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REVIEW PAPER

BAMBARA GROUNDNUT (*Vigna subterranea* (L.) Verdc.): A PROMISING CROP FOR FOOD INDUSTRY

SAHEED ADEWALE OMONIYI[1,2], NOR AFIZAH MUSTAPHA[2], RADHIAH SHUKRI[2], NURUL SHAZINI RAMLI[3], MOHD RAFII YUSOP[4,5], RABIHA SULAIMAN[2,6*]

[1]*Department of Home Science and Management, Faculty of Agriculture, Federal University, Gashua, Yobe State, Nigeria*

[2]*Department of Food Technology, Faculty of Food Science and Technology, Universiti Putra Malaysia, 43400 Serdang, Selangor Darul Ehsan, Malaysia*

[3]*Department of Food Science, Faculty of Food Science and Technology, Universiti Putra Malaysia, 43400 Serdang, Selangor Darul Ehsan, Malaysia*

[4]*Institute of Tropical Agriculture, Universiti Putra Malaysia, 43400 Serdang, Selangor Darul Ehsan, Malaysia*

[5]*Department of Crop Science, Faculty of Agriculture, Universiti Putra Malaysia, 43400 Serdang, Selangor Darul Ehsan, Malaysia*

[6]*Halal Products Research Institute, Universiti Putra Malaysia, 43400 Serdang, Selangor Darul Ehsan, Malaysia*

*Corresponding author: *rabiha@upm.edu.my*

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ABSTRACT. Bambara groundnut is an underutilized food outside the main regions of its consumption. However, after soybean, groundnut, and cowpea, this legume is considered the fourth most significant one. It is an excellent food crop due to various beneficial characteristics, including stress tolerance, nitrogen fixation, and the capacity to grow and sustain in low-input environments. The fact that Bambara groundnut can be eaten untreated demonstrates that it has fewer and least harmful anti-nutritional factors. Due to its well-balanced macronutrient content, this nutrient-dense legume is commonly known as a "complete food". Compared to other legume crops, Bambara groundnut has an excellent nutrition profile for traditional and new food applications, besides the agronomic potential to be planted in many areas globally. Increasing awareness among consumers of Bambara groundnut as a food is needed for this potential crop. This review showed that Bambara groundnut possesses high values of nutritional composition, lower quantity of anti-nutritional properties, and good functional and physico-chemical properties. Discussion on applications of Bambara groundnut in the food industry showed Bambara groundnut could be explored as an alternative source of protein, supplementation of carbohydrate-based foods, and ingredient in many food applications.

Keywords: underutilised crop, non-dairy ingredients, legume, alternative protein, anti-nutritional factors, food security

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Introduction

Bambara groundnut (*Vigna subterranea* (L.) Verdc.) is a leguminous plant of African origin and widely cultivated in sub-Saharan nations (Jahanshiri *et al*., 2022; Nwadi *et al*., 2020). Bambara groundnut, also referred to by common names like the ground bean, Bambara bean, earth pea, Congo goober, and orhog peanut, belongs to the Fabaceae family (Odeniyi *et al*., 2017). According to FAO (2022) data, the total global production of Bambara beans in 2021 was 239,607 metric tons. It should be noted that FAO (2022) reports data on Bambara groundnut as Bambara bean. During the 2001-2021 period, Bambara groundnut production has more than tripled, from 79,306 metric tons in 2001. Similarly, the area under Bambara groundnut has shown a phenomenal increase, from 100,573 hectares in 2001 to 406,911 hectares in 2021. The leading Bambara groundnut producers by quantity (metric tons) in 2021 were Burkina Faso (65,966), Niger (52,211), and Cameroon (40,650), combined, these three countries accounted for two-thirds of the total global production (FAO, 2022).

Bambara groundnut is primarily grown for human consumption and can be consumed in various forms, whether ripe or unripe (Tan *et al*., 2020). Bambara groundnut contains notable nutritional content and a well-balanced amino acid profile, often used to complement low-protein ingredients in the preparation of numerous dishes (Oyeyinka *et al*., 2021). It serves as a key ingredient in a wide range of dishes, such as bread, milk, biscuits, meat alternatives, yogurt, pasta, doughnuts, fufu, and extruded foods, with its usage varying across different communities and countries (Nwadi et al., 2020). Despite its potential, Bambara groundnut has not received consistent attention in terms of commercial processing, possibly due to its relative obscurity as a legume crop in many parts of the world (Adetokunboh *et al*., 2022). In regions where the cost of animal protein is prohibitively high, Bambara groundnut plays a pivotal role as an economical protein source within dietary practices (Mubaiwa *et al*., 2017). Bambara groundnut represents a crucial protein source for a substantial segment of the African population (Adedayo et al., 2021). The versatility and affordability of Bambara groundnut make it a compelling alternative plant-based protein source.

