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EDITED BY
Raju Datla,
Global Institute for Food Security (GIFS), Canada

REVIEWED BY
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University of KwaZulu-Natal, South Africa
Fouad Maalouf,
International Center for Agricultural Research in the Dry Areas, Lebanon

*CORRESPONDENCE
Babasola Daniel Adewale
daniel.adewale@fuoye.edu.ng

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Introduction to food, feed, and health wealth in African yam bean, a locked-in African indigenous tuberous legume

Babasola Daniel Adewale[1]* and Catherine Veronica Nnamani[2]

[1]Department of Crop Science and Horticulture, Federal University Oye-Ekiti, Ikole-Ekiti Campus, Ikole, Nigeria, [2]Plant Systematics and Conservation Biology Research Unit, Department of Applied Biology, Ebonyi State University, Abakaliki, Nigeria

The African yam bean, *Sphenostylis stenocarpa* Hochst Ex. A. Richmond, Harms, is an indigenous tuberous legume of the humid tropics of Africa. Its edible pulse and tuber host significant promises for food, nutrition, and health security. It was identified as a counterpart of cowpea in the 1970s and rated to be highly nutritious, but notable constraints have denied it research and funding attention. "Cowpea revolution" further deprived focus on the African yam bean. However, some research updated and promoted its significant food, feed, and nutritional-pharmaceutical values between 1973 and 2000. The global trend for food diversification has further improved awareness and research on the African yam bean this past decade, but research focus on the tuber is incomparably small. The abundant minerals, vitamins, and bioactive compounds in the two economic products unveiled in the present review assure food, health, and nutritional security. The analytical comparison of nutritional values of the African yam beans and other grain legumes demonstrated the significant place of the crop among its counterparts. Furthermore, investigative research identified the grain as a good substitute for soybean for livestock feed formulations. Although no clinical study has been reported, some *in vivo*, *in vitro*, and *ex vivo* biological activities and human studies of the two economic products revealed their efficacy in the management of anti-natal lactation induction, anemia, diabetes, arthritis, etc. However, African yam bean still suffer displacement in rank, utilization, and popularity compared to the "favored" legumes. While the present review adds to its advocacy, awareness, and utilization, a coordinated research program that will boost its value chain is most necessary for progress.

KEYWORDS
African yam bean, cowpea revolution, food, health, locked-in, nutrition

Introduction

By 2050, the world's population is set to increase by 40%, and the expected agricultural production to match the population is estimated to be 70% (Ebert, 2014). Wheat, rice, and maize, which provide more than 50% of human calorie intake, occupy 555 million ha (i.e., 40%) of the global arable land (Keyzer et al., 2005; Tilman et al., 2011; Stamp et al., 2012). The continued promotion of these few crops at the expense of other useful crops reveals the locked-in concept in crop production agriculture. According to Pahl-Wostl (2009), locked-in is "a situation when institutions and role players in decision-making continue with a conventional approach, despite that it is no longer leading to desired outcomes." Other crops with fewer references have inherent great potential when incorporated into diversified and sustainable food and feed production systems.

Globally, about 80,000 plant species are used for food, feed, and fiber as well as for industrial and medical purposes; 10,000 seems to be a realistic number of edible plant species (Mayes et al., 2012). In Nigeria alone, according to Ogunwusi and Ibrahim (2016), <20 of the identified 5,000 plant species are currently developed and used for food and industrial raw materials. To put it in perspective, about 99% of these useful plants exist as minor crops, many have declined to uncultivated status, others with resilience exist as wild plants, and many are now out of human reach. Per capita availability of pulses in Nigeria is over 10 times less than cereals and roots/tubers (Akah et al., 2021). By inference, the contribution of pulses to daily calorie and protein intake is poor; this is the reason for malnutrition in various communities. This situation is further compounded by a decline in agricultural productivity (especially underutilized legumes), monotonous diets of starchy staples, and/or dietary shifts to exotic high-caloric foods. Legumes are cheap and rich sources of protein, calories, vitamin B, minerals, and dietary fiber. Furthermore, they are low in fat, contain low/no cholesterol, possess a cholesterol-lowering effect, and regulate blood glucose due to their low glycemic index (Ene-Obong et al., 2013; Akah et al., 2021). Hunger, malnutrition, and food insecurity still stare at our faces because of the great and appreciated efforts of improvement on a few crops (Williams and Haq, 2002; Ikhajiagbe et al., 2021) which have not overturned the complex food challenges, especially in sub-Saharan Africa and other developing world. To address this, according to Abberton et al. (2022), crop diversification, cultivation, promotion, and utilization of climate-resilient crops are among the choicest strategies.

The domestication, cultivation, and distribution of the African yam bean (*Sphenostylis stenocarpa* Hochst Ex. A. Richmond, Harms) is very evident in tropical Africa (Potter, 1992; Okpara and Omaliko, 1997), especially central and western Africa, where it had been reported to exhibit very high diversity. Edible pulse and tuber are the two major economic products of the African yam bean (see Figure 1). There is a cultural and regional preference for each in the meals of the Africans; while west Africans mostly eat the seeds (with almost zero consumption of the tubers), the tuber is the major food product for the east and central Africans (Potter, 1992; Nwokolo, 1996). The economic potentials of the African yam bean are immense; the protein in tuber and seed is comparatively higher than most tuberous legumes (Dakora, 2013), the consumption of both seed and tuber by humans and livestock is safe with immense nutritional benefits, the grains are an equal or better substitute for common legumes in livestock feed formulation, and its medicinal properties to address some terminal diseases is worth examining. The beneficial possibilities of African yam bean for humans and livestock are well-documented in this review. The present review seeks to advance the unrealized inherent food, feed, nutrition, and health benefits in the economic products of African yam bean. Information are scattered in literature on the food, feed, and health wealth of this indigenous tuberous legume; this review, therefore, seeks to consolidate them. It is believed that an outcome of this review would be the repositioning of the locked-in crop, leading to its better utility and investment in its research for improved food, feed, health, and wellbeing.

