Enrichment of food blends with bambara groundnut flour: Past, present, and future trends

Oluchukwu M.M. Nwadi1 | Nneka Uchegbu1 | Samson A. Oyeyinka2

1Department of Food Science and Technology, University of Nigeria, Nsukka, Nigeria
2Department of Home Economics and Food Science, University of Ilorin, Ilorin, Nigeria

Abstract
The aim of this paper was to review the literature (1993 to 2019) on the protein content and use of bambara groundnut in processed foods to improve nutritional value. Bambara groundnut is a legume, which is rich in protein. The protein content of bambara groundnut may vary with cultivar, growing conditions, and location as well as processing method. Complementary foods have been formulated with bambara groundnut as an ingredient. Bambara groundnut has also been used in many other food formulations and this has improved the protein content of such foods. Most of the food products containing high quantity of bambara groundnut despite the high protein content are not acceptable based on sensory evaluation especially taste and flavour. Some researchers have attempted to improve on the sensory properties of products containing bambara groundnut through some processing methods such as roasting, germination, and extrusion. Future studies may include improving the sensory properties of products enriched with bambara groundnut as well as investigating the digestibility of the products using in vivo and in vitro methods.

1 | INTRODUCTION

Bambara groundnut is a leguminous crop of African origin. The plant can grow under extreme drought conditions. Nutritionally, bambara groundnut is considered a complete food because of its reasonably high protein content (9.60–40.0%; Ogundele, Minnaar, & Emmambux, 2017; Oyeyinka, Umaru, Olatunde, & Joseph, 2019; Uwere, Uwaegbute, & Adeleji, 1999; Anhwange & Atoo, 2015; Okudu & Ojinnaka, 2017; Oyeyinka, Umaru, Olatunde, & Joseph, 2019; Uwere, Uwaegbute, & Adeleji, 1999; Anhwange & Atoo, 2015; Okudu & Ojinnaka, 2017; Amarteifio, Tibe, & Njogu, 2010; Laary, Ofori, & Kumaga, 2012; Mohammed, 2014; Nti, 2009) and it has a good balance of the essential amino acids (Yao et al., 2015). Traditionally, the grain has been reportedly used in the production of vegetable milk (Brough, Azam-Ali, & Taylor, 1993; Murevanhema & Jideani, 2013), low fat yoghurt (Falade, Ogundele, Ogunshe, Fayemi, & Olloo, 2015), value added snacks (Oyeyinka et al., 2018), and a puree for infant feeding (Oyeyinka, Pillay, & Siwela, 2017). Many researchers claim that bambara groundnut is an underutilized legume (Adzawla et al., 2015; Bonthala et al., 2016; Karunaratne, Walker, & Ruane, 2015; Suhairi, Jahanshiri, & Nizar, 2018). However, it appears that this assertion is no longer valid, because there is recent advancement in the use of the grain in various applications. Furthermore, the bambara groundnut seems to have attained a better status because there are evidences in the literature where the crop has been used to enrich a variety of foods or has been reported to have the potentials for enriching foods. For instance, recent studies reported that bambara groundnut protein hydrolysate and peptide fractions may be potentially used as ingredients in the formulation of functional foods and nutraceuticals against high blood pressure and oxidative stress (Arise,
Nwachukwu, Aluko, & Amonsou, 2017). Bambara groundnut has been reportedly used in complementary feeding. Uvere, Onyekwere, and Ngoddy (2010) and Attaugwu, Nwadi, and Uvere (2016) produced cereal-legume-based (maize and bambara groundnut) complementary food, whereas Hayes, Zulu, Mulenga, and Kaputo (2017) compared the acceptability of complementary foods formulated with locally available ingredients. It was reported that mothers/guardians of children 5 to 30 months old evaluated the product and the product with bambara groundnut as the chief ingredient was highly acceptable. It was reported that this choice could be as a result of commodity cost and mother education suggesting that bambara groundnut could solve protein needs of children. In addition, bambara groundnut represent a good source of insoluble dietary fibre. Diedericks and Jideani (2015) produced acceptable white bread enriched with insoluble dietary fibre, which was isolated from bambara groundnut. Bambara groundnut has also been reportedly used in enriching staples such as maize gruel called ogi. Ogi is a very common food; it is a cereal-based food mostly made from maize and consumed by both children and adults. Some researchers have attempted to increase the nutritional value of ogi with bambara groundnut and have recorded success. Afolabi, Arotupin, Ojo, and Olowokere (2018) fortified ogi from maize, millet, or sorghum with bambara groundnut flour (bambara groundnut [40%] and maize, millet, or sorghum [60%]) and reported 100% nutrient improvement in the protein content of the ogi. The unfortified maize ogi (2.57%) contained a lesser amount of protein compared with the fortified ogi (6.70%). It was reported that the ogi produced from maize and bambara groundnut was the most preferred.