Bambara groundnut exhibits remarkable drought resistance and is known for its ease of cultivation, making it a resilient and potential alternative protein choice. The challenge lies in providing valuable knowledge about Bambara groundnut, a legume that is unfamiliar to many people and remains relatively unacknowledged in many countries (Ndidi *et al*., 2014). Promoting the cultivation and consumption of Bambara groundnut, along with continued research and education on its nutritional benefits, can pave the way for this legume to emerge as a valuable alternative protein source, contributing to improved food security and nutrition in various communities. This review paper provides an extensive overview of Bambara groundnut, delving into its nutritional composition, anti-nutritional factors, functional and physicochemical attributes, as well as its utilization in value-added processing for a variety of food applications.

Characteristics of Bambara groundnut

Bambara groundnut seeds have smooth and hard surfaces. Similar to peanut (groundnut) pod and seed development, the formation of Bambara groundnut starts with an above-ground fertilized flower, while the pods and seeds develop and mature only underground (Toungos *et al*., 2009). Each pod, measuring over half an inch long, bears 1-2 oval or round seeds (nuts), and pods become wrinkled upon partial drying underground. The 100-seed weight of Bambara groundnut generally varies from 280 g to 320 g (Khan et al., 2021). The color of Bambara groundnuts varies from pale yellow to black, cream, and purple to mottled or black-eyed, with or without hilum coloration (Mohammed *et al*. 2016). The cream-colored Bambara groundnut (Figure 1) is widely reported by most authors.

Figure 1. Cream-colored Bambara groundnut

Nutritional composition, phytochemical, anti-nutritional, and functional properties of Bambara groundnut

Nutritional composition and phytochemical of Bambara groundnut

Table 1 shows the proximate composition of Bambara groundnut as reported by different studies. The values reported for proximate composition were 3.80-11.70% (moisture), 2.72–5.37% (ash), 17.41–24.34% (crude protein), 1.40–7.20% (crude fat), 2.05–9.80% (crude fiber) and 50.20–69.18% (carbohydrate). The moisture content of Bambara groundnut was within 9.79-10.90% reported for cowpeas (Aletan, 2018; Antova *et al*., 2014; Gondwe *et al*., 2019), but lower than the moisture content of cowpea of 12.06% and 13.79% reported by Enyiukwu *et al*. (2020) and Karuwal *et al*. (2021), respectively. However, it should be noted that Bambara groundnut is a legume-like cowpea, whose structure and utilizations are similar. The low moisture content of food demonstrates its capacity for long-term storage (Abdulrashid and Hassan, 2021). The values of moisture content reported for Bambara groundnut were low and this signifies that it can be stored for a long time (over one year). The variation in the values of moisture content could be linked to the drying time and drying methods used during processing. The range of ash contents (3.05 – 4.28%) reported for cowpeas (Karuwal *et al*., 2021; Enyiukwu *et al*., 2020; Gondwe *et al*., 2019; Aletan, 2018; Antova *et al*., 2014) were within the range of ash contents reported for Bambara groundnut. The total mineral content in food can be determined by the amount of ash content (Ogunmuyiwa *et al*., 2017). The reported high ash content signifies that Bambara groundnut has high mineral content, especially calcium, magnesium, potassium, phosphorus, and iron. Thus, Bambara groundnut could be utilitised industrially in complementing foods with low mineral contents, especially those based on root and tuber crops.

Table 1. Proximate composition (%) of Bambara groundnut.

Origin	Moisture	Ash	Crude protein	Crude fat	Crude fibre	Carbohydrate	References
Nigeria	5.77	3.00	18.37	4.44	5.02	69.18	Bala and Rano (2022)
Nigeria	10.50	3.26	17.41	4.81	3,41	60.61	Elochukwu (2020)
Nigeria	10.20	3.90	22.40	7.20	4.80	51.00	Okudu and Ojinnaka (2017)
Nigeria	3.80	4.78	24.34	4.99	3.06	59.04	Orhevba and Mbamalu (2017)
Nigeria	7.78	3.53	18.25	5.82	4.58	56.01	Anhwange *et al*. (2015)
Côte d'Ivoire	11.70	2.90	18.80	1.40	9.80	50.20	Yao *et al*. (2015)
Nigeria	10.67	4.18	18.03	6.05	3.91	57.16	Adegunwa *et al*. (2014)
Nigeria	10.30	3.64	21.85	6.90	3.42	53.80	Okafor *et al*. (2014)
Nigeria	6.54	3.05	21.29	6.05	4.67	63.07	Ndidi *et al*. (2014)
Nigeria	9.23	4.36	18.40	5.17	2.05	60.80	Olaleye *et al*. (2013)
Nigeria	6.71	3.75	18.66	6.52	6.49	57.87	Olanipekun *et al*. (2012)
Nigeria	9.82	3.10	22.46	5.80	4.50	55.00	Oyeleke *et al*. (2012)
Nigeria	8.70	5.37	20.27	6.85	6.85	51.96	Abdulsalami and Sheriff (2010)
Nigeria	8.65	2.72	19.77	5.75	2.29	61.82	Abiodun and Adepeju (2011)

