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Nutritional, physicochemical, and sensory characteristics of extruded Bambara groundnut (*Vigna subterranea*)-based ready-to-eat breakfast cereal

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Abstract

Bambara groundnut, malted sorghum, pearl millet, and banana were processed into flours and mixed in the ratio of 50:20:20:10, respectively. Using response surface methodology, screw speed (300–350 rpm), barrel temperature (180°C–220°C), and feed moisture (12%–16%) were varied and their effects on the chemical, physicochemical, sensory, and microbial characteristics of Bambara groundnut-based ready-to-eat breakfast cereal were investigated. The flour blend showed a significant increase in protein (20.00%) as compared to using cereal grains alone. Improved expansion ratio (7.27), protein solubility (0.36%), and in vitro starch digestibility (157.35 μg/g) were achieved. Also, overall acceptability of 8.40 for the sweetened sample as well as microbial stable product were established. Bambara groundnut as a base ingredient for food extrusion can be used to produce a more nutritious, less expensive, and an overall acceptable breakfast cereal.

Practical applications

Breakfast cereals are very handy, especially for urban-based individuals due to tight working schedule resulting to insufficient time for cooking detailed foods. Therefore, the need to remodel the existing starch-based ready-to-eat breakfast cereals to more nutritious protein-based products using affordable local crops is paramount. The use of extrusion cooking would enhance palatability, production yield to meet the daily increasing population, and reduce high postharvest losses due to underutilization of these crops. In summary, the outcome of this study would provide information for the possibility of scaling up production of protein-based ready-to-eat breakfast cereals using available cheap crops and increasing the prevalence of healthy convenience food products in the market.

1 | INTRODUCTION

Bambara groundnut (*Vigna subterranea*) is a legume with significant protein, essential amino acids (Arise et al., 2020), and micronutrient content needed for healthy living (Adeleke et al., 2017). However, Bambara groundnut, like other legumes contain high anti-nutritional factors such as trypsin inhibitors, hemagglutinins, phytate, and oxalate (Unigwe et al., 2017). It is also deficient in sulfur-containing amino acids; cystine and methionine which are sufficient in cereal crops (Arise et al., 2018; Goudoum et al., 2016).

Sorghum (*Sorghum bicolor*) and pearl millets (*Pennisetum glaucum*) are cereal grains used as subsistence crops for food security in arid and semiarid regions (Taylor & Anyango, 2011). This is as a result of their nutritional value, affordability, availability, stress tolerance (biotic and abiotic), good performance with comparable low fertility in weak lands (Arise et al., 2018), and relatively stable shelf life in their dry form with little or no spoilage if stored appropriately (Goudoum et al., 2016). Furthermore, malting of sorghum aids the bioavailability of these nutrients by modifying the structure of the grain to enhance its digestion. However, even in the dried state, cereals are subject

to insect infestation resulting in huge postharvest losses (Falade & Nwajei, 2015). Banana (*Musa sapientum*) is a highly perishable fruit with low glycemic index (GI), a good source of potassium, (Torres et al., 2007), and high in manganese, dietary fiber, vitamins C, and B6 (Emaga et al., 2008), with appealing aroma and taste.

The increasing need for consumers to eat healthy and nutritious foods through the development of convenience ready-to-eat palatable extruded breakfast cereal products from locally available staple crops (Falade & Okafor, 2015; Olapade & Aworh, 2012) cannot be over emphasized. Breakfast cereals are of optimum importance because of their relatively high convenience, ease of preparation and consumption, as well as the nutritive value needed to boost the brain and body (Donato et al., 2019). Generally, breakfast meals are light, but balanced foods requiring little or no in-house cooking prior to consumption (Druce & Bloom, 2006), that are manufactured from only a particular cereal, combination of cereals or together with other crops (Williams, 2014). The essence of the combinations could either be to enhance the nutritive value, reduce unit cost of the products, or utilize the available resources in the locality (Donato et al., 2019).

Extrusion is a process whereby starchy raw food commodities are passed through series of mixing, kneading (cooking), and forming with the help of a die orifice to create desired shapes, textures, and acceptable product style (Navale et al., 2015). Extrusion cooking is extensively used by the food industry to produce palatable cereal-based, ready-to-eat products like snacks, breakfast cereals etc. However, a greater percentage of extruded food products are carbohydrate (cereal/starch) based with minimal protein content. The incorporation of a leguminous crop, particularly Bambara groundnut (up to 50%), in a cereal feed mix for extrusion which could help mitigate the protein-energy malnutrition experienced in developing countries as a result of expensive animal-based proteins (Navale et al., 2015), and increase the utilization of some underutilized crops like Bambara groundnut (Oyeyinka & Oyeyinka, 2018) is yet to be well explored. Therefore, objective of this study was to evaluate the chemical, physicochemical, in vitro digestibility, microbial and sensory, characteristics of Bambara groundnut-based ready-to-eat (RTE) breakfast cereal using extrusion cooking.