African yam bean in research history from 1973 to 2000

African yam bean has been featuring for long in the traditional, cultural, and farming systems of Africans. The first notable documentation on its botany and taxonomy was by Milne-Redhead and Polhill (1971). African yam bean (*Sphenostylis stenocarpa*) (Hochst ex. A. Rich. Harms) came to the limelight during the First International Institute of Tropical Agriculture (IITA) Grain Legume Improvement Workshop held from 29 October to 2 November 1973 at the International Conference Center, IITA, Ibadan, Nigeria. In that conference, Okigbo (1973) introduced the crop, and Rachie (1973) on Highlights on Grain Legume Improvement at IITA 1970–1973 remarked *Sphenostylis stenocarpa* as an exceptionally nutritious crop. Many research attempts followed the introduction of the crop at the conference; a list of some of the major scientific reports and research outcomes on African yam bean between the first notable mention in 1973 to 2000 is presented in Table 1. This time frame was the quiescent period in the research on African yam bean.

We had access to just 51 published documents on African yam bean from 1973 to 2000; regardless, these numbers seem major. Most (77.5%) of the published works appeared in journals, quite a few (18.4%) were in handbooks and books, and 4.1% were in online archives (Table 1). The largest percentage (43%) of the publications were on food science and nutrition, followed by agronomy (20.4%) and general information on the crop (12.2%), most of which were in books (Table 2). Pre-breeding studies on African yam bean were 10.2%, ethnobotanical studies were 4%, and pharmacology, metabolomics, and diversity area were each 2% (Table 1).

Except for the food and nutrition studies, research on other areas or disciplines was very limited within this period. This greatly informs why knowledge of the crop and awareness was very low, even among scholars. Sadly, from Table 1, it is evident that there were no reports on the agricultural extension of African yam bean. Moreover, most of the publications

FIGURE 1
The two economic products of African yam bean pulses with testa morphs and clusters of tubers with irregular shapes from different accessions. Photo by Adewale Daniel.

were in the academic domain, on the shelves as an archive where they may not be available to potential users. More than 90% of the publications during the reviewed time frame were from Nigeria; research contribution from other countries where this crop is also cultivated was very limited. Poor attraction within agronomic research could be due to the long gestation period of the crop compared to other crops with short durations. Furthermore, there was no designated genetic resources conservation unit or center during the period for the conservation of accessions. During this period, most genetic resources of African yam bean for research were obtained from rural endemic sources in the southeastern and western regions of Nigeria. In addition, most of such research used <10 cultivars which were delineated for uniqueness based on seed coat color and color patterns.

However, African yam bean has since witnessed a huge research boost in various disciplines in the past two decades (Ojuederie et al., 2020; Adewale et al., 2021; Nnamani et al., 2021). However, literature on the agricultural extension of African yam beans is still very scanty, and this seems to have a negative correspondence to the general awareness of the crop. The effort of the Genetic Resources Center (GRC), International

TABLE 1 African yam bean in literature within 1973 to 2000 with remarkable research features and outcomes.

General information	Sources	References
i. Introduction of African yam bean as an underutilized tropical African legume. ii. Nutritional constituent in the seed and tuber. iii. Cultivation, distribution and production of the crop.	Five books and one journal article	Okigbo, 1973; Rachie and Roberts, 1974; National Research Council, 1979; Dukes, 1981, 1992; Anochili, 1984; Kay, 1987
Food science and nutrition		
i. Comparative study of proximate, mineral, amino acid, physico-functional characteristics of starches in seeds of African yam bean with some other grain legumes. ii. Identification and evaluation of probable toxic effect in the seed extract, antinutritional factors, nutritive value of sprouted seeds, chemical and sensory properties of its vegetable milks. iii. Processing methods including: presoaking, presoaking with salt, roasting, soaking and heating, fermentation with *Rhizopus microsporus* var.oligosporus to improved physico-chemical properties of the cooked bean, cooking time, protein digestibility, reduction in antinutritional factors and flatus producing oligosaccharides in African yam bean seed. iv. Increase consumption of African yam bean was encouraged for: very high Nitrogen free extract polysacharides, amylose, increased all growth indices, food conversion efficiency, protein efficiency, digestibility, biological values, net protein utilization and retention efficiency in rat. v. The African yam bean whole seed and hull is rich in protein, K and Ca, low in crude fat, cellulose, fatty acid composition, non-cellulose, lignin and phytate.	Two books and 20 journal articles	Evans and Boulter, 1974; Ihekoronye and Ngoddy, 1985; Azuzu and Undie, 1986; Nwokolo, 1987, 1996; Abbey and Berezi, 1988; Njoku et al., 1989, 1991; Edem et al., 1990; Ene-Obong and Carnoville, 1992; Ene-Obong and Okoye, 1992; Obizoba and Nnam, 1992; Oshodi et al., 1995; Agunbiade and Longe, 1996, 1998, 1999a,b; Apata and Ologhobo, 1997; Nnam, 1997; Nwinuka et al., 1997; Agunbiade, 1998; Oboh et al., 1998; Adeyeye et al., 1999
Botany, ethnobotany and pharmacological studies		
i. Basic botany and floral description of *Sphenostylis and Sphenostylis stenocarpa,* synonyms and some health-related folklores about of the crop in Africa ii. Linguistics evidences to ascertain African yam bean origin	Two online documents as at 2009, one book and two journal articles	Allen and Allen, 1981; Azuzu, 1986; Terrell et al., 1986; Potter, 1992; Potter and Doyle, 1992; Rehm, 1994
Pre-breeding studies including intra-specific diversity, metabolomics and seed protein sciences		
i. Species characterization based on: morphology, isozymes, chloroplast DNA ii. Phylogenetic and systematics studies of *Sphenostylis* and *Nesphostylis* iii. Investigation of seed coat hardness through water imbibition rate in seeds of African yam bean iv. Isolation lectin extracts and seed protein from African yam bean seeds v. Review of African yam bean resources in Ghana vi. Floral development and seed yield variability studies in landraces	Eight journal articles	Ene-Obong and Okoye, 1992, 1993; Okoye and Ene-Obong, 1992; Potter and Doyle, 1992, 1994; Togun and Olatunde, 1997; Omitogun et al., 1999; Amoatey et al., 2000; Machuka and Okeola, 2000
Agronomy: utility as fodder, nodulation capacity, fungicide and fertilizer test, grain yield evaluation, etc.		
i. African yam bean is suitable for fodder, food legume and cover crop ii. African yam bean naturally harbor seed borne fungi, e.g. *Fusarium* and *Aspergillus spp.*; pre-planting seed treatment with fungicides significantly improved germination percentage, seedling emergence, overall seed and tuber yield. iii. Staking, sowing date and plant density in significantly affects grain yield of African yam bean iv. African yam bean nodulates profusely with some bacteria species v. Fertilizer response trial on African yam bean and recommendation dosage of NPK for grain production	One book and nine journal articles	Asare et al., 1984; Nwachukwu and Umechuruba, 1991; Umechuruba and Nwachukwu, 1994; Okpara and Omaliko, 1995, 1997; Assefa and Kleiner, 1997; Obiagwu, 1997; Togun and Olatunde, 1998; Schippers, 2000

Institute for Tropical Agriculture (IITA), Ibadan, Nigeria has been very positive. The Center has freely availed researchers with African yam bean accessions, provided training, and supported postgraduate research on the crop. Actors and stakeholders are increasing and the future appears promising for African yam bean research. The increased research concentration on the

TABLE 2 Constraints, gaps, insights and way-forward in African yam bean research.