Bambara groundnut has been used in the production of many food products such as milk, yogurt, bread, biscuits, doughnuts, meat analogue, fura, fufu, pasta, and many extruded foods. The aim of this paper was to review the literature on the protein content and use of bambara groundnut in processed foods to improve nutritional value.

2 | NUTRITIONAL VALUE OF BAMBARA GROUNDNUT

2.1 | Proximate composition

The proximate composition of bambara grains has been found to vary with cultivar and growing locations (Table 1). In general, protein (9.60–40.0%) and carbohydrate (42.0–70.0%) represent the major components of bambara groundnut, whereas ash (2.90–5.37%), fibre (3.41–6.85%), and fat (4.30–7.24%) contents are relatively low. The low fat contents of pulses such as bambara groundnut is expected because it is generally low in fat when compared with oil seeds such as soybean and peanuts (Oyeyinka & Oyeyinka, 2018). Although inherent differences in grains may affect proximate composition, growing conditions may affect the composition of bambara groundnut. For instance, some authors found that five different bambara groundnut genotypes grown under the same conditions showed similarity in their composition (Oyeyinka & Oyeyinka, 2018). The similarity in composition could be associated with the fact that the grains were grown under similar environmental conditions. Based on the different locations (Table 1) from which bambara groundnut was procured for research in the reviewed literature, bambara groundnut is commonly consumed in Africa.

### Table 1 Proximate composition of bambara grains grown in different locations

| Locations       | *Moisture* (%) | *Proteins* (%) | *Carbohydrate* (%) | *Crude fat* (%) | *Ash* (%) | *Crude fibre* (%) |
|-----------------|---------------|----------------|-------------------|----------------|----------|------------------|
| Nigeria, Côte d’Ivoire, Botswana, Namibia, Swaziland, Ghana, South Africa, Zambia, Zimbabwe | 6.35–11.70 | 9.60–40.0 | 42.0–70.0 | 4.30–7.24 | 2.9–5.37 | 3.41–6.85 |
| Nigeria, Côte d’Ivoire, Botswana, Namibia, Swaziland, Sudan, Ghana | 8.81 | 20.56 | 57.21 | 5.94 | 3.75 | 4.69 |

Notes:

References Okafor et al. (2014); El-Gasim, Yagoub, and Abdalla (2007); Abiodun and Adepeju (2011); Anhwange and Atoo (2015); Okudua and Ojinnaka (2017); Ndidi et al. (2014); Yao et al. (2015); Abdulahami and Sheriff (2010); Azman Halimi, Barkla, Mayes, and King (2019).

References Okafor et al. (2014); El-Gasim et al. (2007); Abiodun and Adepeju (2011); Anhwange and Atoo (2015); Okudua and Ojinnaka (2017); Ndidi et al. (2014); Yao et al. (2015); Abdulahami and Sheriff (2010); Azman Halimi et al. (2019); Mazahib, Nuha, Salawa, and Babiker (2013); Amarteifio et al. (2010); Nti (2009); Afoakwa, Budu, and Merson (2007); Ogundele et al. (2017); Olagunju et al. (2018); Oyeyinka et al. (2019); Uvere et al. (1999); Aremu, Ibrahim, and Ekanem (2016); Yake, Amarteifio, and Njogu (2007); Laary et al. (2012); Mohammed (2014).

References Okafor et al. (2014); El-Gasim et al. (2007); Abiodun and Adepeju (2011); Anhwange and Atoo (2015); Okudua and Ojinnaka (2017); Ndidi et al. (2014); Yao et al. (2015); Mazahib et al. (2013); Amarteifio et al. (2010); Nti (2009); Afoakwa et al. (2007); Ogundele et al. (2017); Olagunju et al. (2018); Oyeyinka et al. (2019); Uvere et al. (1999); Aremu et al. (2016); Tibe et al. (2007).

References Okafor et al. (2014); El-Gasim et al. (2007); Abiodun and Adepeju (2011); Anhwange and Atoo (2015); Okudua and Ojinnaka (2017); Ndidi et al. (2014); Mazahib et al. (2013); Amarteifio et al. (2010); Nti (2009); Afoakwa et al. (2007).

References Okafor et al. (2014); El-Gasim et al. (2007); Abiodun and Adepeju (2011); Anhwange and Atoo (2015); Okudua and Ojinnaka (2017); Ndidi et al. (2014); Yao et al. (2015); Abdulahami and Sheriff (2010); Mazahib et al. (2013); Amarteifio et al. (2010).

