate that AYB is rich in protein, minerals and antioxidants with low GI and therefore, can serve as nutraceutical. It is of great

importance to explore its starch, flour and composite flour in producing functional food such as AYB paste called "Amala", bread, biscuit as dietary intervention for prevention and management of diet-related diseases like diabetes, obesity and kwashiorkor. Feeding infants with the blend flour of AYB will contribute to preventing infant malnutrition problems in developing countries. The reviewed papers revealed that pretreatment of AYB by soaking, parboiling before other processing like cooking and roasting has had great improvement on its hard-to-cook and antinutritional factors.

RECOMMENDATION

The government should make a policy that will support the cultivation and more researches on AYB so as to achieve SDG goal 2. The media house and health institutions should stress more on health benefits of AYB to mankind. Further research should be carried out on entho-pharmacological claims of AYB tubers, leaves, flowers and clinical trials of AYB composite flour blends formulated on humans. The mode of processing the leaf of AYB and the safety of eating it should be explored experimentally. Toxicological analysis of the plant should also be established.

LIMITATIONS OF THE STUDY

AYB is cultivated majorly by the primitive farmers in small scale. This limits its industrial utilization and the ethno-pharmacological studies on AYB seeds, leaves and tubers. Governments as well as Food and Agriculture Organization should encourage and promote the industrial cultivation of the novel grain called AYB. This will enhance its maximum utilization to meet dietary needs of mankind and improve food security as well as health status of the people. In addition, there are limitations on the clinical trials of AYB products on kwashiorkor and people suffering from diabetes.

CONFLICT OF INTERESTS

The author has not declared any conflict of interests.

REFERENCES

- Abdulkareem K, Animasaun DA, Oyedeji S, Olabanji OM (2015). Morphological characterization and variability study of African yam beans [*Sphenostylis Stenocarpa* (Hochst Ex A. Rich)]. *Global Journal of Pure and Applied Sciences* 21(1):21-27.
- Abioye VF, Olanipekun BF, Omotosho OT (2015). Effect of varieties on the proximate, nutritional and anti-nutritional composition of nine variants of African yam bean seeds (*Sphenostylis Stenocarpa*). *Donnish Journal of Food Science and Technology* 1(2):017-021.
- Adegunwa MO, Adebowale AA, Solano EO (2012). Effect of thermal

