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Research Article

Proximate composition, anti-nutrient reduction, and functional properties of extruded cassava - bambara groundnut breakfast blends

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Abstract

The need for convenient, nutritious and safe ready-to-eat (RTE) breakfast options in urban areas from locally available commodities necessitated this study. Four formulations were produced from Cassava flour (CF) and Bambaranut (BF) at ratios 90:10 (Sample C), 70:30 (Sample E), 60:40 (Sample F), and 50:50 (Sample G). These blends were extruded and analyzed for proximate composition, pasting properties, anti-nutrient content, texture profile and color. The results of proximate composition (protein, crude fibre, and moisture content) on dry weight basis increased significantly ($p<0.05$) from 12.27 - 15.65%, 0.13 - 0.31% and 12.65 - 14.85% respectively with increase in BF while ash, crude fat and carbohydrate content decreased from 1.2 - 0.71%, 3.79 - 1.27% and 69.80 - 67.42 respectively. Pasting analysis showed Sample E had the highest peak viscosity (4610.50 RVU), indicating strong gelatinization. Anti-nutrients reduced and were within the acceptable levels; phytate (0.12- 0.24 $mg.g^{-1}$), Tannin (011-0.87 $mg.g^{-1}$) and cyanide (0.83-0.89 $mg.g^{-1}$). Texture profile showed minimal variation in chewiness and cohesiveness. Color analysis changed in brightness (L*), redness (a*), and yellowness (b*) across samples. These findings demonstrate that cassavabambara groundnut blends could produce nutrient-rich RTE breakfast meals. This work supports the use of underutilized indigenous crops in addressing food insecurity and malnutrition while promoting value addition.

Keywords

ready-to-eat, breakfast, cassava, flour, bambara groundnut, extrusion, anti-nutrient

Abbreviations

BF – bambara groundnut flour; CF – cassava flour; RTE – ready-to-eat

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Introduction

The fast-paced urban lifestyle in Lagos has heightened the demand for convenient and nutritious breakfast options. Limited leisure time and extended work hours have increased reliance on ready-to-eat (RTE) foods. Beyond nutrition, consumers now demand snacks that are appealing in taste, aroma, and appearance (Uyanwa et al. 2024). Most RTE products are wheat-based due to wheat's gluten-forming ability. However, concerns over the economic burden of wheat importation and rising gluten sensitivities have necessitated the use of nutrient-dense, locally available crops such as legumes, roots, and tubers (Arise et al. 2021). The high cost of wheat and the need to reduce import dependence have further driven interest in gluten-free flours with complementary nutritional and functional attributes **(**Alimi et al. 2023).

Bambara groundnut (*Vigna subterranea (L.) Verdc.*) is a traditional African legume, widely consumed in rural communities. Nigeria, a primary center of origin, is the continent's leading producer, accounting for roughly 100,000 metric tons annually (Tan et al. 2020).

Rich in protein (15-25%), starch (49-63.5%), fat, fiber, and minerals, it offers a balanced nutritional profile. Compared to cow's milk, it provides significant energy and nutrients without cholesterol (Olurin et al. 2021). Its affordability, nutraceutical potential (antidiabetic and anti-cancer properties), and functional properties such as high water and oil absorption make it highly suitable for RTE product development (Egedigwe-Ekeleme et al. 2023; Alimi et al. 2024). Undernourishment can be reduced by using bambara groundnut, which is a source of protein, Carbohydrates, lipids, and minerals like iron. It is easily accessible, yet underutilized and poorly advertised in both domestic and foreign markets (Hillocks et al. 2012). Fighting under-nutrition among children and the general populace at large will be made easier with the intensive use of locally grown crops as sources of energy, protein, vitamins, and minerals.