The crude protein contents of 25.68% (Enyiukwu *et al*., 2020) and 27.13% (Gondwe *et al*., 2019) reported for cowpea were higher than the range of crude protein contents of 17.41 to 24.34% reported for Bambara groundnut, whereas the crude protein contents of 18.54 to 23.62% reported for cowpea (Karuwal *et al*., 2021; Aletan, 2018; Antova *et al*., 2014) were within the range of crude protein contents reported for Bambara groundnut. In addition, the crude protein contents of 35.60 to 39.24% reported for soybean (Uwem *et al*., 2017; Etiosa *et al*., 2018; Bayero *et al*., 2019) were higher than the range of crude protein contents reported for Bambara groundnut. Although Bambara groundnut's crude protein content is lower than that of soybean, it remains on par with other legumes, underscoring its potential as a reliable protein source. Bambara groundnut could serve as a cheap source of plant-based protein in African countries, where malnutrition is one of the major nutritional problems. It has the potential to be an alternative plant-based protein source for food security and food diversification.

The crude fat contents (18.50 to 30.31%) reported for soybeans (Pele *et al*., 2016; Uwem *et al*., 2017; Etiosa *et al*., 2018; Bayero *et al*., 2019) were higher than the crude fat contents (1.40 - 7.20%) reported for Bambara groundnut. However, the crude fat contents (0.97 to 1.70%) reported for cowpeas (Karuwal *et al*., 2021; Enyiukwu *et al*., 2020; Gondwe *et al*., 2019; Aletan, 2018; Antova *et al*., 2014) were within the crude fat contents reported for Bambara groundnut. Since the crude fat contents reported for Bambara groundnut were low, Oyeleke *et al*. (2012) categorized it as a low-fat food, which is ideal for low-fat diets and new product development. Consumption of Bambara groundnut could not pose high risk of cardiovascular problems due to its low-fat content, as Musah *et al*. (2021) revealed that certain cardiovascular problems may be exacerbated by excessive fat consumption.

The crude fiber contents (5.44 to 6.84%) reported for soybean (Pele *et al*., 2016; Uwem *et al*., 2017; Etiosa *et al*., 2018; Bayero *et al*., 2019) and also the crude fiber contents (1.70 to 6.93%) reported for cowpea (Enyiukwu *et al*., 2020; Aletan, 2018; Antova *et al*., 2014) were within the crude fiber contents (2.05 - 9.80%) reported for Bambara groundnut while the crude fiber content (15.08%) reported for cowpea (Gondwe *et al*., 2019) was higher than the range of crude fiber content reported for Bambara groundnut. Bambara groundnut comprises 10.30%, 0.50%, and 9.80% of total dietary fiber, soluble fiber, and insoluble fiber, respectively (Yao *et al*., 2015). Thus, the values of crude fiber contents of Bambara groundnut were in accordance with the values reported for soybean and cowpea contents. Bambara groundnut is rich in dietary fiber, which can support healthy digestion by promoting regular bowel movements and preventing constipation. The study conducted by Abdulrashid and Mhya (2021) provides valuable insights into the potential health benefits of different varieties of Bambara groundnut on liver and kidney functions. The results are promising as they indicated that diabetic rats, fed with diets containing various Bambara groundnut varieties, experienced improvements in liver and kidney functions, as evidenced by the restoration of serum protein and albumin levels and the reduction in AST, ALT, urea, and creatinine concentrations. These findings provide a valuable foundation for future investigations into the health-promoting properties of Bambara groundnut. Different varieties of Bambara groundnut had different glycemic index values, which might reflect the fact that they contained various amounts of fiber. Bambara groundnut had a good glycemic index and glycemic load values that could be taken into consideration for its potential use in the nutritional management of blood glucose in diabetic patients (Abdulrashid and Hassan, 2021).

The carbohydrate contents (5.08 to 38.48%) reported for soybeans (Pele *et al*., 2016; Uwem *et al*., 2017; Etiosa *et al*., 2018; Bayero *et al*., 2019) were lower than the carbohydrate contents (50.20 - 69.18%) reported for Bambara groundnut. Also, carbohydrate contents (54.16 to 63.48%) reported for cowpea (Karuwal *et al*., 2021; Enyiukwu *et al*., 2020; Aletan, 2018) was within the carbohydrate contents reported for Bambara groundnut, while the carbohydrate content (45.64%) reported for cowpea (Gondwe *et al*., 2019) was lower than that in Bambara groundnut. Bambara groundnut contains a high amylose content (35.00%), which might be an intriguing characteristic from both a technological and practical standpoint (Yao *et al*., 2015). Also, Olaleye *et al*. (2013) reported that Bambara groundnut contains cellulose (8.89%) and hemicellulose (2.86%), whereas non-starch polysaccharides of Bambara groundnut contains acid detergent fiber (18.40%), neutral detergent fiber (9.96%) and acid detergent lignin (17.40%). Raffinose and stachyose content of Bambara groundnut ranged from 1.30 to 2.05 g/100g and from 0.86 to 1.48 g/100g, respectively (Adeleke *et al*., 2017). Based on the nutritional data, it is evident that Bambara groundnut is a high-energy food and might be used as a low-cost source of energy as Oyeleke *et al*. (2012) revealed that high carbohydrate content implies that Bambara groundnut would be a relatively affordable source of energy for people.