	Constraints	References	Current research status and some gaps	Insights and way-forward
S/N	**(a). Agronomic**			
1	Longer time to reach maturity (6–8 months)	Okigbo, 1973	Many individuals, groups, institutional and self-funded researches are ongoing in different disciplines on African yam bean in Africa.	Partnership for collaborations and initiation of coordinated researches on African yam bean among all stake holders.
2	Photoperiodic sensitivity	Okpara and Omaliko, 1995	Its nodulation proficiency which cultural cultivation has attested is yet to be identified, investigated and discovered for eco-friendly utilization in soil fertility managements and crop production.	Formalized genetic resources rescue programs and characterizations to unravel germplasm potentials leading to significant agronomic, genetic and nutritional improvement.
3	Climbing growth habit that necessitates staking	Okigbo, 1973		
4	Shattering tendencies of pods at maturity	Adewale et al., 2012		
5	Inconsistencies in tuber production in space and time	Adewale et al., 2012; Ojuederie et al., 2015		
6	Crop cultivation and germplasm is declining	Klu et al., 2001		
	(b). Genetics			
1	Lowering of genetic resources quantity	Akande, 2008	There had been some substantial diversity studies including: genomics, biochemicals, phenotypic etc., but utilization of the discovered potentials in breeding and improvement seem to be most necessary now.	Wider exploration and ethnobotanical survey to harness cultural and useful tool to assist research direction.
2	Available genetic resources are landraces and accessions	Adewale and Odoh, 2013		
3	No improved cultivars	Akande, 2008	Where needed variation for improvement is not available, creation of variation program need to start.	Cultivar development should embrace participatory approach.
4	Chromosome number still needing validation (n =18, 20, 22, 24)	Adesoye and Nnadi, 2011; Popoola et al., 2011		
5	No record of gene action on phenotypic traits	Adewale et al., 2021		
6	Population development and breeding program still invisible	Adewale et al., 2021		
	(c). Utilization			
1	"Beany flavor" due to anti-nutritional factors	Azeke et al., 2005	Uniquely rich tubers of *Sphenostylis stenocarpa* do not have relevance beside other tuberous crops of Africa, moreover, its nutritional richness are hardly known outside Africa. Informative cultural rudiments on the culinary of the crop is fading and would need to be captured in all eco-cultural niches.	Increased rural socio-economic and nutritional awareness and development of market valued products from African yam bean. Increasing research focus on its nutritional novelties, adaptive qualities and links with nutrition, health and livelihoods.

(Continued)

TABLE 2 (Continued)

	Constraints	References	Current research status and some gaps	Insights and way-forward
2	Hard-to-cook	Agunbiade and Longe, 1996; Nwokolo, 1996		
3	Grains availability only in rural markets	Nnamani et al., 2017		
4	Grossly poor knowledge about the crop and its economic products	Olanipekun et al., 2017		
5	Tubers are not displayed commodity even in rural markets			

African yam bean and the number of requests by researchers for its genetic resources prompted GRC to organize a symposium to harness the stakeholders in African yam bean research. The meeting, which was held on 18–19 October 2016 at IITA provided an opportunity for review, updates, and future research. Moreover, the launch of the Society for Underutilized Legume (SUL–www.sulegumes.org) was another outcome of the symposium. The Center currently conserves a diverse collection of over 450 accessions of the African yam bean landraces from Ghana, Nigeria, and the Democratic Republic of Congo; in addition, over 50% of these accessions are from Nigeria (Abberton et al., 2022).

Cowpea revolution: A setback for other indigenous tropical African grain legumes

The launch of the Grain Legume Improvement Program (GLIP) in IITA in 1973 initiated the beginning of the "cowpea revolution." Years following the 1973 workshop greatly promoted cowpea [*Vigna unguiculata* (L.) Walp]. In many respects, cowpea research efforts and improvement programs aided its attraction, wide acceptability, cultivation, and production. Enhanced research concentration on cowpea appears to have been encouraged by the short gestation period (reaching pod production within 3–4 months after planting). Moreover, its three notable growth habits (climbing, bushy, and decumbent/spreading) make cowpea more attractive to subsistence farmers than African yam bean to be grown in sole and/or companion crops. Furthermore, the ability of cowpea to sustainably grow in wider ecologies, especially drier regions, equally supported its competitive advantage over African yam bean both in research and production. Among the various grain legumes, cowpea production experienced the highest growth (4.7% per annum which expanded by 27% between 1994–1996 and 2008–2010, leading to a 90% increase in production (Nedumaran et al., 2015). Since 1970, IITA in Nigeria has worked on breeding and distributing improved cowpea materials and new germplasm lines to over 60 countries (Singh et al., 1997).

Cowpea [*Vigna unguiculata* (L.) Walp.] is still the most widely cultivated and utilized food legume and research material in sub-Saharan Africa and most countries of the world. It is currently considered the single most important pulse in the dry areas of tropical Africa (Snapp et al., 2018). Its consumption has grown at the rate of 3.2% per annum between 1980 and 2009, and the average level of consumption is 4.5 kg/person/year in sub-Saharan Africa (Nedumaran et al., 2015). Between 1971 and 1996, cowpea production and grain yield increased in Nigeria by ∼441 and 410%, respectively (Ortiz, 1998). Cowpea production received steady and tremendous positive growth during the period from 1970 to 2018; its production covered 96% arable land area of the total grain legumes and 98% of the total pulse production (Ortiz, 1998; Nedumaran et al., 2015; Akah et al., 2021). About ten other food legumes with promising values are known in Nigeria, but their production is low and declining, their cultivation, geographical distribution, and production statistics are not available, and their food, feed, nutrition, and health benefits are fading as their utilization declines. The Food and Agriculture Organization Corporate Statistical Database categorized them as pulses that could not be individually differentiated in their compilation due to their limited international and/or local importance.