References Okafor et al. (2014); El-Gasim et al. (2007); Abiodun and Adepeju (2011); Anhwange and Atoo (2015); Okudua and Ojinnaka (2017); Ndidi et al. (2014); Abdulahami and Sheriff (2010); Mazahib et al. (2013).
3 | FOOD ENRICHMENT AND FORTIFICATION

Food enrichment involves the addition of micronutrients to a food product, which were lost during processing, whereas fortification involves additional micronutrients not present (or present in small amounts) prior to processing. For the purpose of this review, both terms will be used interchangeably, because literatures that were reviewed sometimes used enrichment whereas others used fortification. According to Oyeyinka and Oyeyinka (2018), fortification can lead to rapid improvements in the micronutrient status of a population at a reasonable cost, and the foods to be fortified must be consumed adequately by a large proportion of the target individuals in a population. Bambara groundnut has been widely used to improve many staples including bread, cookies, biscuits, breakfast cereal, pasta, traditional foods, cereal, and tuber flours as composites. These are cheap sources of protein for low income earners because animal protein sources result in higher cost (Siva Shankar, Alavi, Edukondalu, Joseph, & Lakshmipathy, 2018).

3.1 Use of bambara groundnut in enriching snacks and pastries

Different snack products have been produced from flour blends of bambara groundnut and other ingredients with bambara groundnut as the major source of protein. Igbabul, Adole, and Sule (2014) produced akpekpa (similar to okpa) from flour blends of bambara groundnut, cassava, and soybean at different levels (100:0:0, 80:20:0, 80:0:20, and 70:15:15) and reported protein content varying between 14.25% and 16.25%; the high protein content of the product is as a result of bambara groundnut and soybean but more from bambara groundnut due to its high proportion in the product. Based on sensory scores, the most acceptable product (80:20:0) was that containing 80% bambara groundnut. Adegunwa, Omolaja, Adewale, and Bakare (2017) produced snacks from composite flours of unripe plantain, bambara groundnut and turmeric. The ratio of bambara groundnut in the different formulations ranged from 35% to 100%. The protein content from the different formulations ranged from 4.23% to 14.81%. This implied that the increase in protein content was dependent on the quantity of bambara groundnut in the formulation. Oyeyinka et al. (2018) produced deep fried snacks (Figure 1) from bambara groundnut flour and paste and reported protein content of 23.41 and 19.35 g/100 g respectively in the products. The decrease in the protein content of the flour after snack production was attributed to heat and Maillard browning.

Doughnut is a wheat-based snack that has been produced by substitution of wheat flour with bambara groundnut flour. Adebayo-Oyetoro, Ogundipe, Ige, & Adeyeye, (2017) prepared doughnuts from composite flour blends of wheat and bambara groundnut mixed at different ratios (90:10, 80:20, 70:30, and 0:100) and reported a protein content of 10.88–11.78%. The protein content increased with the increase in the quantity of bambara groundnut flour. On sensory evaluation, the product with 10% bambara groundnut flour was most acceptable.

Bread is a commonly consumed staple food, which is produced from wheat flour. Many researchers have substituted wheat flour with bambara groundnut flour in bread production. Chinma et al. (2016) produced bread by replacing wheat flour with different proportions of acha and bambara groundnut sourdough flours (0, 5:5, 10:10, and 15:15) and reported protein content of 14.0–16.48%. Improvement of amino acids content compared with white bread was reported (contribution of dietary reference intakes of 50.29–71.65 for protein in male and female was also reported). The sourdough flours’ substitution (10%) in bread significantly increased sensory properties (taste and flavour). Abdualrahman et al. (2019) incorporated bambara groundnut flour at different levels (10%, 20%, and 30%) in kissra bread production. The control kissra (13.37 g/100 g) had lower protein content compared with the fortified kissra with the different levels.
(17.93%, 19.38%, and 20.23%, respectively) of bambara groundnut flour fortification, which could be associated with the high protein content (24.53 g/100 g) of the bambara groundnut flour used for the fortification. This result is in agreement with Erukainure et al. (2016), who found significant improvement in the protein content of bread fortified with bambara groundnut. According to these authors, bread fortified with 15% of bambara groundnut flour inclusion was the most acceptable. Yusufu and Ejeh (2018) also produced bread from composite flour blends of whole wheat and bambara groundnut at different proportions (100:0, 90:10, 80:20, 70:30, and 60:40). The increase in protein content (8.65–18.41%) was attributed to the increase in the quantity of bambara groundnut flour in the blend. The sample with the highest quantity (40%) of bambara groundnut was least acceptable compared with the sample with the least quantity (10%) of bambara groundnut.

Okafor, Ani, and Okafor (2014) produced extruded snacks from flours of bambara groundnut seeds that have been given different treatments (germination and roasting). The raw bambara groundnut had the least protein content (21.85%) compared with the roasted (23.09%) and germinated–roasted (23.20%). Roasting improved sensory properties such as taste and flavour.