Table 2 displays the rich mineral content of Bambara groundnuts, including calcium, magnesium, potassium, phosphorus, iron, zinc, copper, and other micronutrients. The calcium contents (23.16 to 324.00 mg/100g) reported for soybean (Uwem *et al*., 2017; Etiosa *et al*., 2018; Bayero *et al*., 2019) were within the calcium contents (12.75 to 765.00 mg/100g) reported for Bambara groundnut. The calcium contents (19.53 to 200.10 mg/100g) reported for cowpea (Owolabi *et al*., 2012; Inobeme *et al*., 2014; Gondwe *et al*., 2019) were also within the calcium contents reported for Bambara groundnut, while the calcium contents (2.69 mg/100g) reported for cowpea (Biama *et al*., 2020) were lower than the calcium contents reported for Bambara groundnut. The high calcium contents of Bambara groundnut, like other legumes, makes this one useful for a vegetarian meal, as Biel *et al*. (2018) reported that the amount of calcium in leguminous seeds is a crucial element of vegan diets. Nwosu *et al*. (2019) revealed that foods with high calcium contents could be employed in supplemental diets to aid with bone and tooth development. The magnesium contents (24.98 to 281.00 mg/100g) reported for soybean (Uwem *et al*., 2017; Etiosa *et al*., 2018; Bayero *et al*., 2019) were within the magnesium contents (4.21 to 347.15 mg/100g) reported for Bambara groundnut.

Table 2. Mineral content (mg/100g) of Bambara groundnut.

Mineral	**References**					
	Okudu and Ojinnaka (2017)	Yao *et al.* (2015)	Adegunwa *et al.* (2014)	Mathew *et al.* (2014)	Olaleye *et al.* (2013)	Oyeleke *et al.* (2012)
Calcium	387.40	30.20	765.00	12.75	77.70	256.56
Magnesium	192.40	136.00	133.50	4.21	20.90	347.15
Sodium	11.70	NR	9.27	22.40	23.90	135.30
Iron	1.80	8.80	1.89	150.34	4.25	18.51
Zinc	NR	1.90	0.51	4.89	25.60	NR
Potassium	35.60	NR	NR	122.91	50.70	1702.10
Phosphorus	NR	335.80	NR	18.56	38.60	738.04
Copper	0.21	0.50	NR	2.34	NR	NR

NR: Not Reported

The magnesium contents of 8.67 mg/100g and 194.01 mg/100g reported for cowpea by Owolabi *et al*. (2012) and Inobeme *et al*. (2014), respectively, were also within the magnesium contents reported for Bambara groundnut, while the magnesium contents (3.90 mg/100g) reported for cowpea (Biama *et al*., 2020) were lower than the magnesium contents reported for Bambara groundnut. Magnesium contributes to the production of proteins, the release of energy, and the retention of calcium in tooth enamel (Nwosu *et al*., 2019). The high contents of magnesium in Bambara groundnut showed that the legume could be utilized on an industrial scale by adding it to the foods of people suffering from malnutrition.

Both the sodium contents (3.00 mg/100g) reported for soybean (Etiosa *et al*., 2018; Bayero *et al*., 2019) and also the sodium contents (0.51 mg/100g) reported for cowpea (Owolabi *et al*., 2012) were lower than the sodium contents (9.27 to 135.30 mg/100g) reported for Bambara groundnut. However, the sodium contents (80.16 mg/100g) reported for cowpea (Inobeme *et al*., 2014) were within the range of the sodium contents reported for Bambara groundnut, while the sodium contents (218.84 mg/100g) reported for cowpea (Biama *et al*., 2020) were higher than the sodium contents reported for Bambara groundnut. Sodium is required by the body in order to support optimal blood pressure levels and the healthy operation of muscles and neurons (Nwosu *et al*., 2019). Bambara groundnut contains an appreciable amount of sodium contents, which could be good for normal metabolic body activities.

The iron contents of 16.40 mg/100g and 18.00 mg/100g reported for soybean by Etiosa *et al*. (2018) and Bayero *et al*. (2019), respectively, were within the range of the iron contents (1.80 - 150.34 mg/100g) reported for Bambara groundnut. The iron contents of 10.11 mg/100g and 20.10 mg/100g reported for cowpea by Inobeme *et al*. (2014) and Gondwe *et al*. (2019), respectively, were within the range of the iron contents reported for Bambara groundnut, while the iron contents (0.58 mg/100g) reported for soybean (Bayero *et al*., 2019) and those (1.04 mg/100g) reported for cowpea (Owolabi *et al*., 2012) were lower than the range of the iron contents reported for Bambara groundnut. The high iron contents make Bambara groundnuts a potential solution for combating anemia. It is noteworthy that several studies have linked anemia disease with iron deficiency. Thus, Bambara groundnut could be applicable in the food and pharmaceutical industry.