- processing on the biochemical composition, antinutritional factors and functional properties of beniseed (*Sesamum indicum*) flour. *American Journal of Biochemistry and Molecular Biology* 2(3):175-182.
- Adefegha SA, Oboh G (2013). Sensory qualities, antioxidants activities and invitro inhibition of enzymes relevant to type – 2 diabetes by biscuits produced from 5 wheat-bambara groundnut flour blends. *International Journal of Food Engineering* 9:17-28.
- Adewale B, Daniel A, Aremu, CO (2013). The nutritional potentials and possibilities in African yam bean for Africans. *International Journal of Agriculture* 3(1): 8-19.
- Adewale BD, Dumet D. (2010). AYB: A crop with food security potentials for Africa. *Africa Technology Development Forum Journal* 6 (2/4):66-71.
- Adewale BD, Kehinde OB, Aremu CO, Popoola JO, Dumet, DJ (2010). Seed metrics for genetic and shape determinations in African yam bean [Fabaceae] (*Sphenostylis stenocarpa* Hochst. Ex. A. Rich) Harms. *African Journal of Plant Science* 4(4):107-115.
- Ajayi AO (2011). Sustainable dietary supplements: An analytical study of African yam bean *Sphenostylis stenocarpa* and Corn-Zea Maize. *European Journal of Experimental Biology* 1(4):189-201.
- Ajayi FT, Akande SR, Odejide JO, Idowu B, Udoji IA, Abdulrahman F, Hassan LG, Maigandi S, Itodo HU, Udoji IA (2010). Nutritive evaluation of some tropical under-utilized grain legume seeds for ruminant's nutrition. *Journal of American Science* 6(7):1-7.
- Akpan IP, Ebenso IE, Effiong OO, White EE (2012). Performance and organoleptic properties of edible land snail fed *Chromolaena odorata*. *Nigerian Journal of Agriculture, Food and Environment* 8(2):5-8.
- Amakoromo ER, Innocent-Adiele HC, Njoku HC (2012). Microbiological quality of yogurt-like product from African yam bean. *National Science* 10(6):6-9.
- Aniedu C, Aniedu OC (2014). Fortification of cassava fufu flour with African yam Bean flour: Implications for improved nutrition in Nigeria. *Asian Journal of Plant Science and Research* 4(3):63-66.
- Anoshirike OC, Chidozie C, Ugwumba A, Asinobi CO, Anoshirike CO (2018). Chemical composition and organoleptic properties of biscuits made from wheat, African yam bean and cocoyam composite flours. *African Journal Online* 39(1).
- Aremu CO, Ibirinde DB (2012). Bio-diversity study on accessions of African yam bean (*Sphenostylis stenocarpa*). *International Journal of Agricultural Research* (Online), doi: 10.3923/ijar.2012.
- Atangwho IJ, Egbung GE, Ahmad M, Yam MF, Asmawi MZ (2013). Antioxidant versus anti-diabetic properties of leaves from *Vernonia amygdalina* Del. growing in Malaysia. *Food Chemistry* 141(1):3428-3434.
- Atinuke I (2015). Chemical composition and sensory and pasting properties of blends of Maize-African yam bean seed. *Journal of Nutrition Health and Food Science* 3(3):1-6.
- Barrett CB (2010). Measuring Food Insecurity. *Science* 327(5967):825-828.
- Basith Khan MA, Hashim MA, King JK, Govender RD, Mustapha H, Alkaabi J (2020). Epidemiology of type 2 diabetes global burden of disease and forecasted trends. *Journal of Epidemiology and Global Health* 10(1):107-111.
- Chikwendu JN, Obiakor O, Philomena N, Maduforo AN (2014). Effect of fermentation on the nutrient and antinutrient composition of African yam beans (*Sphenostylis stenocarpa*) seeds and pearl millet (*Pennisetum glaucum*) grains. *The International Journal of Science and Technology* 2(12):169.
- Chinedu NS, Nwinyi CO (2012). Proximate analysis of *Sphenostylis stenocarpa* and voadzeia subterranean consumed in South-Eastern Nigeria. *Journal of Agricultural Extension and Rural Development* 4(3):57-62.
- Christian T (2010). Grocery store access and the food insecurity–obesity paradox. *Journal of Hunger and Environmental Nutrition* 5(3):360-369.
- Doughari JH (2012). Phytochemicals and extraction methods, Basic structures and mode of action as potential chemotherapeutic agents, phytochemicals: A global perspective of their role in Nutrition and Health, Dr Venketeshwer Rao (Ed.) ISBN 978-953-51-0296-0.