3.2 | Use of bambara groundnut in enriching breakfast cereal and pasta

Bambara groundnut has also been used in enriching breakfast cereal and extruded products. James et al. (2017) prepared pasta from composite flour blends of partially gelatinized wheat, cassava, and bambara groundnut in different proportions (100:0:0, 64:10:26, 60:12:28, 56:14:30, 52:16:32, and 48:18:34). The protein content (16.20–17.85%) of the pasta was found to increase with increasing quantity of bambara groundnut flour. Although the protein content increased, the sensory properties of the pasta containing high quantity (30%, 32%, and 34%) of bambara groundnut were less acceptable compared with blends containing low quantity (26% and 28%) of bambara groundnut. The blends containing lesser quantity of bambara groundnut compared well with the blend containing 100% wheat flour (control). Bambara groundnut flour has also been reportedly used in enriching breakfast cereal produced from sorghum malt, which could be used in combating protein-energy malnutrition in children (Jidere & Filli, 2015). Gbenyi, Nkama, and Badau (2016) also produced a protein-rich extruded product from the flour blend of sorghum and bambara groundnut in different proportions (90:10, 80:20, and 70:30) and reported that increase in quantity of bambara groundnut flour resulted in increase in protein content.

3.3 | Use of bambara groundnut in enriching traditional foods

Traditional foods are highly relished by rural dwellers as well as people living in urban areas especially when the food is prepared under hygienic conditions. These foods have become part of the diet of many, and efforts have been made to improve their nutritional value either through fermentation or the addition of protein-rich grain such as bambara groundnut. For example, fura (millet flour-based food) was fortified with bambara groundnut (Figure 2), and the fortified product showed adequate quantities of essential amino acids with higher lysine content compared with the control sample (Filli, Nkama, & Jideani, 2013). Some authors reported marginal increase (~8%) in protein content for fura fortified with 30% bambara groundnut (Adebayo-Oyetoro, Shotunde, Adeeye Samuel, & Ogundipe, 2017). Another important traditionally fermented food that is commonly consumed in Africa is fufu. Fufu, a staple food is a fermented cassava product, which is usually boiled before consumption (Ndam et al., 2019; Obadina, Oyewole, Sanni, Tomlins, & Westby, 2010; Otoo, Essuman, Gyimah, & Bigson, 2018).

Olapade, Babalola, and Awoh (2014) supplemented fufu with bambara groundnut flour at different levels (10%, 20%, 30%, 40%, and 50%) and reported increased protein content (13.35–18.87%). The protein content increased with the increase in the quantity of bambara groundnut flour. However, based on sensory evaluation, the sample with 10% substitution of bambara groundnut was the most preferred.

Adedokun, Onyeneke, Nwokeke, and Obiloma (2017) prepared meat analogue from flour blends of bambara groundnut flour or bambara groundnut protein isolate and African yam bean at different proportions (50:50, 60:40, and 40:60). Meat analogue was also prepared from 100% bambara groundnut flour, bambara groundnut protein isolate, and African yam bean. The sample with 100% bambara groundnut protein isolate had the highest protein content (36.4%) whereas other samples had lower protein content (20.0% to 34.3%). However, on sensory evaluation, the samples with bambara groundnut flour had higher mean scores compared with samples containing bambara groundnut protein isolate. Agu, Ezeh, and Jideani (2014) improved acha-based biscuit (Figure 3) with bambara groundnut and unripe plantain (100:0:0, 80:10:10, 70:20:10, 60:30:10, and 50:40:10) and reported acceptable sensory properties (colour, taste, flavour, texture, and crispness) of the product. The protein content ranged between 5.30% and 7.51%. The product was also suitable for diabetic patients. Olanipekun, Otunola, Adejuyitan, and Adeyanju (2012) fermented bambara groundnut flour using Rhizopus oligosporus and Rhizopus nigricans and reported that fermentation within 3 days improved the nutritive value (the protein increased from 18.66–22.60%). Bambara groundnut flour was recommended as a supplement in the diet. It was concluded that it could play a role in preventing cardiovascular diseases and obesity.

3.4 | Use of bambara groundnut in enriching cereal and tuber flours as composites

Awolu (2018) produced composite flour blends from wheat, cocoyam, and bambara groundnut (60:30:10 and 72:19:9). The protein content ranged from 11.11% to 20.35%. Addition of bambara groundnut improved the protein content of the composite flour blends. Oluwole
and Olapade (2011) produced extruded food product from a blend of white yam meal and bambara groundnut meal at a ratio of 80:20. Ogunmuyiwa et al. (2017) prepared extruded snack from composite flour blends of bambara, corn bran, and cassava starch and reported protein content of \(3.26-17.62\%\), which was attributed to bambara groundnut. It was concluded that bambara groundnut is a nutritious legume because it resulted in a protein dense product. Honi, Mukisa, and Mongi (2018) produced extruded products from orange-fleshed sweet potato and bambara groundnut and reported that an increase in quantity of bambara groundnut resulted in an increase in the protein content \(4.08-15.03\%\) of the product. Chima and Fasuan (2017) produced biscuits from different ratios \(100:0:0, 0:100:0, 0:0:100, 40:30:30, 30:30:40, \) and \(50:40:10\) of flour blends of wheat, bambara groundnut, and aerial yam and reported protein content of \(7.90-17.08\%\). The protein content increased with the increase in the quantity of bambara groundnut flour. The sample with the ratio \(40:30:30\) was moderately accepted.