The zinc contents of 2.70 mg/100g and 3.00 mg/100g reported for soybean by Etiosa *et al*. (2018) and Bayero *et al*. (2019), respectively, were within the zinc contents (0.51 to 25.60 mg/100g) reported for Bambara groundnut. The zinc contents (1.03 to 7.00 mg/100g) reported for cowpea (Inobeme *et al*., 2014; Gondwe *et al*., 2019; Biama *et al*., 2020) were within the zinc contents reported for Bambara groundnut, while the zinc contents (0.24 mg/100g) reported for soybean (Bayero *et al*., 2019) and those (0.34 mg/100g) reported for cowpea (Owolabi *et al*., 2012) were lower than the zinc contents reported for Bambara groundnut. Appreciated values of the zinc contents were reported for Bambara groundnut, thus, its consumption could potentially improve the usual growth and development of the body system, as Rolf *et al*. (2021) revealed that zinc is a micronutrient that is important for the body to function properly.

The potassium contents (216.00 mg/100g) reported for soybean (Bayero *et al*., 2019) were within the potassium contents (50.70 - 1702.10 mg/100g) reported for Bambara groundnut. The potassium contents of 733.03 mg/100g and 1122.89 mg/100g reported for cowpea by Inobeme *et al*. (2014) and Biama *et al*. (2020), respectively, were within the potassium contents reported for Bambara groundnut, while those (17.68 mg/100g) reported for cowpea (Owolabi *et al*., 2012) were lower than the potassium contents reported for Bambara groundnut. Potassium plays a critical role in the functioning of the human body by protecting against diabetes, renal dysfunction, heart disease, and obesity (Mathew *et al*., 2014).

The phosphorus contents of 695.20 mg/100g and 722.00 mg/100g reported for soybean by Etiosa *et al*. (2018) and Bayero *et al*. (2019), respectively, were within the phosphorus contents (18.56 - 738.04 mg/100g) reported for Bambara groundnut, while the phosphorus contents (0.92 mg/100g) reported for cowpea (Biama *et al*., 2020) were lower than those reported for Bambara groundnut. Bambara groundnut's higher phosphorus contents and its addition to the diet could lead to stronger bones, as Nwosu *et al*. (2019) revealed that phosphorus and calcium are tightly related and calcium phosphate that results from the combination of the two minerals gives bones their hard structure.

The copper contents (2.00 mg/100g) reported for soybean (Bayero *et al*., 2019) and those (1.02 mg/100g) reported for cowpea (Inobeme *et al*., 2014) were within the copper contents (0.21 - 2.34 mg/100g) reported for Bambara groundnut. Copper and nickel are important micronutrients that are only toxic in excess, but necessary in lesser amounts for the body to operate properly (Biel *et al*., 2018). Since Bambara groundnut's copper contents were low, its inclusion in the diet could assist in regular metabolic activities.

Table 3 shows the amino acid profile of Bambara groundnut as reported by Musah *et al*. (2021), Awolu and Olokunsusi (2017), and Yao *et al*. (2015). Several other studies (Bujang and Taib, 2014; Yao *et al*., 2015; Awolu and Olokunsusi, 2017; Kudełka *et al*., 2021; Musah *et al*., 2021) have reported wide variations in the amino acid content of Bambara groundnuts. It is worth noting that such variations in amino acid contents are cultivar-dependent and are also due to variations in the agronomic practices (e.g., fertilization, irrigation) and agroecology of the Bambara groundnut growing regions.

Table 3. Amino acid profile of Bambara groundnut.

Amino acid	**Musah *et al*. (2021) g/100g**	**Awolu and Olokunsusi, (2017) mg/100g**	**Yao *et al*. |(2015) mg/g**
Leucine	7.12	660.26	102.1
Lysine	6.26	135.38	80.20
Isoleucine	4.06	223.25	54.50
Phenylalanine	4.43	263.35	76.90
Tryptophan	0.87	NR	6.00
Valine	4.29	280.25	62.40

Methionine	1.33	120.26	6.40
Histidine	2.55	163.37	38.60
Threonine	4.16	37.58	44.30
Arginine	6.79	235.37	74.80
Proline	3.14	455.35	53.60
Tyrosine	3.09	NR	31.30
Cysteine	1.33	105.00	24.10
Alanine	3.71	420.25	51.40
Glutamic acid	12.56	122.37	209.50
Glycine	3.70	220.25	46.50
Aspartic acid	NR	435.33	146.10
Serine	NR	345.36	68.50
Cysteine	NR	105.25	NR

NR: Not Reported

Anti-nutritional properties of Bambara groundnut

Table 4 shows the anti-nutritional properties of Bambara groundnut values ranged from 0.09 to 7.15 mg/100g, 4.54 to 18.41 mg/100g, and 1.06 to 5.02 mg/100g for tannin, phytate, and oxalate, respectively. Bambara groundnut contains 0.14 g/100g, 0.34 g/100g, and 1.01 g/100g of alkaloids, flavonoids, and saponin, respectively (Olaleye *et al*., 2013). The phytate content (345.00 mg/100g) reported for soybean (Ari *et al*., 2012) was higher than the phytate contents reported for Bambara groundnut. The phytate content (5.33 mg/100g) reported for cowpea (Owolabi *et al*., 2012) was within the phytate contents reported for Bambara groundnut.