Cassava (*Manihot esculenta Crantz*), the world's third most important energy crop after rice and maize, is a starchy root crop crucial to food security and livelihoods in developing countries (Olorode and Sobowale 2021). It contains 60-70% moisture and up to 35% carbohydrates, mostly as amylopectin. Biofortified yellow cassava offers added vitamin A, which is vital for vision and immune function, especially in populations with limited access to animal protein. Extrusion cooking is a widely used technique in food processing, involving mixing, kneading, cooking, and shaping of starchy materials into appealing food products (Singh et al. 2017). It enables the production of shelf-stable, nutritionally enhanced convenience foods using diverse raw materials selected for their functional and sensory properties (Okafor and Falade 2023). The extrusion process has become an ever more accepted procedure in food industries to develop novel products, including snacks and baby foods. Food extrusion is used to convert a diversity of constituents to transitional products or ready to use ones, such as breakfast cereals, snacks, infant food, instant soups, breadcrumbs, finished vegetable protein, meat substitute, modified starches, confectionery, pasta, powdered beverages, cookies, granola, and cones. A major advantage of extrusion cooking is producing various extruded products from low-cost raw materials under nominal process. Despite prior research on bambara-based extrudates, no study has specifically targeted the development of extruded RTE breakfast meals from cassava and bambara groundnut blends for adult nutritional needs. The food industry can produce a "high protein", "glutenfree" snacks and other food products and this will provide further information on the use of both cassava tubers and Bambara groundnut and will encourage their use by the food processing industries, hence, fostering conservation, domestication, improvement and

utilization of these locally produced underused species. This study therefore aims to develop and evaluate the proximate composition, antinutritional factors, pasting, texture, and color characteristics of extruded RTE breakfast meals from cassava and bambara groundnut flour blends.

Materials and Methods

Materials. Yellow root cassava (*Manihot esculenta*) (improved variety; TMS 070593) was obtained from the local farm in Ede Osun State, Nigeria. Bambara (*Vigna subterranea*) groundnut seeds and other ingredients required for the production were purchased from a local market in Oyingbo, Lagos State, Nigeria. Analytical-grade supplies were utilized for all other equipment and chemicals.

Method

Processing of bambara groundnut into flour. The procedure outlined by Muyanwa et al. (2024) to produce Bambara groundnut flour. Bambara groundnuts were sorted to get rid of unwanted items like dirt and stones and to distinguish between seeds that were infected with insects and those that were desired. In addition, broken, wrinkled, and immature seeds were separated out and left in a bucket with a lid to soak in water for four days at room temperature. After soaking, the seeds were then dehulled (the soaking eased removal of the outer coat), and allowed to dry in a cabinet oven at 50°C for 2 days. Following their dehulling, the grains were ground in a Warring laboratory mill blender and sieved through a 250 mm screen mesh to produce fine flour. The flour was subsequently kept in air-tight ziplock bags prior to use

Processing of yellow root cassava into flour. Yellow root cassava was processed into flour using a procedure outlined by Okoye and Ezeugwu (2019). After thoroughly cleaning the whole cassava roots to get rid of any stubborn dirt, they were manually peeled using kitchen knives made of stainless steel. Clean water was used to rewash the peeled roots and rinsed, a commercial hammer mill was used to grate yellow root cassava into a mash and bagged to remove water. The cake that resulted from the dewatering process was broken up into small pieces and sieved. The sifted semi dried mash was oven-dried (hot air electric drying oven) at 50°C for 4 h. Following the drying process, the samples were ground and screened using a 250 mm mesh sieve to produce smooth yellow-root cassava flour with consistent particle size. After that, the flour was sealed in a black polypropylene bag and stored at room temperature until it was needed again.

Formulation of composite flour. To produce the experimental composite flour, a substitution procedure was used to formulate four (4) proportions of different ratios as represented in Table 1. The flours were thoroughly mixed using Eurosonic electric blender for 1min to obtain homogenous flour blends which were well labeled and stored in airtight containers at room temperature prior to its requirement.

Table 1. Blend ratio for extruded breakfast products from cassava and bambara groundnut flour

Samples	Cassava flour, %	Bambara groundnut flour, %
C	90	10
E	70	30
F	60	40
G	50	50

Extrusion process. Method described by Olorode and Sobowale (2021) was adopted. Extrusion was carried out using a complete line of fabricated extruder, which has a motor coupled with a speed reducer (extrusion by mechanical friction), besides a single extrusion screw, with 130 mm of barrel diameter, 440 mm of extruder length, a hydraulic cooling system for temperature control, variable speed, and 50 $kg.h^{-1}$ capacity. During the extrusion process a portion of the next test material was used to purge the extruder. The extruded samples were allowed to cool and then kept in plastics bags hermetically sealed until evaluation.