- Elsie BB, David BK (2016). Effect of African yam beans (*Sphenostylis stenocarpa*) on the quality characteristic of extended meat ball. *Journal of Food and Nutrition Research* 4(2):121-126.
- Enujiugha VN, Talabi JY, Malomo SA, Olagunju AI (2012). DPPH radical scavenging capacity of phenolic extracts from African yam beans (*Sphenostylis stenocarpa*). *Food and Nutrition Sciences* 3:7-13.
- Esan YO, Fasasi OS (2013). Amino acid composition and antioxidant properties of African yam bean (*Sphenostylis stenocarpa*) protein hydrolysates African. *Journal of Food Science and Technology* 4(5):100-105.
- Fan S, Polman P (2014). An ambitious development goal: Ending hunger and undernutrition by 2025. In 2013 Global food policy report. Eds. Marble, Andrew and Fritschel, Heidi. Washington, D.C.: International Food Policy Research Institute (IFPRI) 2:15-28.
- FAO/WHO (1991). Protein quality evaluation report of joint FAO/WHO Expert Consultant, FAO. *Food Nutrition* 51:119-121
- FAO/WHO/UNU (1985). Energy and protein requirements. *Nutrition Report Series* 724, Geneva.
- Frank UE, Rita NO, Chukwuemeka SA (2016). Effect of African yam bean (*Sphenostylis stenocarpa*) on serum calcium, inorganic phosphate, uric acid, and alkaline phosphatase concentration of male albino rats. *Journal of Agricultural Science* 8(1) ISSN 1916-9752 E-ISSN 1916-9760.
- Gallego SM, Pena LB, Barcia RA, Azpilicueta CE, Iannone MF, Rosales EP (2012). Unravelling cadmium toxicity and tolerance in plants: Insight into regulatory mechanisms. *Environmental and Experimental Botany* 83:33-46.
- Gbenga-Fabusiwa FJ (2019). Proximate, mineral and physicochemical properties of starch extracted from pigeon-pea (*Cajanus cajan*) and varieties of African yam beans (*Sphenostylis stenocarpa*). *Journal of ChemResearch* 1(1):121-131.
- Gbenga-Fabusiwa FJ, Oladele EP, Oboh G, Adefegha SA, Fabusiwa OF, Osho, Enikuomehin A, Oshodi AA (2019). Glycemic Response in Diabetic Subjects to Biscuits Produced from Blends of Pigeon Pea and Wheat Flour. *Plant Foods for Human Nutrition* 74:553-559.
- Gbenga-Fabusiwa FJ, Oladele EP, Oboh G, Adefegha SA, Oshodi AA (2018a) Nutritional properties, sensory qualities and glycemic response of biscuits produced from pigeon pea-wheat composite flour. *Journal of Food Biochemistry* 42:e12505a.
- Gbenga-Fabusiwa FJ, Oladele EP, Oboh G, Adefegha SA, Oshodi AA (2018b) Polyphenol contents and antioxidants activities of biscuits produced from ginger-enriched pigeon pea–wheat composite flour blends. *Journal of Food Biochemistry* e12526. <https://doi.org/10.1111/jfbc.12526>
- Godfray HCJ, Beddington JR., Crute IR, Haddad L, Lawrence D, Muir JF, Pretty J, Robinson S, Thomas SM, Toulmin C (2010). Food Security: The Challenge of Feeding 9 Billion People. *Science* 327(5967):812-818.
- Heuze V, Tran G (2016). African yam bean (*Sphenostylis stenocarpa*). Feedipedia, a programme by INRA, CIRAD, AFZ and FAO. <https://www.feedipedia.org/node/704> Last updated on March 16, 2016, 11:56.
- Hickel J (2019). "The contradiction of the sustainable development goals: Growth versus ecology on a finite planet". *Sustainable Development*. Wiley, 27(5):873-884.
- Igyor MA, Yusufu PA, Sengav IA (2011). Functional and sensory properties of fermented fura powder supplemented with soy. *Nigerian Food Journal* 29(1):113-121.
- Ikemefuna CO, Julian S (2010). The nutritive value of African yam bean (*sphenostylis stenocarpa*): Nitrogen and mineral utilization. *Ecology of Food and Nutrition* 22(4):297-305.
- Iwe MO, Onyeukwu U, Agiriga Fatih Yildiz AN (2016). Proximate, functional and pasting properties of FARO 44 rice, African yam bean and brown cowpea seeds composite flour. *Journal Cogent Food and Agriculture* 2(1).
- Kandala NB, Madungu TP, Emina JBO, NPD, Cappuccio, FP (2011). "Malnutrition among children under the age of five in the Democratic Republic of Congo (DRC): Does geographic location matter?". *BMC Public Health*. Springer Science and Business Media