Moreover, where legumes are concerned, to enhance the availability of cheap protein, very few (soybean, groundnut, and cowpea) are mostly supported by research and policy promoters (Foyer et al., 2016). The study by Saka et al. (2004) identified the Lima bean (*Phaseolus lunatus*), pigeon pea (*Cajanus caja*), African yam bean (*Sphenostylis stenocarpa*), and Bambara groundnut (*Voandzea subtteranean*) as prominent minor grain legumes that are grown in mixture with major crops on an average range land area of 0.2–0.4 ha. In total, these four grain legumes occupy <10% of the total cultivated land area in southwestern Nigeria. It is characteristic that their production is mostly among the older farmers (50 years and above) who produce an average of 80% of the total production. Their declining cultivation status may have prompted Klu et al. (2001), Ikhajiagbe (2003), Saka et al. (2004), and Adewale and Odoh (2013) to remark that these traditional grain legumes are moving toward extinction.

Dakora (2013) argued that the process of displacement of indigenous food crops by the introduction of new crop species continues to occur to date through the disproportionate promotion in the cultivation of newly introduced commercial crops by national and international research centers and local departments of Agriculture. The increasing promotion of non-indigenous crops in many African countries has consequentially resulted in the marginalization of many domesticated and undomesticated food plants. In his report, Dakora (2013) specifically cited the decline in the use of the tubers *Sphenostylis* and other indigenous food genera.

The promising food, feed, and health resources in African yam bean are unambiguously clear. Okpara and Omaliko (1995) found it to be a very good substitute for cowpea in forest agro-ecologies. The agro-zone is the endemic region for its genetic resources, cultivation, and production. Since the grain productivity of cowpea is not well-supported in rainforest and southern Guinea savanna regions of Nigeria and west Africa, a focused research development on this humid tropical legume could be enhanced given its potential for improved livelihood, which is now well-documented. Summarily, the African yam bean is well-adapted to vast environmental conditions, especially the humid tropics where it has been part of the food, economic, and medicinal resources with remarkable sustainability. It has supported household subsistence in central and west Africa.

Constraints to wide utilization of African yam bean and prospects

As reported in the literature (Machuka and Okeola, 2000; Adewale and Odoh, 2013; Okoye and Nkemakonam, 2018; Oshomoh and Ilodigwe, 2018), poor or low acceptability, adoption, and utilization of African yam bean have been due to classified constraints highlighted in Table 2. These are:

- **Agronomic**—demanding and challenging cultural practices coupled with poor demand and marketing which reduces farmers' enthusiasm for increased production.
- **Genetics**—no improved cultivar yet, available genetic resources are accessions and landraces, and poor knowledge of gene action of traits.
- **Utilization**—hard-to-cook nature of the bean which demands high fuel, cost, and time, the presence of anti-nutritional factors (ANF), "beany" flavor, unpleasant smell and taste, and food value of tuber unknown and neglected in utilization.

There is no record of the geographical distribution and production statistics of African yam bean by the Food and Agricultural Organization (FAO). This makes projection for strategy development difficult. Regardless, Table 2 offers some insights, gaps, and way forward on African yam bean research. According to Eneh et al. (2016), the list of constraints in African yam bean is inconsequential owing to the positive significant food, nutrient, and medicinal loads it hosts; the major constraint is inappropriate awareness. This is because knowledge of the nutrition and other potentials of crop species reflects their preference in human menu lists and considerations in other forms of utilization (Saka et al., 2004).

The significant impediment to African yam beans' acceptability is the prolonged cooking time to get the paste by the boiling process. This problem has prevented the utilization of its invaluable food security potential as long cooking period affects consumers' choices, nutrient contents, anti-nutrient condition, demands much energy usage—a factor of higher cost, long waiting time for meal readiness, etc. (Shitta et al., 2021). One of the findings in the report by Shitta et al. (2021) is that the cooking hours were dependent on the cooking methods used, the energy source, and the germplasm considered. This suggests that cooking time in African yam bean is genetically influenced. Seed hardness is heritable but can also be influenced by environmental factors at production and storage stages (Argel and Paton, 1999; Sandhu et al., 2018). Therefore, understanding the genetic basis of cooking time is necessary for improving the trait of the bean. A pre-breeding program involving the testing a large quantity of germplasm for its cooking time can suggest the selection of genotypes with a lower cooking time for subsequent advancement.

African yam bean: A safe, medicinal, and nutritious food

Consumption of African yam bean as food and drug is safe. Christopher et al. (2013) and Nwankwo et al. (2018) observed that the extract from the seed was non-toxic and did not show behavioral changes for humans and animals at a concentration of 5,000 mg/kg. Igbo folklore medicine had long identified the crop to contain ingredients for the treatment of anemia, and Nwaoguikpe (2008) wrote a follow-up remark highlighting that African yam bean has an anti-sickling effect on sickled hemoglobin due to its high content of hydrophobic amino acids. Esan and Fasasi (2013) reported the content of hydrophobic amino acids in African yam bean seed to be 33.99 g/100 g. The

TABLE 3 Anti-nutritional factors, amino acid and bioactive compound in the seeds and tubers of African yam bean as revealed in literature.