Proximate composition. Moisture, ash, protein, fat, fiber and carbohydrate content were determined using AOAC (2019) standard methods. Protein was determined by the Kjeldahl method, fat by Soxhlet extraction, and fiber by acid-base digestion. The percentage of available carbohydrates was calculated by subtracting the total contents of moisture, total ash, crude protein, crude fat, and crude fiber content from 100%.

Pasting properties. The method described by Olurin et al. (2021) was adopted to determine the pasting properties of the composite flours using a Rapid Visco Analyzer (Newport Scientific Pty Ltd., Warrie-Wood NSW 2012, Australia).

Anti-nutritional properties. Tannin, phytate, oxalate and cyanide contents were all determined according to the methods described by AOAC (2019).

Texture profile analysis (TPA). Texture characteristics such as hardness, cohesiveness, springiness, peak force, height, area, weight, chewiness etc. were evaluated using a texture analyzer following the method of Nwachukwu and Eze (2022).

Colour analysis. Minolta Chroma meter was used based on (CIE) L* a* b* scale to determine the colour properties such as such as lightness (L*), redness (a*) and yellowness (b*) of the extruded breakfast meal according to the method described by Feili et al. (2013).

Statistical analysis. All experimental data were reported as mean ± SD (standard deviation) of duplicate determinations. The data obtained were subjected to one-way analysis of variance (ANOVA) whereas Duncan's multiple range test (DMRT) was conducted to separate the means at $P<0.05$ (95 % confidence interval). These were achieved using the Statistical Package for Service Solution (SPSS) version 25.0. Data were presented in tabular and graphical forms.

Results and Discussion

Proximate composition of the extruded breakfast products. The proximate composition of food products provides vital information on their nutritional quality and suitability for healthconscious consumers. It includes moisture content, total ash, crude fat, crude fibre, crude protein, and carbohydrate, which together determine shelf life, energy value, and nutritional adequacy (Ali et al. 2024).

Moisture content ranged from 12.65% (Sample C) to 14.88% (Sample G), showing a significant increase ($p<0.05$) with higher Bambara groundnut inclusion (Table 2). Higher moisture in Sample G (50:50) may be due to the hygroscopic nature of legume proteins and their higher water-binding capacity (Adegunwa et al. 2021). Lower moisture in Sample C suggests longer shelf stability and reduced microbial activity. According to Carmo et al. (2019), moisture content above 14% in extruded flours may increase the risk of microbial spoilage, thus moisture levels should ideally be kept below this threshold for safe storage. This makes Samples C and E more suitable for long shelf life.

Ash content, which reflects the mineral content, significantly decreased from 1.20% (C) to 0.71% (G). The reduction may be attributed to dilution of cassava's native mineral content by Bambara groundnut, or possible mineral leaching during extrusion (Mohammed et al. 2024). Total ash content present in food can be used as a measure of mineral elements present in food. Ash is the remains left after organic matter and moisture have been removed as a result of heating (Ojo et al. 2016). Although Bambara is a good protein source, it contains lower ash compared to cassava flour, which aligns with the observed values. Similar trends have been reported by Kaur et al., (2023c) in cassava-legume blends.

Table 2. Proximate composition of extruded products from cassava flour and bambara groundnut flour

Sample	Moisture, %	Total ash, %	Crude fat, %	Crude fiber, %	Crude protein, %	Carbohydrates, %
C	12.65±0.02^{a}	1.20±0.02^{d}	3.79±0.02^{d}	0.31±0.02^{b}	12.27±0.03^{a}	69.80±0.01^{d}
E	13.28±0.03^{b}	1.10±0.01^{c}	2.44±0.02^{c}	0.31±0.05^{b}	13.70±0.03^{b}	69.23±0.01^{c}
F	13.87±0.03^{c}	0.95±0.01^{b}	1.78±0.03^{b}	0.17±0.01^{a}	14.57±0.03^{c}	68.66±0.08^{b}
G	14.88±0.03^{d}	0.71±0.01^{a}	1.23±0.03^{a}	0.13±0.01^{a}	15.65±0.03^{d}	67.41±0.03^{a}

Sample C - 90% CF and 10% BGF; Sample E - 70% CF and 30% BGF; Sample F - 60% CF and 40% BGF; Sample G - 50% CF and 50% BGF.