2 | MATERIALS AND METHODS

Cream variety of Bambara groundnut, cereal grains (sorghum and pearl millet), and banana fruit at stage 5 of ripening (Yap et al., 2017) chart, used for the experiments were obtained from Enugu (Ogboette market), Nigeria.

2.1 | Preparation of raw materials for extrusion

Bambara groundnut (*Vigna subterranea)* was washed, boiled in 5% of caustic soda for 5 min and processed into flour (Mazahib et al. 2013). Malted Sorghum flour was prepared using the method described by Ogbonna et al. (2012). Pearl millet was washed drained and semi-wet milled using an electric hand mill (Romer serial II mill, Romer Labs, USA), then, dried and milled again into flour (Anuonye et al., 2009). The ripe banana fruits were washed, peeled, and kneaded fresh with the aforementioned sorghum flour in the ratio 1:1 (wt/wt), to form a dough. The dough was flattened with a stainless-steel rolling pin, then, placed in a precision cross flow gravity oven drier (Model STG40 Precision group, Chicago) at 38°C for 3 hr and milled in a hammer mill (Labmill-257, Gibbons, Essex, UK). The flours were sieved with a screen (250 μm) and blended in the ratio of 50:20:20:10 for Bambara groundnut, sorghum, pearl millet, and banana-mix, respectively, with a final moisture content of 11.27% (Table 2).

2.2 | Design of the extrusion experiment

The experiment was designed using Box–Behnken experimental design under Response Surface Methodology (RSM). The design was a two-level model, which had no center points just the low and high ranges. The factors (independent variables) selected for the purpose of this study were screw speed (300–350 rpm), feed moisture (12%–16%), and barrel temperature (180°C–220°C). The RSM was used to randomized experimental runs with the aim to reduce bias from systematic observation of responses (dependent variables) which resulted to 17 runs and the most desirable chosen on the basis of highest protein content, overall acceptability, among others (Table 1). Dependent variables were crude protein, carbohydrate, moisture content, overall acceptability, expansion index, and mass flow rate. After which extrusion cooking was conducted in a twin-screw extruder (Model DZ65-III, Brabender Duisburg, Germany), with die diameter of 5 mm, blend feed rate of 2 kg/min and expansion ratio of 7.62. When the runs were stable, the samples were collected and further treated as unsweetened, sweetened, and sweetened-flavored. The unsweetened samples were conveyed into the drier without further treatment, while 10 kg of the extrudates were sprayed with 2 L of 50% sucrose concentration solution. The sprayed samples (5 kg) were conveyed to the drier as sweetened, the remaining 5 kg further sprayed with liquid banana flavor (supplied and distributed by Mekang, Nigeria) at a rate of 0.15 g/kg. The extruded samples were conveyed into the drier (Model no. ALC-5, Blaw-knox, New York) and dried at 105°C for 15 min (Caparino et al., 2012). The RSM was used to narrow the experimental runs into an optimal desirable run.

2.3 | Determination of proximate composition, mineral, and vitamin contents of the samples

Proximate composition was analyzed using AOAC (2016), and the carbohydrate content calculated by difference. Trace minerals were determined after triple acid digestion according to standard method of AOAC (2016) and adopted by (Olapade & Ogunade, 2014) using atomic absorption spectrophotometer (M304, Perkin-Elmer, Japan). The vitamin contents were determined using the method described by Sunnyvale (2009), employing High-Performance Liquid Chromatography (HPLC) (Model 1710, Spark, Holland) 25°C.

TABLE 1 Experimental design for the extrusion of Bambara groundnut-based ready-to-eat (RTE) breakfast cereal

Run	Coded levels			Actual levels		
	X_1	X_2	X_3	Screw speed (rpm)	Barrel temp (°C)	Feed moisture (%)
1	0.000	0.000	0.000	325	200	14
2	0.000	0.000	0.000	325	200	14
3	−1.000	0.000	−1.000	300	200	12
4	0.000	1.000	1.000	325	220	16
5	0.000	0.000	0.000	325	200	14
6	0.000	−1.000	1.000	325	180	16
7	0.000	0.000	0.000	325	200	14
8	1.000	0.000	1.000	350	200	16
9	−1.000	0.000	1.000	300	200	16
10	1.000	−1.000	0.000	350	180	14
11	0.000	1.000	−1.000	325	220	12
12	1.000	0.000	−1.000	350	200	12
13	0.000	−1.000	−1.000	325	180	12
14	1.000	1.000	0.000	350	220	14
15	−1.000	−1.000	0.000	300	180	14
16	−1.000	1.000	0.000	300	220	14
17	0.000	0.000	0.000	325	200	14

TABLE 2 Proximate compositions of the selected crops, flour blend, and extruded samples