### 3.5 Use of bambara groundnut in complementary food

Complementary foods have also had improved nutritional value through addition of bambara groundnut. Anyika, Obizoba, and Nwamarah (2009) formulated a protein-rich food suitable for complementary feeding from African yam bean and bambara groundnut, which was supplemented with either sorghum or crayfish. Ijarotimi and Olopade (2009) produced complementary food from composite flours of cooking banana and bambara groundnut in two different ratios, 70:30 and 60:40, and reported 31.8% and 42.4% of the...
recommends a higher quantity of bambara
groundnut possessed higher biological value of 90.5% compared with
75.9% for the formulation with lower quantity of bambara groundnut
(an increase in the quantity of bambara groundnut supplementation
resulted in a corresponding increase in amino acids composition).
Uvere et al. (2010) produced different samples of complementary
food based on different treatments such as fermentation, malting, and
different combinations of fortificants. All the samples contained com-
posite flour blend of maize (70%) and bambara groundnut (30%). The

3.6 Use of bambara groundnut in milk and yogurt
production

Due to the growing concern of lactose intolerance, efforts have been
grounded towards developing alternative milk for the lactose intolerant.
Examples of such milk include milk from plant or vegetable sources
such as those extracted from soybean or bambara groundnut.

Hardy and Jideani (2017) reported that bambara groundnut has
prospects in improving food security through shelf-stable food prod-
ucts, which could be produced from it. They produced protein-rich
bambara groundnut milk powder from bambara groundnut flour and
water through spray drying of bambara groundnut milk. In this form,
the bambara groundnut milk powder, which is rich in protein, may be
used to enrich other foods with low protein content. Yogurt has been
produced from bambara groundnut milk by some researchers. Pahane,
Tatsadjiu, Bernard, and Njintang (2017) produced bambara ground-

**TABLE 2** Different products enriched or fortified with bambara groundnut

| Product name | Bambara groundnut (%) | Increase in protein (%) | Reference |
|--------------|------------------------|-------------------------|-----------|
| Akpekpa (similar to okpa) | 70–100 | 14.25–16.25 | Igbabul et al. (2014) |
| Snacks (from composite flours of unripe plantain, bambara groundnut, and turmeric) | 35–100 | 4.23–14.81 | Adegunwa et al. (2017) |
| Deep fried snacks (bambara groundnut flour and paste) | 100 | 23.41–19.35 | Oyeyinka et al. (2018) |
| Doughnut (wheat and bambara groundnut flours) | 10–100 | 10.88–11.78 | Adebayo-Oyetoro, Shotunde, et al. (2017) |
| Bread (from acha and bambara groundnut sourdough flours) | 5–15 | 14.0–16.48 | Chinma et al. (2016) |
| Kissra bread | 10–30 | 17.93–20.23 | Abdualrahman et al. (2019) |
| Bread (whole wheat and bambara groundnut flours) | 10–40 | 8.65–18.41 | Yusufu and Ejeh (2018) |

(Continues)
properties especially taste and flavour were not acceptable. Processing methods that can improve these sensory properties needs to be adopted so as to increase sensory acceptability. With the exception of milk and yogurt from bambara groundnut, processing methods such as roasting, germination, and extrusion cooking can be used to address these problems. Some researchers have attempted to produce extruded snacks with bambara groundnut as an ingredient.

### TABLE 2 (Continued)

| Product name                                                                 | Bambara groundnut (%) | Increase in protein (%) | Reference                                      |
|------------------------------------------------------------------------------|-----------------------|-------------------------|------------------------------------------------|
| Extruded snacks                                                             | 100                   | 23.09–23.20             | Okafor et al. (2014)                            |
| Pasta (from composite flour blends of partially gelatinized wheat, cassava, and bambara groundnut) | 26–34                 | 16.20–17.85             | James et al. (2017)                             |
| Fura (millet flour-based food)                                              | 30                    | 8                       | Adebayo-Oyetoro, Ogundipe, et al. (2017)        |
| Fufu (fermented cassava product)                                            | 10–50                 | 13.35–18.87             | Olapade et al. (2014)                           |
| Meat analogue (from flour blends of bambara groundnut flour or bambara groundnut protein isolate and African yam bean) | 40–100                | 34.3–36.4               | Adedokun et al. (2017)                          |
| Biscuits (acha, bambara groundnut, and unripe plantain)                     | 10–40                 | 5.30–7.51               | Agu et al. (2014)                               |
| Fermented bambara groundnut flour (using *Rhizopus oligosporus* and *Rhizopus nigricans*) | 100                   | 18.66–22.60             | Olanipekun et al. (2012)                        |
| Composite flour blends (from wheat, cocoyam, and bambara groundnut)         | 9–10                  | 11.11–20.35             | Awolu (2018)                                    |
| Extruded snack (from composite flour blends of bambara groundnut, corn bran, and cassava starch) | 10–80                 | 3.26–17.62              | Ogunmuyiwa et al. (2017)                        |
| Extruded product (from orange-fleshed sweet potato and bambara groundnut)   | 20–100                | 4.08–15.03              | Honi et al. (2018)                              |
| Biscuits (from flour blends of wheat, bambara groundnut, and Aerial yam)     | 30–100                | 7.90–17.08              | Chima and Fasuan (2017)                         |
| Complementary food (from composite flours of cooking banana and bambara groundnut) | 30–40                 | 31.8–42.40              | Ijarotimi and Olopade (2009)                    |
| Complementary food (from maize and bambara groundnut)                       | 30                    | 18.35–19.05             | (Uvere et al., 2010)                            |
| Complementary food (from maize and bambara groundnut)                       | 30                    | 13.40–16.05             | Attaugwu et al. (2016)                          |
| Bambara groundnut milk and bambara groundnut milk powder (from bambara groundnut flour and water) | 100                   | 0.9–7.6                 | Hardy and Jideani (2017)                        |
| Bambara groundnut milk (through aqueous flour extraction by dehulling and parboiling) | 100                   | 19.7–25.47              | Pahane et al. (2017)                            |
| Yoghurt from bambara groundnut milk                                         | Further increase of 1.8–2.6 |