- LLC 11(1):261.
- Kinyoki DK, Osgood-Zimmerman AE, Folayan MO, Tantawa ME, Shaviful Islam SM (2020). Mapping child growth failure across low and middle-income countries". *Nature* 577(7789):231-234.
- Kumar Y, Nalini KB, Menon J, Patro DK, Banerji BH (2013). Calcium sulfate as bone graft substitute in the treatment of osseous bone defects, a prospective study. *Journal of clinical and diagnostic research: JCDR* 7(12):2926.
- Lama P (2017). "Japan's food security problem: Increasing self-sufficiency in traditional food". *IndraStra Global* 7:7.
- Magdi AO (2010) Effect of traditional fermentation process on the nutrient and antinutrient contents of pearl millet during preparation of Lohoh. *Journal of the Saudi Society of Agricultural Sciences* 10(1):1-6.
- Masika MP, Wouters E, Kalambayi KP, Kiumbu NM, Mutindu MS, Suguimoto SP, Techasrivichien T, Wellington LB, El-saaidi CP, Peter OM, Kihar M (2014). "Food insecurity is associated with increased risk of non-adherence to antiretroviral therapy among HIV-infected adults in the Democratic Republic of Congo: A Cross-Sectional Study". *PLOS ONE* 9:e85327.
- Michael ON, Etim EE, Innocent OO (2018). Investigation on the anti-diabetic activity of *Sphenostylis stenocarpa* seed milk extract in alloxan-induced diabetes rats. *International Journal of Scientific and Research Publications* 8(8):824 ISSN 2250-3153.
- Morales A (2011). "Marketplaces: Prospects for social, economic, and political development". *Journal of Planning Literature*. 26 (1):3-1.
- Ngwu EK, Aburime, LC, Ani, PN (2014). Effect of processing methods on the proximate composition of African yam bean (*Sphenostylisstenocarpa*) flours and sensory characteristics of their gruels. *International Journal of Basic and Applied Sciences* 3(3):285-290.
- Nneoma EO, Uchekukwu N, Eke-Obia E (2012). Production and evaluation of biscuits from African yam bean (*Sphenostylis stenocarpa*) and wheat (*Triticum aestivum*) flours. *Food Science and Quality Management*. 7.
- Nwankwo MO, Ekeanyanwu CR (2011). *Nutritional Pharmacology and Phytochemicals Lambert Publication Germany*. pp. 01-12.
- Nwokeke B, Adedokun I., Osuji C (2013). Effect of blending on the proximate, pasting and sensory attributes of Cassava-African yam fufu flour. *International Journal of Research Publications* 3(8):1-7.
- Nwosu JN (2010). "Effects of soaking, blanching and cooking on the antinutritional properties of asparagus bean (*Vigna sesquipedalis*) flour." *Nature and Science* 8(8):163-167.
- Oboh H, Osagie A, Omotosho A (2010). Glycemic response of some boiled legumes commonly eaten in Nigeria. *Diabetologia Croatica* 39(4):125-131.
- Ogbonnaya M, Onumadu KS, Nwogu OG, Ben-Udechukwu C (2018). Proximate composition and sensory evaluation of blends of cassava fufu, Cooking banana (*Musa saba*) and African yam bean (*Sphenostylis stenocarpa*) composite flours and paste. *Research Journal of Food Science and Quality Control* 4(1):2504-6145.
- Ohanmu EO, Ikhajagbe B, Edegbai BO (2018). Nitrogen distribution pattern of african yam bean (*Sphenostylis stenocarpa*) exposed to cadmium stress. *Journal of Applied Sciences and Environmental Management* 22(7):1053-1057.
- Okafor GL, Usman GO (2010) Production and evaluation of breakfast cereals from blends of African yam bean (*Sphenostylis stenocarpa*), maize (*Zea mays*) and defatted coconut (*Cocos nucifera*). *Journal of Food Processing and Preservation*. 10.1111/jfpp.12060.
- Okonkwo CC, Njoku UO, Mbah AM (2013). Anti-anaemic effect of methanol seed extract of *Sphenostylis stenocarpa* (African yam bean) in Wistar albino rats. *African Journal of Pharmacy and Pharmacology* 7(45):2907-2913.
- Okoye PC, Anoliefo GO, Ikhajagbe B, Ohanmu EO, Igiebor FA, Aliu E (2019). Cadmium toxicity in African yam bean (*Sphenostylis stenocarpa*) (Hochst. ex A.Rich.) Harms genotypes. *Acta agriculturae Slovenica* 114(2):205-220.
- Olasoji J, Akande S, Owolade O. (2011). Genetic variability in seed quality of African yam bean (*Sphenostylis stenocarpa* Hoscht. Ex A. Rich Harms). *African Journal of Agricultural Resources* 6(27):5848-5853.