Table 4. Antinutritional factors of Bambara groundnut.

Tannin (mg/100g)	Phytate (mg/100g)	Oxalate (mg/100g)	References
0.45	4.54	1.06	Okudu & Ojinnaka (2017)
0.96	15.30	1.22	Adegunwa *et al*. (2014)
0.09	14.40	5.02	Olaleye *et al*. (2013)
7.15	6.94	NR	Oyeleke *et al*. (2012)
0.32	18.41	1.34	Abiodun & Adepeju (2011)

NR: Not Reported

Functional and Pasting properties of Bambara groundnut flour

Adegunwa *et al*. (2014) reported bulk density (0.80 g/ml), dispersibility (80.67%), water absorption index (84.33%), foam capacity (24.67%), emulsification capacity (77.57%) and water binding capacity (6.33%) for Bambara groundnut flour. Musah *et al*. (2021) reported bulk density (0.85 g/ml), water absorption capacity (1.65%), foam capacity (16.00%), and oil absorption capacity (0.70%), while Okafor *et al*. (2014) reported foam capacity (33.30%), water binding capacity (1.70%) and oil binding capacity (1.30%) for Bambara groundnut flour.

Table 5 shows the pasting properties of Bambara groundnut flour as reported by Odeniyi *et al*. (2017), Adegunwa *et al*. (2014), and Abiodun and Adepeju (2011). The values reported ranged from 100.83 to 8,844cP, 94.92 to 8,568cP, 5.92 to 276cP, 145.25 to 21,600cP, 50.33 to 13,032cP, 4.13 to 7.00 min and 81.60 to 95.00℃ for peak viscosity, trough viscosity, breakdown viscosity, final viscosity, setback viscosity, peak time and pasting temperature, respectively. The value of peak viscosity (19.17cP), breakdown viscosity (5.33cP), final viscosity (32.83cP), and setback viscosity (19.17cP) of soybean reported by Ratnawati *et al*. (2019) was lower than the values reported for peak viscosity, breakdown viscosity, final viscosity and setback viscosity of Bambara groundnut. The peak viscosity (210cP) and breakdown viscosity (119cP) of soybean reported by Agume *et al*. (2017) were within the peak viscosity and breakdown viscosity reported for Bambara groundnut. However, the trough viscosity (91cP), final viscosity (103cP), and setback viscosity (12cP) of soybean reported by Agume *et al*. (2017) were lower than the trough viscosity, final viscosity, and setback viscosity reported for Bambara groundnut.

Table 5. Pasting properties of Bambara groundnut flour dispersions.

Viscosity (cP)					Peak time (min)	Pasting temp. (℃)	References
Peak	**Trough**	**Breakdown**	**Final**	**Setback**			
251.4	99.1	152.3	2,932	501	4.13	81.60	Odeniyi *et al.* (2017)
8,844	8,568	276	21,600	13,032	7.00	85.33	Adegunwa *et al.* (2014)
100.83	94.92	5.92	145.25	50.33	6.73	95.00	Abiodun & Adepeju (2011)

Utilization of Bambara groundnut

Fortification of cereal, production of snacks, biscuits, and other products

Ogunmuyiwa *et al*. (2017) studied the inclusion of Bambara groundnut with corn bran and cassava starch for the production of extruded snacks. The inclusion of Bambara groundnut increased the crude protein, ash, and crude fiber contents of the extruded snacks as the level of percentage inclusion of Bambara groundnut increased. Arise *et al*. (2020) studied croissant snacks produced by blending Bambara groundnut with wheat. The moisture, ash, crude protein, crude fiber, and crude fat content increased, while the carbohydrate content decreased in the Bambara ground-wheat flour blends and the croissant snacks produced from them. The bulk density and water absorption capacity of the flour blends increased as the inclusion of Bambara groundnut increased, but there was a decrease in the swelling and oil absorption capacities. However, a decrease in oil absorption capacity alongside an increase in the water absorption capacity of the flour blends could be linked to a higher concentration of hydrophilic amino acids found in Bambara groundnut. Regarding the pasting profile, there was an increase in setback viscosity and pasting temperature, but a decrease in peak viscosity, trough, breakdown viscosity, final viscosity, and peak time as the proportion of Bambara groundnut increased.

There was a decrease in swelling power, water absorption capacity, and dispersibility, but an increase in oil absorption capacity and least gelation concentration of Bambara groundnut-breadfruit blends as the proportion of Bambara groundnut increased (Arinola and Omowaye-Taiwo, 2020). This decrease could be the result of variations in the carbohydrate and protein levels of the two flours, while the high least gelation concentration may have been caused by the addition of Bambara groundnut, which increased the protein content of the flour blends due to reduced thermodynamic affinity of the protein for aqueous solution. These researchers concluded that Bambara groundnut-breadfruit blends demonstrated a variety of functional and pasting qualities and might be used to substitute more expensive flours such as yam flour and whole wheat flour that are frequently used to make dumpling dough. Awolu and Olokunsusi (2017) worked on blending Bambara groundnut with amaranth grain and reported that the protein, ash, lysine, methionine, tryptophan, threonine, oil absorption capacity, swelling capacity, and least gelation content of the Bambara groundnut and amaranth grain flour blends have been significantly increased with the addition of Bambara groundnut. It was mentioned that the limiting amino acids specific to cereals and legumes were successfully overcome by the combination of amaranth grain and Bambara groundnut.