4 | SUMMARY AND FUTURE RESEARCH

Bambara groundnut is a legume rich in protein that has been used to enrich different food products such as snacks and pastries, breakfast cereal and pasta, traditional foods, cereal, and tuber flours as composites. These portray bambara groundnut as an important legume. More research needs to be carried out on bambara groundnut to explore all the inherent potentials of the legume. Furthermore, researches on the utilization of the grain should go beyond adding it to foods to enrich the nutritional value. Future studies may be required to understand the in vitro digestibility of the enriched foods as well using state of the art facilities to analyse the foods.

DATA AVAILABILITY STATEMENT

None.

ORCID

Oluchukwu M.M. Nwadi https://orcid.org/0000-0002-2885-3713
Samson A. Oyeyinka https://orcid.org/0000-0002-5760-541X
REFERENCES

Abdualrahman, M. A. Y., Ma, H., Yagoub, A. E. A., Zhou, C., Ali, A. O., & Yang, W. (2019). Nutritional value, protein quality and antioxidant activity of Sudanese sorghum-based kisra bread fortified with bambara groundnut (Voandzeia subterranea) seed flour. Journal of the Saudi Society of Agricultural Sciences, 18(1), 32–40. https://doi.org/10.1016/j.jssas.2016.12.003

Abdulsalami, M., & Sheriff, H. (2010). Effect of processing on the proximate composition and mineral content of bambara groundnut (voandzeia subterranea). Bayero Journal of Pure and Applied Sciences, 3(1), 188–190. https://doi.org/10.4314/bajopas.v3i1.58781

Abiodun, A. O., & Adepeju, A. B. (2011). Effect of processing on the proximate composition and mineral content of bambara groundnut (Voandzeia subterranea L Verd.) Flourd. Advance Journal of Food Science and Technology, 3(4), 224–227. Retrieved from. http://maxwellsici.com/print/ajfst/v3-224-227.pdf

Adebayo-Oyetoro, A., Shotunde, A., Adeyeaye Samuel, A., & Ogundipe, O. (2017). Quality evaluation of millet-based fura powder supplemented with bambara groundnut. International Journal of Food Science, Nutrition and Dietetics, 6(3), 358–362. https://doi.org/10.19070/2326-3350-1700063

Adebayo-Oyetoro, A. O., Ogundipe, O. O., Ige, O. F., & Adeeye, S. A. O. (2017). Quality assessment of doughnut prepared from wheat flour enriched with bambara nut flour. Journal of Culinary Science and Technology, 15(3), 272–283. https://doi.org/10.1080/15428052.2016.1269708

Adedokun, I., Onyenene, E., Nwokeke, B., & Obiloma, A. (2017). Proximate composition and sensory properties of meat analogue from blends of plant protein sources of bambara nut and African breadfruit seeds. Nigerian Journal of Agriculture, Food, and Environment, 13(4), 198–102.

Adegunwa, M. O., Omolaja, N. O., Adebowale, A. A., & Bakare, H. A. (2017). Quality evaluation of snacks produced from blends of unripe plantain, bambara groundnut and turmeric flour. Journal of Food Processing and Preservation, 41(1), 1–8. https://doi.org/10.1111/jfpp.12760

Adzawla, W., Donkoh, S., Nyarko, G., O'Reilly, P., Olayide, O., & Awai, P. (2015). Technical efficiency of bambara groundnut production in northern Ghana. UDS International Journal of Development, 2(2), 37–49.