Crops	Crude protein (%)	Crude fiber (%)	Fat (%)	Ash (%)	Moisture content (%)	Carbohydrates (%)	Energy value (kJ/100 g)
Bambara groundnut	$22.35^{d} \pm 0.00$	$4.62^{a} \pm 0.01$	$4.88^{b} \pm 0.12$	$2.92^{ab} \pm 0.00$	$9.72^{ab} \pm 0.01$	$54.52^{a} \pm 0.00$	–
Sorghum	$12.2^{b} \pm 0.01$	$5.46^{ab} \pm 0.10$	$4.12^{ab} \pm 0.03$	$2.31^{ab} \pm 0.00$	$9.14^{a} \pm 0.00$	$66.76^{b} \pm 0.13$	–
Pearl millet	$9.23^{a} \pm 0.00$	$6.41^{ab} \pm 0.00$	$3.29^{a} \pm 0.11$	$2.22^{a} \pm 0.00$	$8.47^{a} \pm 0.12$	$70.34^{b} \pm 0.01$	–
Sorghum + Banana (1:1)	$13.44^{b} \pm 0.11$	$7.32^{b} \pm 0.01$	$4.65^{b} \pm 0.02$	$3.14^{b} \pm 0.00$	$12.87^{b} \pm 0.02$	$58.58^{a} \pm 0.00$	–
Flour Blend	$20.0^{c} \pm 0.01$	$4.12^{a} \pm 0.11$	$3.99^{a} \pm 0.00$	$2.5^{ab} \pm 0.00$	$11.27^{b} \pm 0.01$	$57.48^{a} \pm 0.00$	–
LSD	1.8007	2.3410	1.1191	0.8972	1.7032	5.0674	–
Unsweetened	$17.24^{a} \pm 0.03$	$2.99^{a} \pm 0.03$	$2.51^{a} \pm 0.04$	$1.96^{a} \pm 0.03$	$8.81^{a} \pm 0.01$	$66.72^{a} \pm 0.01$	$358.43^{b} \pm 0.22$
Sweetened	$15.60^{b} \pm 0.11$	$3.15^{b} \pm 0.04$	$2.44^{a} \pm 0.02$	$2.07^{b} \pm 0.01$	$8.94^{b} \pm 0.01$	$67.82^{b} \pm 0.04$	$355.64^{a} \pm 0.09$
Sweetened-flavor	$15.32^{c} \pm 0.06$	$3.15^{b} \pm 0.05$	$2.64^{b} \pm 0.01$	$2.06^{b} \pm 0.01$	$8.96^{b} \pm 0.01$	$67.90^{c} \pm 0.01$	$356.63^{a} \pm 0.23$
LSD	0.1903	0.1066	0.0719	0.0486	0.026	0.0609	1.261

Note: Values with different superscript along a column are significantly different at $p \geq .05$.

2.4 | Evaluation of protein solubility (PS)

Protein solubility of the extruded product was determined using the method described by McWatters et al. (2002). Ten (10 cm^3) of the filtrate obtained from the water-holding capacity experiment above was analyzed for its nitrogen content using the Kjeldahl method of protein determination. Conversion of nitrogen to protein factor (6.25) was used to calculate the percentage soluble protein.

2.5 | Determination of amino acid content

Amino acid content of the samples was determined using amino acid analyzer as described by Okoye et al. (2016). The unsweetened samples were hydrolyzed after being defatted, evaporated, and then, injected into the analyzer. Limiting amino acid of the sample was determined using the formula described by Ezekiel et al. (2012).

$$\text{Chemical score} = \frac{\text{mg primary limiting amino acid per g test protein}}{\text{mg same amino acid per g reference protein}} \times \frac{100}{1}. \quad (1)$$

2.6 | Determination of color parameters

The CEI Lab color parameters of the flours and extruded samples were determined using the method described by Falade and Okafor (2015). A colorimeter (CR-410, Konica Minolta, Sensing Inc., Japan) was used to objectively evaluate the CIE Lab parameters of the flour blend and extruded samples.

2.7 | Determination of physicochemical properties of the extrudates

pH was determined using 10% wt/vol dry bases of sample to distilled water and the value read from a pH meter (Model B-212, Kyoto, Japan), as described by Onwuka (2005).