Anti-nutritional factors	Seed/Grain										Tuber	
Saponin (%)	0.111 ± 0.007	Ajibola and Olapade, 2016			0.07	Anya and Ozung, 2019					0.000302	Konyeme, 2021
Oxalate (%)	0.005 ± 0.0007		0.45	Shitta et al., 2022	0.01		0.00963	Abioye et al., 2015			0.000517	
Phytate (%)	0.013 ± 0.0004		5.16		0.72		0.259		0.00408	Adegboyega et al., 2020	0.000314	
Alkaloids (%)	0.227 ± 0.015				0.78						37.07	
Tannin (%)	0.003 ± 0.0008		0.0047	Shitta et al., 2022	0.34		0.01315	Abioye et al., 2015	2.38	Adegboyega et al., 2020	0.000251	
Trypsin (TIU/mg)	2.782 ± 0.205				0.21		0.32 ± 0.04				0.000223	
HCN (mg/kg)	7.184 ± 0.228				0.03							
Steroids (%)					0.02							
Total Glucosides (g/100g)											10.02	Konyeme, 2021
Total organic acids (ppm)											0.001726	
Amino acids and bioactive compounds												
Total Phenolics (g/100g)											23.52	Konyeme, 2021
Total Flavonoids (g/100g)											10	
Ascorbic Acid (mg/100g)					4.99 ± 0.15	Abioye et al., 2015						
β-Carotene (μg/100g)					70.19 ± 4.07							
Haemagglutinins (mg/100g)					0.35 ± 0.05							
Total Amino acids (g/100g)											13.25	Esan and Fasasi, 2013
Total Essential Amino Acid (TEAA) (g/100g)							53.69	Esan and Fasasi, 2013				
Total Non-Essential amino acid (TNEAA) (g/100g)							46.07					
TEAA/Total Amino Acid (%)							53.82					
Total Sulfur Amino Acid (Methionine+Cystine) (g/100g)							10.88					
Aromatic Essential Amino Acid (Phenylalanine+Tyrosine) (g/100g)							9.93					
TEAA/TNEAA (%)							116.54					
Hydrophobic Amino Acid (g/100g)							33.99					

oral administration of the extract to anemic Wistar albino rat at 100, 200, and 400 mg/kg body weight as investigated by Christopher et al. (2013) showed a significant increase ($p < 0.05$) in the packed cell volume (PCV), red blood cells (RBC) and hemoglobin concentration in the rat after 4 days of treatment. The observation justified the correctness of the long-held folklore as the observed increase in PCV, RBC, and hemoglobin concentration was speedy and comparable with Ranferon (a standard blood tonic drug) often used in the treatment of anemia (Christopher et al., 2013). The extract administration restored anemic conditions in rats, thus giving credence to the use of African yam bean in the management of anemia in humans and animals. Among the many lists of deficiencies and attending health challenges especially in Africa according to Baldermann et al. (2016) are iron deficiency and anemia, iodine deficiency and mental impairments, vitamin A deficiency, and blindness. The use of some of the neglected species could alleviate most of these health issues. The consumption of African yam bean grains experimentally enhanced recovery from anemia (Christopher et al., 2013). Ajayi et al. (2009) remarked that the seeds of African yam bean hold a high quantity of Iron. Konyeme et al. (2020) equally reported that the same mineral was highest in the tuber of African yam bean.

The seeds of African yam bean are potential sources of supplements in human and ruminant livestock (Ajayi et al., 2009). The whole seed is rich in potassium and phosphorus (Oshodi et al., 1995). The seeds are also rich in magnesium, calcium, and zinc but low in sodium and copper (Edem et al., 1990). Since anemia has been implicated in the etiology of many diseases, Christopher et al. (2013) strongly recommended the consumption of this plant for the full benefit of its nutritional and medicinal properties. The nutritional qualities of these seeds gave the seeds novel properties that made the legume a potential but latent nutraceutical (Nwankwo et al., 2018). Ndidi et al. (2014) reported that African yam bean grains have low caloric value, which makes it an interesting healthy food because high-fat diets lead to increased blood cholesterol levels and cardiovascular-related health issues. Details of anti-nutritional factors, amino acids, and bioactive compounds in both seeds and tuber of African yam bean based on literature is presented in Table 3. Anti-nutritional factors, some bioactive compounds, and amino acids were higher in the seed compared to the tuber.

Moreover, in the seed, the proportion of the essential amino acid in the total amino acid was higher than 50% (Table 3).

Nutritional profile of African yam bean grain

Awareness of the nutritional value of African yam bean seems to be improving in recent times. A survey among 500 respondents in the five Igbo-speaking states in southeastern Nigeria by Nnamani et al. (2017) revealed that proportional quantities of the population had a good awareness of the food and nutritional values inherent in African yam bean seeds. They further reported that the grain is sold at a significantly higher price than cowpea and other legumes. African yam bean is a rare legume that offers rich food, medicine, and nutrient-dense value for humans and livestock (Onyenekwe et al., 2000; Azeke et al., 2005; Akinmutimi et al., 2006). That it is exceptionally nutritious (Rachie, 1973) has long been the assertion of older adults in villages where they are highly relished and preferred over other contemporary legumes. The grain of the African yam bean has high metabolic energy, true protein digestibility (62.9%), moderate mineral content, and high-water absorption capacity (Ukom et al., 2019). The amino and fatty acid contents are comparable to those of most edible pulses. It also carries over 32% essential amino acids, with lysine and leucine being predominant (Onyenekwe et al., 2000) with very low-fat content. African yam bean is a nicely rounded non-fat food, containing 50–75% carbohydrate, 20–25% protein, about 1% oil, and about 6% fiber; all these provide nearly 400 calories per 100 g dry-weight (National Research Council, 2006). George et al. (2020) recently aggregated and presented the range of proximate composition in African yam bean grains from different authors as carbohydrate (49.88–63.51%), protein (19.53–29.53%), ash (1.86–5.35%), fat (1.39–7.53%), and fiber (2.47–9.57%). The nutrient density of the crop makes it a viable food crop for ameliorating food security and malnutrition challenges being faced in many developing countries, *via* direct consumption or fortification and enrichment of less nutritious staples (George et al., 2020). It provides a complete meal with significant mineral and vitamin loads. Table 4 shows that the contents of crude fiber, carbohydrates, and lipids were highest in African yam bean in comparison with soybean, cowpea, and bambara groundnut. Furthermore, the sodium and zinc contents were higher in quantity than the other legumes (Table 4). This makes it a qualified meal for food, nutrition, and health.

African yam bean tubers—A neglected product of the species

African yam bean is an underutilized crop (Potter and Doyle, 1992; Nwokolo, 1996; Azeke et al., 2005). Comparing the consumption, utilization, and research focus on the two economic products of African yam bean, the tuber has suffered more neglect. Predominantly in west Africa, the crop grows as an intercrop with other crops such as cassava, maize, yam, sorghum, and cocoyam (Saka et al., 2004) and primarily for the aerial pods which produce the pulse. Most farmers have denied ever seeing the tubers of African yam bean; the few who have seen it noted it as insignificant compared to the major carbohydrate providers (i.e., root and tuber crops), and hence, it is not cherished. Moreover, since the African yam bean is usually intercropped mainly for the aerial pulse, an intuitive probe to the subterranean part of the plant to get tubers is usually a rare venture (if ever attempted) among farmers whose carbohydrate needs are made available from major tuberous crops. This may answer why the African yam bean tuber has been a neglected product within the neglected species, especially in west Africa. Therefore, to most farmers in southeastern and western Nigeria, African yam bean tuber has poor economic relevance beside yam (*Dioscorea rotundata*), cassava (*Manihot esculenta*), sweet potatoes (*Ipomea batatas*), Irish potato (*Solanum tuberosum*), cormels from Tania (*Xanthosoma sagitifolium*), and Taro (*Colocasia esculenta*).