Afoakwa, E. O., Budu, A. S., & Merson, A. B. (2007). Response surface methodology for studying the effect of processing conditions on some nutritional and textural properties of bambara groundnuts (Voandzeia subterranea) during canning. International Journal of Food Sciences and Nutrition, 58(4), 270–281. https://doi.org/10.1080/09637480601154277

Afolabi, F., Arotupin, D. J., Ojo, T., & Olowokere, T. (2018). Improving nutritive value of fermented cereal porridge ‘Ogi’ by fortifying with bambara nut. Croatian Journal of Food Science and Technology, 10(1), 51–57. https://doi.org/10.17508/CJFST.2018.10.1.10

Agu, H. O., Ezeh, G. C., & Jideani, A. I. O. (2014). Quality assessment of acha-based biscuit improved with bambara nut and unripe plantain. African Journal of Food Science, 8(5), 278–286. https://doi.org/10.5897/ajfs2013.1130

Amartefio, J. O., Tibe, O., & Njug, R. M. (2010). The nutrient composition of bambara groundnut landraces (Vigna subterranea, L. Verd.) cultivated in Southern Africa. Agricultura Tropica et Subtropica, 43(1), 1–5. Retrieved from. http://erepository.oonbi.ac.ke/handle/11295/54406

Anhwange, B., & Atoo, G. (2015). Proximate composition of indigenous bambara nuts (Vigna subterranea (L.) Verdc.). Journal of Pure and Applied Sciences, 2(1), 11–16. Retrieved from. https://www.academia.edu/11571182/Proximate_Composition_of_Indigenous_Bambara_nuts_Vigna_subterranea_L_Verd_c

Aniyka, J. U., Obizoba, I. C., & Nwamarah, J. U. (2009). Effect of processing on the protein quality of African yambean and bambara groundnut supplemented with sorghum or crayfish in rats. Pakistan Journal of Nutrition, 8(10), 1623–1628. https://doi.org/10.3923/pjn.2009.1623.1628

Aremu, M., Ibrahim, H., & Ekam, B. (2016). Effect of processing on in-vitro protein digestibility and anti-nutritional properties of three underutilized legumes grown in Nigeria. British Biotechnology Journal, 14(1), 1–10. https://doi.org/10.9754/bbj/2016/22581

Arise, A. K., Nwachukwu, I. D., Aluko, R. E., & Amonosou, E. O. (2017). Structure, composition and functional properties of storage proteins extracted from Bambara groundnut (Vigna subterranea) landraces. International Journal of Food Science and Technology, 52(5), 1211–1220. https://doi.org/10.1111/ijfs.13386

Attaquwu, R. N., NWadi, O. M. M., & Uvere, P. O. (2016). pH changes during fermentation of fortified maize–bambara groundnut malt and maize-cowpea malt complementary foods. Sky Journal of Food Science, 5(5), 36–44.

Awolu, O. O. (2018). Rheological evaluation of cocoyam-bambara groundnut-xanthan gum composite flour obtained from the optimization of its chemical composition and functional properties. Rheology, 2(1), 2–9. Retrieved from. https://www.researchgate.net/publication/323074257

Azman Halimi, R., Barkla, B. J., Mayes, S., & King, G. J. (2019). The potential of the underutilized pulse bambara groundnut (Vigna subterranea (L.) Verdc.) for nutritional food security. Journal of Food Composition and Analysis, 77(2019), 47–59. https://doi.org/10.1016/j.jfca.2018.12.008

Bonthala, V. S., Mayes, K., Moreton, J., Blythe, M., Wright, V., May, S. T., ... Twycross, J. (2016). Identification of gene modules associated with low temperatures response in bambara groundnut by network-based analysis. PLoS ONE, 11(2), 1–18. https://doi.org/10.1371/journal.pone.0148771

Brough, S. H., Azam-Ali, S. N., & Taylor, A. J. (1993). The potential of bambara groundnut (Vigna subterranea) in vegetable milk production and basic protein functionality systems. Food Chemistry, 47(3), 277–283. https://doi.org/10.1016/0308-8146(93)01061-8

Chima, J. U., & Fasuan, T. O. (2017). Development and quality evaluation of biscuits formulated from flour blends of wheat, bambara nut and aerial yam. Annals. Food Science and Technology, 19(1), 51–56. Retrieved from. www.afst.valahia.ro

Chima, C. E., Anuonye, J. C., Ochene, O. B., Abdullahi, S., Oni, S., Yakubu, C. M., & Azeez, S. O. (2016). Effect of acha and bambara nut sourdough flour addition on the quality of bread. LWT - Food Science and Technology, 70, 223–228. https://doi.org/10.1016/j.lwt.2016.02.050

Diedericks, C. F., & Jideani, V. A. (2015). Physicochemical and functional properties of insoluble dietary fiber isolated from bambara groundnut (Vigna subterranea [L.] Verdc.). Journal of Food Science, 80(9), 1933–1944. https://doi.org/10.1111/1750-3841.12981

El-Gasim, A., Yagoub, A., & Abdalla, A. A. (2007). Effect of domestic processing methods on chemical composition, in vitro digestibility of protein and starch and functional properties of bambara groundnut (Voandzeia subterranea) seed. Research Journal of Agriculture and Biological Sciences, 3(1), 24–34.