2.7.1 | Determination of water absorption index (WAI) and water solubility index (WSI)

Water solubility and water absorption index were determined using the method of Yousf et al. (2017). Extruded samples (2.5 g) were grounded and stirred into 30 cm^3 of distilled water in a 50 cm^3 test tube for 30 min, and centrifuged at 3,000 x *g* for 15 min. The supernatant evaporated to dryness at 105°C for 35 min. The residue after centrifugation weighed and used to determine the water absorption index. The dried solids recovered after evaporation used to determine dry solid percentage for Water Solubility Index (Equation 2).

$$\text{WAI} = \frac{\text{Sediment Weight}}{\text{Dry solids Weight}} \quad (2)$$

$$\text{WSI}(\%) = \frac{\text{Weight of solids recovered from supernatant}}{\text{Weight of dry sample}} \times \frac{100}{1} \quad (3)$$

2.7.2 | Determination of moisture retention (MR) and water-holding capacity (WHC) of extruded samples

The feed and extrudates moisture contents were determined gravimetrically (AOAC, 2016) and used in the determination of MR (Equation 4). Water-holding capacity (WHC) of the extruded product was determined using the method described by Deshpande and Poshadri (2011).

$$\text{MR}(\%) = \frac{\text{Product moisture (before drying)}}{\text{Feed moisture}} \times \frac{100}{1} \quad (4)$$

$$\text{WHC}(\%) = \frac{\text{Weight of wet extrudates} - \text{weight of dry extrudates}}{\text{Weight of dry extrudates}} \times \frac{100}{1} \quad (5)$$

2.7.3 | Evaluation of oil (OAC) and milk (MAC) absorption capacities of extruded samples

Oil absorption capacity of the extruded product was determined using the method described by Kaushal et al. (2019). Each extruded (2 g) sample was stirred in 10 cm^3 grand oil in a centrifuge tube and centrifuged (Model *MSE*, Bench Top, England) for 15 min at 3,500 x g. After which, the supernatant was carefully decanted and the weight gained by the sample calculated as its oil absorption capacity (Equation 6).

$$\text{OAC}(\text{g}) = \text{Weight gained in oil} - \text{initial weight of extrudate's powder}. \quad (6)$$

Milk absorption capacity (MAC) of the extruded products were determined using the method described by Rinaldi et al. (2000). Each extrudate (4 g) was mixed with 30 cm^3 of milk (1% fat) for 3 min at 8°C, and the milk drained from the extrudates using a mesh screen made of stainless steel (2.8 microns) for about 10 s. The milk absorption capacity was calculated using (Equation 7).

$$\text{MAC}(\%) = \frac{(\text{weight of drained extrudate (g)} - \text{initial weight of extrudate (g)})}{\text{Initial weight of extrudate (g)}} \times \frac{100}{1} \quad (7)$$

2.7.4 | Determination of loose (LBD) and packed (PBD) bulk densities of flours/ground extrudates

The loose and packed bulk densities were determined following the method described by Deshpande and Poshadri (2011). The extrudate's flour was filled into a 50 cm^3 cylinder up to 20 cm^3 mark and tapped severally (10 times). The mass of the 20 cm^3 of the sample was measured and packed bulk density calculated (Equation 8). Approximately 1 g of ground extrudates was added to a 10 cm^3 cylinder containing toluene and the up-thrust movement in the level of the toluene measured. Loose bulk density was calculated using (Equation 9).

$$\text{PD}\left(\text{g/cm}^3\right) = \frac{\text{Mass of 20 cm}^3\text{ (g)}}{\text{Volume of the sample }(20\,\text{cm}^3)} \quad (8)$$

$$\text{LD}\left(\text{g/cm}^3\right) = \frac{\text{Mass of the sample (g)}}{\text{Rise in toluene level }(\text{cm}^3)} \quad (9)$$

2.7.5 | Determination of bulk density (BD) of extrudates

Bulk density was determined by Deshpande and Poshadri (2011) method. The mean diameter and length of 100 readings of the extrudates were measured with a venire caliper (Model 500-196, Mitutoyo, America), calculated and the volume of the extrudates determined (Equation 10).

where d = average diameter of extrudates in cm, L = average length of extrudates in cm, then

$$\text{BD}\left(\text{g/cm}^3\right) = \frac{\text{Mass of extrudates (g)}}{\text{Volume of extrudates }(\text{cm}^3)} \quad (10)$$

where Volume of extrudate (cm^3) = $\pi d^2 L/4$.

2.7.6 | Determination of in vitro starch digestibility (IVSD)

In vitro starch digestibility of the extruded product was determined using the method described by Singh et al. (2009). Solutions of defatted extrudate flour and amylase (50 mg/cm^3) in 0.2 M of phosphate buffer of pH 7.0 and 0.4 mg of pancreatic amylase (1,300 μ/mg) in 1 cm^3 of 0.2 M phosphate buffer of pH 6.9 were prepared, respectively. A 0.5 cm^3 of the amylase solution was stirred into the extruded sample's mixture and left to stand for 2 hr at 20°C. Thereafter (incubation period), 2 cm^3 of 3,5-di-nitrosalicyclic acid solution prepared, added to the suspension and heated to boiling for 5 min Ezugwu et al. (2015). Then, allowed to cool, filtered, the filtrate absorbance measured at 550 nm (Model Et71 Systronics Company, India), using glucose as standard and the values denoted as μg of glucose released/ gram of each sample.