Nutritional profile of African yam bean tuber

The awareness that the crop produces tuber is visited with the feeling that the underground root would be toxic. Ojuederie et al. (2020), in their study, established that consumption of the tubers of African yam beans was harmless to Wistar rats and human beings. They found that it contained fewer antinutrients; for example, the proportion of the phytate in the tuber to the seed was in the general ratio of 4:10; trypsin inhibitors and lectin were not identified in tubers of some genotypes and the content of cyanogenic glycoside was very negligible. Specifically, its consumption by Wistar rats did not trigger any toxic effect in the tissues and organs of the specimen. Therefore, the investigation by Konyeme et al. (2020) updated the rich nutritional value of the tubers, while the research of Ojuederie et al. (2020) supported their safe consumption by human beings and livestock.

Table 5 provides the comparative ranges in values for proximate and mineral contents in the tuber of African yam bean, *Pachyrhizus*, cassava, sweet potato, and Irish potato drawn from various studies. African yam bean had the lead in crude protein with 13.25% amino acid (Table 3), total ash, and fat. Moreover, the comparison of its content with the nine minerals revealed that it holds the top position (Table 5). This comparison confers significance on the crop above the other contemporary roots and tubers, further confirming the earlier assertion of the National Research Council (1979) and Amoatey et al. (2000).

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TABLE 4 Ranges in proximate, mineral and vitamin contents on dry matter basis in the seed of African yam bean, cowpea, soybean and bambara ground nut as revealed in literature.

S/N	Items	Range of values in literature for AYB	Ref.	Range of values in literature for Cowpea	Ref.	Range of values in literature for Soybean	Ref.	Range of values in literature for BGN	Ref.
Proximate composition									
1	Moisture content (%)	7.9–13.3	a, b, e	7.23–12.82	g, h, i, j	3.86–8.07	k, l, m	9.20–10.2	n, o, p, q
2	Crude ash (%)	1.86–5.35	a, b, c, d, e	3.24–4.2	g, h, i, j	4.29–4.92	k, l, m	3.40–4.36	n, o, p, q
3	Crude fat (%)	1.32–1.88	a, b	0.44–2.98	g, h, i	18.5–28.2	k, l, m	5.57–7.2	n, q
4	Crude protein (%)	17.66–24.31	a–e	23.01–26.44	g, h, i, j	31.19–37.69	k, l, m	16.44–22.40	n, o, p, q
5	Crude fiber (%)	2.47–10.5	a–e	1.86–4.4	g, h, i, j	4.99–6.27	k, l, m	1.45–4.80	n, o, p, q
6	Carbohydrate (%)	57.65–70.46	a, b, c, e	53.87–59.34	g, h, j	16.31–30.47	k, l, m	44.10–62.87	n, o, p, q
7	Dry matter (%)	87.55–91.09	c, d	NA		96.12 ± 0.23	m	NA	
8	Total lipid (%)	7.68 ± 0.21	c	4.03 ± 0.19	j	NA		5.17–7.60	o, p
9	Ether extract (%)	1.02–5.12	d, e	NA		NA		NA	
10	NFE (%)	48.47–59.94	d, e	53.51 ± 4.49	j	NA		NA	
Minerals									
1	Calcium (ppm)	240–4,360	e, f	202.86–2,420	g, h, j	231.6–10,800	k, l, m	350–38,740	o, p, q
2	Magnesium (ppm)	4,320–5,810	e, f	77.56–1,157	g, h, j	249.8–25,824	k, l, m	2,090–19,240	o, q
3	Potassium (ppm)	3,610–11,640	e, f	244.83–111,922.5	g, h, j	16,300	m	3,150–5,070	o, p, q
4	Sodium (ppm)	42,130	e	14.52–21,405.8	g, h, j	300–3,300	l, m	1,170–2,390	o, q
5	Phosphorus (ppm)	2,340–2,740	e, f	86.53–154.62	g, h	5,300–69,520	l, m	1,740–3,960	o, p
6	Manganese (ppm)	NA		NA		0.615	k	390	p
7	Iron (ppm)	100–1,260	e, f	7.5–140	h, j	579–1,640	k, l	180–425	o, q
8	Copper (ppm)	2,300	e	NA		NA		3,000	p
9	Zinc (ppm)	5,000	e	5.0–101.93	g, h, j	241.4–270	k, l	2,560–13,900	o, p
Vitamins									
1	Vit. C (mg/100g)	12.94 ± 0.26	c	NA				1.79	q
2	Vit. B1 (mg/100g)	0.12 ± 0.03	c	NA				0.4	q
3	Vit. B2 (mg/100g)	0.19 ± 0.03	c	NA				0.15	q
4	Vit. B3 (mg/100g)	0.53 ± 0.02	c	NA				2.34	q
5	B-carotene (mcg/100g)	NA		NA				8.83	q
6	Vit. E (mg/100g)	NA		NA				0.85	q

Range of values is the mean of means of presented values for the different items in the results sections of every publication cited, n–number of accessions/cultivars/genotypes considered in the various studies. Significant variations existed among the cultivars employed in the different studies.

AYB, African yam bean; BGN, Bambara ground nut; NA, Not applicable; NFE, Nitrogen free extract; Vit., Vitamins; Ref., References.

a, Adegboyega et al. (2020), n = 25; b, Ajibola and Olapade (2016), n = 5; c, Nnamani et al. (2018), n = 34; d, Anya and Ozung (2019), n = 2; e, Ameh (2007); f, Ojuederie and Balogun (2019), n = 4; g, Biama et al. (2020), n = 15; h, Antova et al. (2014), n = 4; i, Aletan (2018), n = 2; j, Owolabi et al. (2012), n = 5; k, Uwem et al. (2017), n = 3; l, Ogbemudia et al. (2017); m, Nwosu et al. (2019), n = 20; n, Igbabul et al. (2013); o, Olaleye et al. (2013); p, Musah et al. (2021); q, Okudu and Ojinnaka (2017).