Erukainure, O. L., Okafor, J. N. C., Ogunjii, A. Ukazu, H., Okafor, E. N., & Eboagwu, I. L. (2016). Bambara–wheat composite flour: Rheological behavior of dough and functionality in bread. Food Science & Nutrition, 4(6), 852–857. https://doi.org/10.1002/fsn3.356

Falade, K. O., Ogundele, O. M., Ogunshe, A. O., Fayemi, O. E., & Ocilo, F. C. K. (2015). Physico-chemical, sensory and microbiological characteristics of plain yoghurt from bambara groundnut (Vigna subterranea) and soybeans (Glycine max). Journal of Food Science and Technology, 52(9), 5858–5865. https://doi.org/10.1007/s13197-014-1657-3
groundnut starch. *Food Hydrocolloids*, 75, 62–71. https://doi.org/10.1016/j.foodhyd.2017.09.012

Oyeyinka, S. A., Umaru, E., Olatunde, S. J., & Joseph, J. K. (2019). Effect of short microwave heating time on physicochemical and functional properties of bambara groundnut starch. *Food Bioscience*, 28, 36–41. https://doi.org/10.1016/j.foodbio.2019.01.005

Oyeyinka, S. A., Tijani, T. S., Oyeyinka, A. T., Arise, A. K., Balogun, M. A., Kolawole, F. L., ... Joseph, J. K. (2018). Value added snacks produced from bambara groundnut (*Vigna subterranea*) paste or flour. *LWT - Food Science and Technology*, 88, 126–131. https://doi.org/10.1016/j.lwt.2017.10.011

Pahane, M. M., Tatsadjieu, L. N., Bernard, C., & Njintang, N. Y. (2017). Production, nutritional and biological value of bambara groundnut (*Vigna subterranea*) milk and yoghurt. *Journal of Food Measurement and Characterization*, 11(4), 1613–1622. https://doi.org/10.1007/s11694-017-9541-2

Siva Shankar, A., Satyanarayana, C. V. V, Alavi, S., Edukondalu, L., Joseph, M., & Lakshmipathy, R. (2018). Study on cereal-legume based complementary foods for infants. *International Journal of Current Microbiology and Applied Sciences*, 7(8), 3310–3317. https://doi.org/10.20546/ijcmas.2018.708.354

Suhairi, T. A. S. T. M., Jahanshiri, E., & Nizar, N. M. M. (2018). Multicriteria land suitability assessment for growing underutilised crop, bambara groundnut in Peninsular Malaysia. *IOP Conference Series: Earth and Environmental Science*, 169(2018), 1–9. https://doi.org/10.1088/1755-1315/169/1/012044

Tibe, O., Amarteifio, J., & Njogu, R. (2007). Trypsin inhibitor activity and condensed tannin content in bambara groundnut (*Vigna Subterranea* (L) Verdc) grown in Southern Africa. *Journal of Applied Sciences and Environmental Management*, 11(2), 159–164. https://doi.org/10.4314/ jasem.v11i2.55021

Uvere, P. O., Onyekwere, E. U., & Ngoddy, P. O. (2010). Production of maize-bambara groundnut complementary foods fortified pre-fermentation with processed foods rich in calcium, iron, zinc and provitamin A. *Journal of the Science of Food and Agriculture*, 90(4), 566–573. https://doi.org/10.1002/jsfa.3846

Uvere, P. O., Uwaegbute, A. C., & Adedeji, E. M. (1999). Effects of malting on the milling performance and acceptability of bambara groundnut (*Voandzeia subterranea* Thouars) seeds and products. *Plant Foods for Human Nutrition*, 54(1), 49–57. https://doi.org/10.1023/a:1008177221438

Yao, D. N., Kouassi, K. N., Erba, D., Scazzina, F., Pellegrini, N., & Casiraghi, M. C. (2015). Nutritive evaluation of the bambara groundnut Ci12 landrace (*Vigna subterranea* (L) Verd.c. [Fabaceae]) produced in Cote d'Ivoire. *International Journal of Molecular Sciences*, 16(9), 21428–21441. https://doi.org/10.3390/ijms160921428

Yusufu, M., & Ejeh, D. (2018). Production of bambara groundnut substituted whole wheat bread: Functional properties and quality characteristics. *Journal of Nutrition & Food Sciences*, 08(05), 1–7. https://doi.org/10.4172/2155-9600.1000731

How to cite this article: Nwadi OMM, Uchegbu N, Oyeyinka SA. Enrichment of food blends with bambara groundnut flour: Past, present, and future trends. *Legume Science*. 2020;2:e25. https://doi.org/10.1002/leg3.25