2.8 | Sensory evaluation of the extruded samples

Extruded samples were evaluated using methods adapted by Adeola (2009). The sensory evaluation was carried out by untrained panelists in batches of 20. The samples were properly coded and served on white plates under standard lighting conditions at room temperature (27 ± 2°C). Sensory attributes, including appearance, texture (crispiness), taste, and overall acceptability of the extruded products were evaluated using a nine (9) point hedonic scale (1, denoting dislike extremely to 9, representing like extremely). Each participant received the samples, water in a glass for mouth rinsing in between evaluations of each samples and sensory questionnaires. Extrudates were considered acceptable if their average panelist score for overall acceptance is greater than 6 (like slightly) as described by Ghoshal and Mehta (2019).

2.9 | Enumeration of total viable bacterial and fungal counts of the extruded samples

The viable fungal and bacterial count analyses were performed on the extruded samples using the method described by Akhigbemidu et al. (2015). A 10-fold serial dilutions for each sample was prepared in peptone water 0.1% and 1% glucose broth and immediately plated onto standard plate count Agar (PCA) Sabouraud dextrose Agar and Potato Dextrose Agar. The PCA plates were incubated at 37°C for 48 hr while the SDA and PDA plates incubated at 27°C for 72 hr. The colony forming unit (cfu/g) were carried out on plates showing between 30 and 300 colonies with the help of Quebec colony counter (Model 3325, Lecia Quebec, Darkfield). The enumeration of the viable microbial count was conducted in duplicate (Cheesbrough, 2005).

2.10 | Statistical analysis of collected data

Mean values obtained from triplicate experimental runs was calculated for each analysis. Obtained data were statistically analyzed accordingly using Analysis of Variance (ANOVA) method (system of statistical Analysis, version 9.2 program (2008), SAS Inc., USA). Duncan's (1955) multiple range test applied for the Least Significance test Difference (LSD) used to separate means at P ($\alpha_{0.05}$).

3 | RESULTS AND DISCUSSION

3.1 | Chemical composition of extrudates

The proximate composition of the individual commodity and the blend is shown in Table 2. Bambara groundnut flour (22.35%) contained significantly higher crude protein than the blend (20.0%), sorghum (12.20%), sorghum-banana mix (13.44%), and pearl millet (9.23%). Crude protein values of the commodities were significantly different, however, sorghum and sorghum-banana mix were statistically similar (Table 2). Whole milled sorghum and pearl millet flours exhibited the highest carbohydrate and total dietary fiber contents of 66.76% and 70.34%, and 5.46% and 6.45%, respectively. The moisture, protein, fat, and ash contents of Bambara were similar to the values reported by Heinemann et al. (2005). Sorghum and pearl millet provided the required carbohydrate needed for effective puffing/expansion of the samples (Mohammed et al., 2011; Ogbonna, 2011). Moisture, protein, fat, and ash contents of the grains were also similar to previous report (Sandercock et al., 2010). Millet used in this study had protein (9.23%), lipid (3.29%), and ash (2.22%), which was comparable to similar report (Rampersaud, 2009). Therefore, effective blending of legumes and cereals could produce flour blend with well improved crude protein content than when whole cereal grains are used alone. Also, their fiber content was higher than in individual legume, resulting in carbohydrate content that would be better digested due to the higher fiber content. Other likely advantages included complete essential amino acid make up (Mensah & Tomkins, 2003), yielding a nutritious blend and could be used to prepare recommendable balanced diet.

3.2 | Proximate composition of the extruded samples

Table 2 presents the proximate composition of the extruded samples, noting a significant decreasing protein value as the treatment/additives increased. The crude protein content of the unsweetened, sweetened, and sweetened-flavored samples was 17.24%, 15.60%, and 15.32%, respectively. Ogunmuyiwa et al. (2017) had similar protein content for extruded snack blends of Bambara, cassava starch, and corn bran flour. The protein content decreased probably because the additives was a carbohydrate (sucrose) and added to the

sharing percentage of the proximate makeup of the extruded samples. However, the carbohydrate content of unsweetened (66.72%), sweetened (67.82%), and sweetened-flavored (67.90%) was not significantly different. Ash content ranged from 1.96% to 2.07% for unsweetened and sweetened samples, respectively, with significant difference exhibited among the samples. These values were lower (3.52%–3.90%) than those reported by Olapade and Aworh (2012), from extruded flour blends of fonio and cowpea, probably due to the lower extrusion temperature (140°C) used in that study compared to the current investigation. If increased crude protein content was the only selection criteria, the unsweetened sampled with the highest protein content would have been selected. However other criteria including sensory, microbial stability among others would make significant contribution in the selection.