Formulated samples with 5% of germinated Bambara groundnut and 95% of germinated millet samples have the appropriate functional qualities for baby formula (James *et al*., 2018). Arinola and Omowaye-Taiwo (2020) produced dumpling dough from breadfruit and Bambara groundnut blends at a ratio of 90:10; 80:20; 70:30 and 60:40, respectively, and determined its sensory acceptability using nine points hedonic scale. The dumpling dough made from 80%:20% flour blend was the most preferred in terms of all sensory attributes (taste, aroma, color, mouthfeel, texture, mouldability, and overall acceptability) and concluded that it is feasible to make palatable dumpling dough using a blend of 80% breadfruit flour and 20% Bambara groundnut flour.

Agu *et al*. (2014) worked on biscuits produced from flour blends of acha, Bambara groundnut, and unripe plantain. The physical properties, proximate composition, and sensory qualities of biscuits were enhanced by the inclusion of Bambara groundnut and unripe plantain flour, where the biscuits comprised some nutrients needed by diabetic people with stable shelf life. Atoyebi *et al*. (2017) investigated the sensory acceptability of Bambara groundnut products in Ibadan, southwestern, Nigeria. The quality attributes of cooked Bambara groundnut paste known as okpa were acceptable to the panelists. Oluwamukomi *et al*. (2021) evaluated the nutritional composition and sensory acceptability of maize-Bambara groundnut-based snacks. The inclusion of 20% Bambara groundnut flour produced a nutritious and acceptable snack. Similarly, Ihuoma *et al*. (2022) evaluated the microbiological quality, nutritional composition, and sensory acceptability of maize-Bambara groundnut snack bars. The snack bars were microbiologically safe, snack bar produced from

50% maize and 50% Bambara groundnut had the highest calorie content, while the snack bar produced with 100% Bambara groundnut had the highest protein content.

Bambara groundnut-based products made from germinated Bambara groundnut had a significantly lower tannin content, which may be a result of the seeds being soaked and dehulled (Lyimo *et al.*, 2004). The panelists accepted both bread and porridge made from germinated and non-germinated Bambara groundnut, and wheat flour and Bambara groundnut may have application in the production of composite flour and as a supplement to food. Ola and Adewole (2019) investigated the nutritional composition and physical properties of biscuits made from fermented Bambara groundnut and wheat flour blends. Their results showed that the protein content of the biscuit produced from the flour mixes was higher than that of wheat flour. As the amount of Bambara groundnut flour increased, the thickness and diameter of the biscuits gradually increased. It was further stated that the increase in diameter may be caused by a drop in the gluten content as a result of the increase in Bambara groundnut flour (Ola and Adewole, 2019). Bambara groundnut, sorghum, groundnut, and soybean are readily available locally in Nigeria and easy to grow in tropical climates with high yields; their blends could be made into acceptable ready-to-eat breakfast cereal foods (Usman, 2021).

The total flavonoid and phenolic contents of Bambara groundnut extracts were dependent on the length of boiling time and varieties of grain (Oyeyinka et al., 2021). The analysis of Bambara groundnut extracts showed a lack of activity against Candida albicans but had some degree of inhibitory effect on *Escherichia coli*. The observed pattern of antibacterial activity is correlated with the total phenolic and flavonoid contents of the extracts. The research reported that tannin, saponin, steroid, alkaloid, cardiac glycoside, and flavonoid were all detected in varieties of Bambara groundnut, but no anthraquinones were detected.

Production of malt, milk, and yoghurt

Adetokunboh *et al*. (2022) worked on Bambara groundnut malts and syrup products. The authors produced four specialty malts (base, caramel, roasted, and toasted malts) from Bambara groundnut and revealed that all of the specialty malts had a noticeable variance in their lightness, redness, yellowness, chroma, and color, as caramel malt (14.12%), having the lowest protein content, and toasted malt (17.58%) having the highest protein content. The range of protein contents (14.12 – 17.58%) reported for Bambara groundnut malts was higher than the range (11.80 – 13.10%) reported for malted barley by Arif *et al*. (2011) and Makeri *et al*. (2013).

Lysine was the greatest amino acid for the base (61.97 mg/g), caramel (52.67 mg/g) and roasted (38.89 mg/g), whereas aspartic acid was the highest for toasted malt (14.46 mg/g), but methionine was the least abundant amino acid for all the four specialty malts (Adetokunboh *et* al., 2022). The protein content of the specialty syrups from Bambara groundnut is 9.73%, 10.37%, 11.10%, and 11.35% for the base, caramel, roasted, and toasted malt, respectively. Specialty malt syrup showed a high percentage of protein content that might be helpful to customers. Due to the different amino acid concentrations in Bambara groundnut specialty malts, caused by the drying conditions, it is possible to produce food and beverage functional components using the base malt with the highest amino acid concentration (Adetokunboh *et al*., 2022). It was concluded that specialty Bambara groundnut malt has nutrients that can be added to the diets of people for their health advantages, and its application in the food and beverage industries ought to be promoted.