Crude fat content showed significant reduction ($p<0.05$) across the blends from 3.79% (C) to 1.23%. Fat gives a lubricating effect as well as enhances the eating quality of foods. The decline in fat content with higher Bambara inclusion may seem contradictory since legumes typically contain more lipids. However, extrusion conditions likely promoted lipid oxidation or volatilization, especially in legume-rich formulations (Kaur et al. 2023b). Eke-Ejiofor et al. (2022) also noted that high extrusion energy can significantly reduce measurable fat in legume-based flour blends. During extrusion, there is formation of amyloselipid complex and the rate depends on the type of lipid and starch present (Ojo et al. 2016). Therefore, high viscosity of the feed used may have resulted into formation of lipid complex thereby causing the reduced fat content in the extruded snacks.

The significantly low Crude fibre ranged from 0.13% (G) to 0.31% (E). The lower fibre content in Samples F and G could result from fibre degradation during extrusion and dilution by the less fibrous Fibre is responsible for the movement of food during digestion in the body. Also, cassava flour is rich in resistant starch and non-soluble fibre, which may degrade under thermal shear. Similar findings were reported by Nehemaih et al. (2016), who observed that extrusion significantly reduced fibre fractions in cereal-legume blends, especially at higher feed moisture levels. The crude fibre contents of the extruded snack was within the recommended range of not more than 6 g dietary fibre and other non-absorbable carbohydrate per 100 g dry matter (FAO/WHO 1994).

Protein content significantly increased from 12.27% (C) to 15.65% (G), consistent with increasing levels of Bambara groundnut (20-24%) (Ali et al. 2021). These findings indicate that protein enrichment was successful, with the highest protein value in Sample G, making it most suitable for adult nutritional needs. This aligns with Paesani et al. (2020), who reported improved protein content in extruded cassava-legume blends, highlighting their suitability for combating protein-energy malnutrition. In the process of extrusion cooking, the components of the feed materials come in contact with pressure and high temperature and this damages or improves the protein quality in the extruded materials (Ojo et al. 2016). Proteins are compound that have amino acids as building blocks. During the process of extrusion cooking, disulfide bonds are broken down and may also reform which may harm the protein quality of the extruded snacks (Azeez et al. 2014). Other studies have also reported a similar increase in protein in coconut-composite fours (Adebayo-Oyetoro et al. 2020, Adebayo-Oyetoro et al. 2021). Protein is required as the building blocks for the body, necessary for growth and the repairs of damaged tissues (Adebayo-Oyetoro et al. 2021, Olatidoye et al. 2021). Protein content of foods are determined as nitrogen multiply by a factor (N × 6.25), and apparent protein content is not affected by extrusion temperature as nitrogen is not affected by heat (Dababa et al. 2016).

Carbohydrate content was highest in Sample C (69.80%) and lowest in Sample G (67.41%), showing a significant ($p<0.05$) decrease with more Bambara inclusion. This inverse relationship results from substitution of carbohydrate-rich cassava with protein-rich Bambara groundnut. These results align with energy-balancing trends in composite flours (Oladele and Oshodi 2022). Lower carbohydrate levels in Bambara-rich samples may support diabetic-friendly formulations, as previously observed by Cecilia et al. (2006).

Pasting properties of the extruded products. Pasting properties are critical functional parameters that reflect the behavior of starch-containing flours during heating and cooling in aqueous systems (Omoba et al. 2024). The pasting profile measured using a Rapid Visco Analyzer (RVA) includes peak viscosity, trough viscosity, breakdown viscosity, final viscosity, setback viscosity, peak time, and pasting temperature. The results are presented in Table 3. Peak viscosity reflects the maximum swelling capacity of starch granules during heating. Sample E (70% cassava, 30% Bambara) recorded the highest peak viscosity (4610.50 RVU), significantly different ($p<0.05$) from the other blends. The lowest was Sample G (3438.00 RVU), suggesting reduced starch availability due to increased protein and lipid interference from Bambara groundnut. This agrees with Kaur et al. (2023b) and Carmo et al. (2019), who observed that inclusion of legume flour reduces peak viscosity by diluting starch concentration and introducing protein-starch interactions, limiting granule swelling.