The energy values of the extruded samples ranged from 356.64 kJ/100 g to 358.43 kJ/100 g for the sweetened and unsweetened flavored, respectively. The sweetened and unsweetened samples were similar, and were significantly different from the sweetened-flavored samples (Table 2).

In most of the micro nutrients, the unsweetened samples had higher nutrient values than others, with high magnesium and potassium contents (Table 3). The presence of vitamins and minerals in breakfast meals is very important as it provides the necessary nutrients needed by body to start off the day. Their mineral contents are adequate and coupled with the fact that the samples will mostly be taken with milk, a balanced diet is ensured.

3.3 | Amino acid composition of the extruded samples

The glutamic acid of the extrudate had the highest composition (1.18 mg/g) compared to others (Table 4). Glutamic acid plays key roles in the metabolic regulation of amino acids, avoiding injuries in the tissue, enhancing activities of antioxidants, healing of wounds and protein synthesis, immunity improvement and treatment of cardiovascular diseases, cancer, diabetes, metabolic disorders in obesity, and many inflammatory diseases (Wang et al., 2013). From the chemical score, leucine is the limiting amino acid in the extruded sample. It is important to know the quality of protein in a food, as amino acids are very useful in the day to day activities of the human body. For instance, they serve as protein building blocks, precursors needed to synthesize important biological body substances like hormones, nucleotides etc., enhances cell signaling, gene expression, and many more (Mohanty et al., 2014).

3.4 | Color parameters of the flour blend and extruded samples

The color (Hunter *L*, *a*, *b*) indices were significantly different ($p < .05$) for some of the samples (Table 5). This could be due to the nonenzymatic browning reaction that occurred due to presence of sugar from the added banana, low moisture content and high temperature that prevailed within the extruder barrel. The Hunter *L*, *a*, *b* values are in agreement with values obtained by Arueya and Osundahunsi (2015) for extruded soy-cocoa and corn starch.

3.5 | Physicochemical characteristics of the extruded sample

The pH of the extruded samples ranged from 6.47 (unsweetened) to 6.93 (sweetened), as shown in Table 6. This value is similar to the findings of Arueya and Osundahunsi (2015) for extruded samples derived from extruded soy-cocoa and corn starch. The pH value of a food system is very important in deciding the best preservative methods to be applied and to consumers for health-conscious reasons.

Water absorption index (WAI), the gel weight reached per gram of dry basis, of the unsweetened (3.75) extrudate was significantly higher than the other samples. The water solubility index (WSI) of the sample was 0.6 which was in alignment with the results of previous research (Obatolu et al., 2006). However, this result was

TABLE 3 Mineral and vitamin content of the extruded samples

Mineral	Unsweetened (mg/g)	Sweetened (mg/g)	Sweetened-flavored (mg/g)	LSD
Na	$0.81^{b} \pm 0.01$	$0.74^{a} \pm 0.00$	$0.72^{a} \pm 0.00$	2.932
Mg	$1.18^{c} \pm 0.01$	$1.10^{b} \pm 0.01$	$1.01^{a} \pm 0.00$	4.703
Ca	$0.38^{b} \pm 0.00$	$0.35^{a} \pm 0.01$	$0.33^{a} \pm 0.00$	2.094
Zn	$0.37^{b} \pm 0.01$	$0.03^{a} \pm 0.01$	$0.03^{a} \pm 0.02$	0.721
K	$3.48^{b} \pm 0.01$	$3.26^{a} \pm 0.00$	$3.22^{a} \pm 0.01$	6.095
Fe	$0.04^{a} \pm 0.06$	$0.032^{a} \pm 0.00$	$0.30^{a} \pm 0.00$	1.035
Cu	$0.16^{b} \pm 0.04$	$0.14^{b} \pm 0.02$	$0.13^{a} \pm 0.00$	1.973
Vitamins				
B1	$0.04^{a} \pm 0.01$	$0.39^{a} \pm 0.02$	$0.38^{a} \pm 0.00$	1.113
B2	$0.01^{a} \pm 0.05$	$0.01^{a} \pm 0.04$	$0.01^{a} \pm 0.00$	0.050

Note: Means in the same row with same superscript letters are not significantly different at $p \leq .05$.