Bambara groundnut yogurt consumption had no negative effects on the heart, liver, or kidneys and these characteristics provide Bambara groundnut yogurt and Bambara groundnut milk with a better perspective on the part it can play in the lowering of protein-energy malnutrition (Pahane *et al*., 2017). Falade *et al*. (2015) studied plain yogurt from Bambara groundnut and soybeans and observed that milk yields from Bambara groundnut (47.00%) and soybean (52.20%) indicated that soybean was a more effective source of milk than Bambara groundnut. The apparent viscosities and total solids of Bambara groundnut and soybean yogurts increased at 7°C, but decreased during storage, resulting in yogurt of high quality. While the microbiological quality and profiles of both Bambara groundnut and soybean yogurts were identical, Bambara yogurt was preferred over soybean yogurt.

Tan *et al*. (2020) developed a powdered drink mix from Bambara groundnut and soybean with respective ratios of 10:90, 20:80, and 30:70 Bambara groundnut: soybean. The protein and fat contents of the Bambara groundnut-soybean drink mix increased, while the ash and carbohydrate contents decreased as the Bambara groundnut powder increased in the formulations. The color of the Bambara groundnut-soybean drink mix gets darker with an additional Bambara groundnut powder in the formulation. The sample that contained 10% Bambara groundnut and 90% soybean powder received scores for appearance (76%), flavor (54%), viscosity (88%), grittiness (66%), and overall acceptability (72%), and the formulation has the best profile since the majority of the sensory characteristics fall within the just-about-right range. The Bambara groundnut-soybean powder mix remained microbiologically viable after six months at room temperature, and *in vivo* tests revealed that the powdered mix could lower total cholesterol levels in rats.

Production of starch, protein isolate, and concentrate

Arise *et al*. (2015) investigated protein concentrate extracted from Bambara groundnut local varieties using two extraction methods, and reported that Bambara groundnut concentrates made using acid precipitation had much higher yields (52%) and protein contents (79%) than those made through salt solubilization. The use of pH 8 NaOH to adjust the pH may have improved the ability of the protein to be extracted which may account for the higher protein yield. When comparing the color of protein concentrates, those made using acid precipitation had a slightly brownish appearance, higher redness, and higher yellowness values than concentrates made by salt solubilization. The salt solubilized protein concentrates absorbed slightly more water (2.4 mL/g) and the main storage proteins in the concentrate produced by salt solubilization are albumin and globulin which might cause the high water absorption capacity. The foaming capacity and stability decrease with rising pH, and protein concentrates prepared using the salt solubilization method displayed better functional properties for foaming stability, water absorption capacity, foaming capacity, oil absorption capacity, and emulsion activities. It was concluded that the most suitable technique for improving the functionality and utilization of the protein concentrate from Bambara groundnut may be salt solubilization.

Protein isolates from two varieties of Bambara groundnut, using two extraction methods (isoelectric precipitation and micellization techniques), showed that the isoelectric precipitation method produced a higher yield of protein isolate (56.08-58.70 g/100 g) than the micellization technique (14.40-15.60 g/100 g). Lysine, leucine, and arginine were all abundantly present in Bambara groundnut, but glutamic and aspartic acids were the most prevalent amino acids in Bambara groundnut protein isolates. Bambara groundnut flour and isolates are excellent sources of protein and are high in essential amino acids, except for amino acids containing sulfur. The functional properties of the micellized protein isolates were superior to those of the isoelectric protein isolates and Bambara groundnut is an effective raw material for the food industry, as well as a useful source of additional protein for most cereals (Adebowale *et al*., 2011).

Adeleke *et al*. (2018) investigated protein concentrate and isolate from two varieties of Bambara groundnut. The oil absorption capacity of the protein concentrate of Bambara groundnut cultivars was found to be higher than that of their raw samples and the protein concentrate of the cultivars had the highest water absorption capacity, indicating that an increase in the protein level increases the water absorption capacity. It was concluded that Bambara groundnut cultivars have the potential to be used industrially to create protein products that are shelf-stable and could be a valuable ingredient in food formulations.

Conclusions

Bambara groundnut is a nutrient-dense legume crop that is mainly grown and consumed in Sub-Saharan countries of Africa. This review showed that Bambara groundnut possesses comparatively high values of nutritional composition mainly protein, and iron, a lower quantity of anti-nutritional properties than other legume crops, and better functional and physico-chemical properties. Knowledge of Bambara groundnuts and exposure to information about this underutilized legume may encourage potential researchers and industries to explore Bambara groundnut as an alternative source of plant based protein, supplementation of carbohydrate-based foods, and ingredient in many food applications such as dairy, beverages, and pasta industries.

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