- Olisa BS, Ajayi SA, Akande SR (2010). Physiological quality of seeds of promising African yam bean (*Sphenostylis stenocarpa* (Hochst. Ex A. Rich) Harms) and pigeon pea (*Cajanus cajan* L. Mill sp.) Landraces. *Research Journal of Seed Science* 3:93-101.
- Oyedele TA, Kehinde IA, Afolabi CG, Oyedeji EO (2019). Effects of storage methods and mycoflora on proximate composition of African Yam Bean (*Sphenostylis Stenocarpa* Hochst Ex Rich) seeds. *Journal of Agricultural Science and Environment* 18(1).
- Ojuederie OB, Balogun MO (2019). African yam bean (*Sphenostylis Stenocarpa*) tubers for nutritional security. *Journal of Underutilized Legumes* 1(1):56-68.
- Oshomoh EO, Ilodigwe, CC (2018). Ameliorative potential of biocharcoal on sodium azide toxicity in African yam bean (*Sphenostylis stenocarpa* Hochst. Ex. A. Rich) Harms. *Journal of Applied Sciences and Environmental Management* 22(5):681.
- Osuagwu AN, Nwofia GE (2014). Effects of spent engine oil on the germination ability of eleven accessories of Africa yam bean seeds (*Sphenostylis stenocarpa* Hochst ex A. Rich) Harms. *Journal of Agriculture and Veterinary Science* 7(1):59-62.
- Padulosi S, Thompson J, Rudebjer P 2013. *Fighting poverty, hunger and malnutrition with neglected and underutilized species: Needs, challenges and the way forward*. Bioversity International. Rome. ISBN 978-929043-941-7. <http://www.bioversityinternational.org>
- Petrikova I, Hudson D (2017). "Which aid initiatives strengthen food security? Lessons from Uttar Pradesh". *Development in Practice* 27(2):220-233.
- Popoola JO, Adegbite AE, Obembe OO, Adewale BD, Odu BO (2011). Morphological intraspecific variability in African yam bean (AYB) (*Sphenostylis stenocarpa* Ex. A. Rich) Harms. *Scientific Research and Essay* 6(3):507-515.
- Sam SM (2019). Nutrient and antinutrient constituents in seeds of *Sphenostylis stenocarpa* (Hochst. Ex A. Rich.) Harms. *African Journal of Plant Science* 13(4):107-112.
- Sarwar N, Gao P, Seshasai SR, Gobin R, Kaptoge S, Di Angelantonio E, Ingelsson E, Lawlor DA, Selvin E, Stampfer M, Stehouwer CDA, Lewington S, Pennells L, Thompson A, Sattar N, White IR, Ray KK, Danesh J (2010). Diabetes mellitus, fasting blood glucose concentration, and risk of vascular disease: a collaborative meta-analysis of 102 prospective studies. *Emerging Risk Factors Collaboration. Lancet* 26(375):2215-2222.
- Sasson A (2012). Food security for Africa: an urgent global challenge. *Agriculture and Food Security* 1: 2. <https://doi.org/10.1186/2048-7010-1-2>
- Soetan K, Olugboyega O, Charles O, Karigidi KO (2018). Comparative *in vitro* antioxidant activities of six accessions of African yam beans (*Sphenostylis Stenocarpa* L.). *Annals Food Science and Technology* 19(3):455-461.
- Uche S, Ndidi C, Unekwojo N, Abbas O, Aliyu M, Francis GB, Oche O (2014). Proximate, antinutrients and mineral composition of raw and processed (boiled and roasted) *Sphenostylis stenocarpa* Seeds from Southern Kaduna, Northwest Nigeria. *Hindawi Publishing Corporation. ISRN Nutrition Article ID 280837:9*.
- Ukegbu PO, Uwaegbute AC, Nnadi MC (2015). Organoleptic and nutritional evaluation of African yam bean (*Sphenostylis stenocarpa*) flour enriched complementary foods. *Scholars Journal of Agriculture and Veterinary Sciences* 2(2A):97-101.
- Uwaegbute AC, Ukegbu PO, Ikpeoha A (2012). Effect of germination on cooking, nutrient composition and organoleptic qualities of African yam bean (*Sphenostylis stenocarpa*). *Journal of Biology, Agriculture Healthcare* 2(8):28-32.
- Yusufu PA, Egburu, FA, Egwueh SID, Pega, GL, Adikwu MO (2013). Evaluation of complementary food prepared from sorghum, African yam beans (*Sphenostylis stenocarpa*) and mango mesocarp flour blends, *Pakistan Journal of Nutrition* 12(2):205-208.
- Yusufu PA, Netala J, Opega JL. (2016). Chemical sensory and microbiological properties of cookies produced from maize, African yam bean and plantain composite flour. *Indian Journal of Nutrition* 3(1):122.