TABLE 4 Amino acid composition and score of the extruded samples

Amino acids	Amount (mg/g Protein)	FAO/WHO amino acid reference (mg/g)	Amino acid scores (mg/g)	Chemical score (%)
Threonine	0.23 ± 0.00	42	134.57	32.20
Isoleucine	0.23 ± 0.01	54	132.25	40.83
Glycine	0.31 ± 0.00	–	–	–
Serine	0.28 ± 0.00	–	–	–
Lysine	0.37 ± 0.00	85	216.94	39.18
Histidine	0.17 ± 0.01	32	99.19	32.26
Alanine	0.06 ± 0.01	–	–	–
Leucine	0.52 ± 0.01	95	307.65	30.88
Glutamic acid	1.18 ± 0.00	–	–	–
Proline	0.18 ± 0.01	–	–	–
Valine	0.30 ± 0.00	63	177.49	35.49
Tyrosine	0.18 ± 0.02	–	–	–
Chemical score				30.88
Limiting amino acid				Leucine

TABLE 5 Color parameters of the flour blends and extruded samples

Samples	*L*	*a*	*b*
Flour blends	$73.62^{d} \pm 0.01$	$6.97^{c} \pm 0.02$	$10.01^{a} \pm 0.02$
Unsweetened	$52.79^{c} \pm 0.01$	$5.46^{b} \pm 0.00$	$16.38^{c} \pm 0.00$
Sweetened	$49.91^{b} \pm 0.02$	$5.63^{b} \pm 0.02$	$16.10^{bc} \pm 0.03$
Sweetened-flavored	$46.96^{a} \pm 0.00$	$4.72^{a} \pm 0.00$	$13.37^{b} \pm 0.00$
LSD	2.678	0.712	3.012

Note: Means in the same column with same superscript letters are not significantly different at $p \leq .05$.

TABLE 6 Physicochemical properties of the extruded samples

Properties	Unsweetened	Sweetened	Sweetened-flavored	LSD
pH	$6.47^{a} \pm 0.08$	$6.93^{b} \pm 0.01$	$6.35^{a} \pm 0.05$	0.114
WAI	$3.75^{a} \pm 0.02$	$4.44^{b} \pm 0.10$	$4.31^{b} \pm 0.43$	0.506
WSI	$0.68^{a} \pm 0.04$	$0.96^{b} \pm 0.05$	$0.95^{b} \pm 0.01$	0.100
MR	$25.69^{a} \pm 0.04$	$26.49^{b} \pm 0.11$	$27.00^{c} \pm 0.02$	0.184
WHC (%)	$422.05^{a} \pm 1.63$	$434.50^{b} \pm 4.10$	$440.00^{b} \pm 2.26$	7.439
OAC	$5.52^{b} \pm 0.13$	$5.05^{a} \pm 0.11$	$4.90^{a} \pm 0.03$	0.259
MAC (%)	$2.76^{a} \pm 0.04$	$2.85^{a} \pm 0.00$	$2.94^{a} \pm 0.04$	0.111
PS	$0.36^{a} \pm 0.01$	$0.35^{a} \pm 0.01$	$0.42^{a} \pm 0.01$	0.259
PBD (g/cm^3)	$0.51^{a} \pm 0.11$	$0.49^{a} \pm 0.03$	$0.55^{a} \pm 0.01$	0.175
LBD (g/cm^3)	$0.97^{a} \pm 0.01$	$1.26^{b} \pm 0.03$	$1.32^{c} \pm 0.01$	0.047
BD (g/cm^3)	$250.02^{a} \pm 3.01$	$308.02^{b} \pm 4.31$	$280.23^{a} \pm 2.11$	32.471
IVSD (μg/g)	$157.35^{b} \pm 0.21$	$151.05^{a} \pm 0.35$	$150.60^{a} \pm 0.07$	0.627

Note: Means in the same row with same superscript letters are not significantly different at $p \leq .05$.

in disagreement with values reported by Yousf et al. (2017), probably due to the different food ingredients used (Obatolu et al., 2006). Moisture retention (MR) values of the samples were between 25.69 (unsweetened) and 27.00 (sweetened) with significant difference among the samples. Expectedly, moisture retention decreased as barrel temperature increased. Since at higher barrel temperature

TABLE 7 Sensory attributes of the extruded samples

Samples	Appearance	Aroma	Taste	Crunchiness	Overall acceptability
Unsweetened	$8.50^{b} \pm 0.14$	$7.95^{a} \pm 0.21$	$5.75^{a} \pm 0.07$	$7.35^{a} \pm 0.35$	$7.00^{a} \pm 0.14$
Sweetened	$7.60^{a} \pm 0.14$	$7.85^{a} \pm 0.07$	$7.55^{b} \pm 0.35$	$6.75^{a} \pm 0.21$	$8.40^{c} \pm 0.14$
Sweetened-flavored	$7.45^{a} \pm 0.07$	$7.65^{a} \pm 0.07$	$7.30^{b} \pm 0.28$	$6.85^{a} \pm 0.07$	$7.89^{b} \pm 0.02$
LSD	0.3184	0.3518	0.6875	0.6276	0.3017

Note: Means in the same column with same superscript letters are not significantly different at $p \leq .05$

(>200°C), the heat would be intense enough to reduce the available moisture from the initial feed moisture content of the blended flour as compared to other temperatures. The samples exhibited high water-holding capacity (WHC) 422.05% (unsweetened) to 440.00% (sweetened-flavored). Hot extrusion would result into a porous and dry intercellular structure due to high expansion ratio, causing the sample to accommodate and absorb more moisture between its intercellular walls unlike its initial form.