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TABLE 5 Ranges in proximate and mineral contents in the tuber of African yam bean, *Pachyrhizus*, cassava, sweet and irish potato as revealed in literature.

S/N	Items	Range of values in literature for AYB	Ref.	Range of values in literature for *Pachyrhizus spp*	Ref.	Range of values in literature for Cassava	Ref.	Range of values in literature for Sweet potato	Ref.	Range of values in literature for Irish potato	Ref.
Proximate component											
1	Crude protein (%)	8.32–14.45	a, b, c	6.03–6.1	d, e	1.29–2.62	f, g	3.15–3.36	j, k	1.69–8.26	l, m
2	Moisture Content (%)	39.4–55.5	a, b, c	77.75	d	6.55	f	67.28–71.70	j, k	69.35–78.42	l, m
3	Total ash (%)	2.44–7.69	a, b, c	1.94–2.27	d, e	1.39–4.48	f, g	1.24–3.32	j, k	0.96–2.5	l, m
4	Crude fiber (%)	2.4–9.8	a, b, c	6.64	e	1.28	g	0.43–2.38	j, k	0.57–0.88	l, m
5	Crude fat (%)	1.28–2.77	a, c	0.57	e	0.44–2.82	f, g	0.28–2.29	j, k	0.07–2.3	l, m
6	Carbohydrate (%)	54.47–79.24	a, b, c	13.34–91.12	d, e	90.34	f	23.18–24.98	j, k	16.57–18.06	l, m
7	Calorific value (Kjg-1)	1,451	a	388.79	e	NA		134.369	j		
8	NFE (%)	71.18	b	NA		88.88	g	NA			
9	Ether extract (%)	0.6	b	0.37	d	NA		NA			
Minerals											
1	Calcium (ppm)	500–2,680	a, b			783.33	h	2,560	i		
2	Magnesium (ppm)	1,670–4,670	a, b			850	h	2,352	i		
3	Potassium (ppm)	7,400–48,790	a, b			3,166.67	h	31,650	i		
4	Sodium (ppm)	21,440	b			54.15	h	3,184	i		
5	Manganese (ppm)	114.06	c			28.87	h	NA			
6	Iron (ppm)	80–3,160	a, b, c			156.76	h	63	i		
7	Zinc (ppm)	78.56–3,750	b, c			7.33	h	1,540	i		
8	Copper (ppm)	31.02–1,600	b, c			7.08	h	NA			
9	Phosphorus (ppm)	20–66,010	a, b			1,051	h	4,380	i		

*AYB, African yam bean; Ref., References; NFE, Nitrogen free extract, quantitative estimates were on dry matter basis.
a, Ojuederie and Balogun (2019), n = 4; b, Ameh (2007); c, Konyeme et al. (2020), n = 17; d, Ascheri et al. (2014), n = 5; e, Buckman et al. (2018); f, Nilusha et al. (2021), n = 5; g, Fakir et al. (2012), n = 7; h, Adeniji et al. (2007), n = 5; i, Sanoussi et al. (2016), n = 10; j, Aweke and Roba (2016), n = 10; k, Alam et al. (2016), n = 9; l, Gikundi et al. (2021), n = 3; m, Ezekiel et al. (2020).

Promotional initiatives to improve African yam bean utilization

Poor monotonous diets, with low calorific quantity and quality, void of nutritional and food diversity, are the primary cause of poor human health in many developing countries (Nnamani et al., 2021). Nutrient-dense diets based on diverse crops deliver better nutrition and greater health with additional benefits for human productivity (Chivenge et al., 2015). This is why food and nutrition security are a foundation for human livelihood. Agunwah et al. (2019) emphasized that the African yam bean represents a source of alternative protein supplements and its protein isolates possess certain characteristics that aid in protein enrichment for some food products.

The identification of the potential nutritional value inherent in African yam bean and the poor acceptability-adoption complexes have led to the development of some initiatives to bring the crop in part or whole to the urban menus. Consumption of processed food and light snacks is a common feature in urban centers. With the growing consumer awareness of the need to consume healthy foods, the presence of fiber, some useful starch, and essential fatty acids, African yam bean is a good candidate for the development of new functional foods for consumer health (George et al., 2020). Since African yam bean is available, affordable, and inexpensive, its incorporation in food products and continual utilization promise nutrition and health benefit to consumers across all socio-economic statuses. Some initiatives employed the grain legume as a fortifier in biscuits (Idowu, 2014) and cookies (Okoye and Obi, 2017). They noted that this readily available nutritionally-dense grain legume satisfactorily fortified biscuits and cookies, improving calcium, potassium, phosphorus, magnesium, and iron contents and widely improving the physicochemical properties of the two confectioneries including their color. Elusoji (2015) reported that all the cookies made from wheat flour supplemented with African yam bean flour compared favorably well with the control (100% wheat flour). Therefore, cookies production from wheat flour blended with African yam bean may be a promising initiative to increase the consumption and utilization of the crop. Positively, the utilization of African yam bean in the production of cookies would improve the nutritional value of cookies and hence the acceptability of the crop, and the consumption of such composited cookies and biscuits could increase the utilization of African yam bean, thereby increasing the economic power of local farmers. This could also reduce the importation of wheat, thus saving foreign exchange and enhancing food security (Igbabul et al., 2015; Ikhajiagbe et al., 2021). African yam bean utilization initiative research by Igbabul et al. (2015) led to the successful production of acceptable cookies from composite flours of wheat, cocoyam, and African yam bean; the product was remarked to have increased protein, ash, and crude fiber.

Health benefits of African yam bean

The report by Azuzu (1986) seemed to be the first study on the medicinal qualities of the crop in curing stomach aches and acute drunkenness. There is no record of clinical studies on the usefulness of both the seed and tuber of the crop. However, successful *in vitro* and human studies revealed the efficacy of the crop in the management of anemia, diabetes, and arthritis.