Oil Absorption Capacity (OAC) of sweetened-flavored to unsweetened samples varied from 4.90 to 5.52, respectively. The milk absorption capacity (MAC) of the extruded samples varied between 2.76% (unsweetened) and 2.94% (sweetened-flavored), however, no significant difference was observed. Expectedly, products extruded at high barrel temperature (>180°C) would have the high milk absorption capacity, extruded products are expected to be well dehydrated due to the excess heat.

Protein solubility (PS) of the extruded samples exhibited no significant difference among samples, with values between 0.35% and 0.42% for sweetened to sweetened-flavor, respectively. This value might be due to the complexes formed by tannins and polyphenols with proteins in the flour blend which consequently increases the degree of cross-linking and decreases the solubility of proteins (Navam et al., 2014). Also, the extrusion barrel temperatures exceeded the denaturation temperature (70°C) of Bambara protein (Lui et al. 2016). It is accepted that the protein solubility could be negatively affected, however, since extrusion is a high-temperature short-time (HTST) process, its high-temperature impact should be minimal.

As shown in Table 6, the bulk density ranged between 0.25 g/cm^3 (unsweetened) and 0.308 g/cm^3 (sweetened). Bulk Density (BD) is a vital feature of extruded products helps with information on packaging, handling, and distribution. Extruded puffed samples are mostly lightweight but bulky.

The In vitro starch digestibility (IVSD) of the samples showed no significant difference (Table 7). This could be associated to the lowering of chymotrypsin trypsin inhibitory activities at higher extruder barrel temperature, which eventually improves the IVSD (Alonso et al., 2000). Also, extrusion cooking above the gelatinization temperature of cereals would adversely affect IVSD. However, the HTST cooking probably reduced the damaging effect on the starch digestibility.

TABLE 8 Microbial load during storage of the extruded samples

Period of storage (weeks)	Microbial counts, cfu/g					
	Total plate count			Total molds and yeast counts		
	US	SD	SF	US	SD	SF
0	NG	NG	NG	NG	NG	NG
1	NG	NG	NG	NG	NG	NG
2	NG	NG	NG	NG	NG	NG
3	NG	NG	NG	NG	NG	NG
4	NG	NG	NG	NG	NG	0.2×10^{1}

Abbreviation: NG, no growth.

3.6 | Sensory parameters of the extruded sample

The sweetened samples had the highest scores of overall acceptability and taste of 8.40 and 7.55, respectively (Table 7), while the unsweetened samples were preferred in terms of appearance (8.50). This showed that the products were pleasant to the taste buds of the consumers. However, the taste of the sweetened and sweetened-flavored samples was similar but significantly different from the unsweetened. The addition of sugar enhanced the taste but the added flavoring did not indicate significant improvement. Although the unsweetened samples showed higher score than others, no significant difference was observed in the crunchiness of the samples. This indicated that the addition of sugar and flavor to the samples did not alter the crunchiness significantly. However, it was observed that the sweetened and sweetened-flavored samples were darker in appearance than the unsweetened samples, and they received lower scores. Arise et al. (2018) reported similar results for maize snacks.

3.7 | Microbiological parameters of the extrudates

The result from this study indicated that no viable microbial count was observed throughout the storage period of 4 weeks (Table 8), when samples were kept at 27 ± 2°C. Whereas yeast and mold (0.2×10^{1}) was observed at the fourth week, only on the sweetened-flavored samples (Table 8). This could be because of the presence

of the flavor which also enacted a slightly oily nature to the samples, causing the attraction of mold after 4 weeks, though at a minimal count. The results obtained are similar to values reported Gibson (2003) which showed no growth (NG) after six (6) months of culturing his extruded samples. This is expected as extruded products are usually dried to a very safe moisture content (<9%), with no or minimal post extrusion handling contaminations. Microbial test is very important in food product development as it indicates the quality and safety level of the food for human consumption (Pansawat et al., 2008). Also, total viable count in a food gives information on the general quality and outstanding shelf life of that food. Therefore, going by the microbial status of the extruded samples, it is showed that the samples are of good quality and safe for consumption.

4 | CONCLUSION

Bambara groundnut flour, as a base ingredient when blended with cereals and fruit, could be used to successfully produce a ready-to-eat breakfast cereal using extrusion cooking. The proximate composition indicated a protein content of up to 17.24% and improved digestibility was achieved. Also, high overall sensory acceptability and safe microbial status was observed. Therefore, the use of Bambara groundnut as the base ingredient did not only produce an increased nutritional food product, but also a breakfast cereal with reduced cost for the masses.

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CONFLICT OF INTEREST

The authors have declared no conflicts of interest for this article.

DATA AVAILABILITY STATEMENT

Data available on request from the authors.

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