Traditional culinary and health

A report of its medicinal value in traditional Igbo settings in Enugu State, Nigeria, informed as follows: the seed is an important ingredient utilized in the topical treatment of stroke, insomnia, diabetes, measles, and stress. In addition, the liquid extract of mashed African yam bean cooked seed is often served to lactating mothers to induce and improve lactation after delivery. The fried seed coat are grounded and used in the treatment of stroke (Nnamani et al., 2018). Moreover, the roasted bean is traditionally prepared to entertain guests during marriage ceremonies. The legume is also reported to be of importance in the management of chronic diseases like diabetes, hypertension, and cardiovascular diseases because of its high dietary fiber content (Enwere, 1998). Nwankwo et al. (2018) reported the anti-diabetic activity of the seed extract of African yam bean. The seed milk extract of *S. Stenocarpa* possessed anti-diabetic activity like the reference drug glibenclamide. Graded doses of the seed milk extract were reported to have a blood glucose-lowering effect in a time and concentration-dependent manner (Nwankwo et al., 2018).

Management of gouty arthritis

African yam bean has a long history of pharmacological potential, especially in the management of gout and arthritis in addition to the already known nutritional properties (Eneh et al., 2016). There are a lot of other health benefits that can be derived from this plant. According to Soetan and Adeola (2018), the bioactive compounds in the grains of African yam beans have pharmacological and beneficial effects on disease management. Phenolic extracts from African yam bean seed (See the range of values in Table 3) have antioxidant power and the ability to scavenge free radicals (Enujiugha et al., 2012). The pathology of gout involves the deposition of urate crystals at the joints and tissues (Nsirim, 1999). Consumption of African yam bean was observed to reduce uric acid levels in the serum thus mopping up urate crystals (Eneh et al., 2016). This research unveiled the potential of African yam bean to contain potent bioactive ingredients for gouty arthritis management. The study by Eneh et al. (2016) equally identified the use of the crop as a local analgesic. Their findings revealed the African yam bean as a valuable and indispensable leguminous crop whose nutritional and pharmacological properties need to be commercially harnessed.

African yam bean grain as alternative crude protein for livestock feeds

Protein components in livestock feeds are the costliest. Soybean has been mostly used but their availability and cost are often challenging. This has made the consideration of alternative grain legumes a quest. African yam bean has been suggested as a very good substitute because its crude protein content falls within the range of values required for the substitution of soybean (Akinmutimi et al., 2006). In their research on weaner rabbit, Akinmutimi et al. (2006) observed that the feed-to-gain ratio increased as the quantity of raw African yam bean meal increased in the diet and became significantly different from the control (not fed on African yam bean). In another study on broiler chicken, Akinmutimi et al. (2011) reported that African yam bean supported better growth performance, low mortality, improved carcass characteristics, and cost per kg weight gain of meat, especially when the beans were boiled before usage as feed materials. This was a development over the initial research on weaner rabbits in which raw African yam bean was used.

Feed consumption by the rabbits was low when the content of African yam beans was much higher in the feeds of the rabbits. The presence of saponin and tannin was implicated (Akinmutimi et al., 2006) for the low feed intake. Processing by boiling reduced trypsin inhibitor and hydrocyanic acid and increased feed intake by the broiler chickens (Akinmutimi et al., 2011; Ndidi et al., 2014). In another study by Okereke et al. (2011) on finisher feeds for broiler chickens, toasting the grains enhanced feed intake, and supported optimum growth. Processing of the seed before utilization as a feed component yielded very good and highly comparable results (Anya and Ozung, 2019). Moreover, fermentation with lime subdued the beany flavor of the meals from African yam bean grains (Ngwu et al., 2014); for instance, Ajayi (2011) noted that fermentation grossly reduced phytate content in African yam bean meals. Okereke et al. (2011) further found that the replacement of the more expensive conventional feed ingredients with alternative cheap and affordable grain legumes was a possible solution to the escalating cost of livestock feeds. Fermentation and roasting increased the nutrient content and acceptability of its meal by livestock.

Conclusion and future research

African yam bean, like many other legume species, is an excellent food, low in fat, and rich in protein, fiber, minerals, and vitamins. Identification of the adoption driver for any species is an appropriate primary process; sometimes, genetic improvement may be secondary while markets or food politics could be primary. Some of the constraints to underutilization may be addressed in the laboratory and field plots, while others may need advocacy and market development strategy; sometimes in practice, many will need both. So, identifying crops that stand out as having the trait (and associated market) show higher potential than other common crops and are capable of improving food security is the first task (Mayes et al., 2012). This review unveils the food, feed, and health benefits of African yam bean. What do orphan crops have to offer that is not in the mainstream of the most used crops? Identification and realization of such potential according to Mayes et al. (2012) could justifiably lead to consideration of its/their uniqueness.

Most cultural systems or indigenous communities have cultivated and utilized diverse traditional crop varieties/landraces. The knowledge from seed to the table of such crops remains with the diverse indigenous cultures. They are not documented but are socially embedded in the cultures, traditions, and beliefs, they were locally derived and have for many years co-evolved with the ecosystem and lifestyle of each cultural domain (Berkes et al., 2000; Chivenge et al., 2015). The information in them has always been transferred through generations, observations and narrations. The present world of science which lacks knowledge of these crops and cannot find archival documentaries has one option—to directly link to the past through consultations with the indigenous cultures. Nnamani et al. (2018) did that for African yam bean among the five Igbo community states of Nigeria with very significant discoveries.

On Olanipekun's et al. (2017) concerns on the lack of knowledge about underutilized crops in the intellectual domain, future research on rescuing underutilized crops including African yam bean could be difficult if basic information (some of which are still intact with the indigenous communities) are not duly and promptly harnessed. The gap between the past and the present has made the quest for research on the underutilized crop unappealing because the link to past culture is often undocumented, and the benefits they provide are unknown because uses and possibilities from them died with the history. Important uses and functions of these species in the past as food or drug would have to be traced. Information from such search would lead to the realization of the forgotten or unknown importance of the crops. Therefore, since African yam bean is cultivated and utilized in different cultures in most parts of Nigeria and west and central Africa, a national survey to rescue fading important information and germplasm collection is urgently needed.

It is clear from the literature that locked-in crops such as the African yam bean have suitable and promising place in addressing human food, livestock feeds, and nutritional problems. In the future, harnessing its utility includes: significant awareness creation on the crop, its products and end products, policy support of its productivity/availability, research to address the inherent hard-to-cook and anti-nutritional problems, and innovative valorization along its value chain. This will enhance its attraction and drive the demand for is consumption and utilization. According to Akah et al. (2021), tireless efforts toward achieving some of these should, therefore, be pursued by all stakeholders to curb the prevalent nutritional problems.

Author contributions

BA and CN: conceptualization, literature search, outline planning, and review and editing. BA: original draft. Both authors contributed to the article and approved the submitted version.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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