Table 3. Pasting properties of extruded breakfast products from cassava and bambara groundnut flour blends

Sample	Peak viscosity, RVU	Trough viscosity, RVU	Breakdown viscosity, RVU	Final viscosity, RVU	Setback viscosity, RVU	Peak time, min	Pasting temperature, ℃
C	3816.00±5.74^{e}	2526.50±9.09^{c}	1289.50±4.65^{bc}	3768.50±3.33^{d}	1242.00±4.24^{ab}	5.03±0.05^{a}	78.05±0.07^{a}
E	4610.50±7.89^{g}	3004.50±5.76^{d}	1606.00±8.50^{cd}	4526.50±5.45^{f}	1522.00±5.06^{b}	5.10±0.05^{a}	79.25±0.00^{a}
F	4168.00±2.21^{f}	2873.00±3.45^{d}	1295.00±2.23^{bc}	4114.00±2.73^{e}	1241.00±2.72^{ab}	5.13±0.09^{a}	79.48±0.60^{ab}
G	3438.00±7.07^{c}	2237.00±3.53^{b}	1201.00±9.60^{b}	3519.50±4.24^{c}	1282.50±1.77^{ab}	5.20±0.00^{a}	83.10±0.00^{c}

Sample C - 90% CF and 10% BGF; Sample E - 70% CF and 30% BGF; Sample F - 60% CF and 40% BGF; Sample G - 50% CF and 50% BGF.

Pasting characteristics is largely depended on amylase to amylopectin ratio of the starch. This indicates that the carbohydrate components of the flour samples will not breakdown until it is properly cooked and peak viscosity was reported to be important to the user in order to obtain a useable starch paste (Carmo et al. 2019). When starch-based foods are heated in an aqueous environment, they undergo a series of changes known as gelatinization and pasting. These are two of the most important properties that influence quality and aesthetic considerations in the food industry, since they affect texture and digestibility as well as the end use of starchy foods. The pasting properties are important as it is used in predicting the behaviour of flour during and after cooking. Peak viscosity is the ability of starch to swell freely before their physical breakdown. High peak viscosity is an indication of high starch content and also related to the water binding capacity of starch (Ali et al;., 2024). Peak viscosity is the maximum viscosity attained during or soon after the heating portion of the test in RVU. It also provides an indication of the viscous load likely to be encountered during mixing (Ali et al., 2024). Trough viscosity, indicating the starch paste's ability to withstand breakdown under continuous heating, ranged from 2237.00 RVU (G) to 3004.50 RVU (E). The higher values in E and F reflect greater paste stability, likely due to the optimal cassava - Bambara ratio improving starch gelatinization and matrix cohesion (Cecilia et al. 2006). The trough is the minimum viscosity value in the constant temperature phase of the RVA profile and measures the ability of paste to withstand breakdown during cooling. The breakdown viscosity value is an index of the stability of starch (Ali et al., 2024). Breakdown is a measure of susceptibility of cooked starch granules to disintegration and has been reported to affect the stability of the flour products. A low breakdown value suggests that they are more stable under hot condition due to lower concentration of starch in the sample and it is in agreement with (Ali et al., 2024) who observed that viscosity correlated with concentration of starch-in given food material. Breakdown viscosity, calculated as the difference between peak and trough, measures the fragility of starch granules under shear and heat. Sample E also had the highest (1606.00 RVU), indicating rapid disintegration, possibly due to more swollen granules (Ali et al., 2024; Olatidoye et al. 2021). Lower breakdown in Sample G (1201.00 RVU) shows better paste resistance, likely enhanced by Bambara proteins. Final viscosity is the most commonly used parameter to define the quality of a particular starch-based sample, as it indicates the ability of the material to form a viscous paste or gel after cooking and cooling as well as the resistance of the paste to shear force during stirring. Final viscosity indicates the ability of the material to form a viscous paste or gel after cooking and cooling. Final viscosity reflects the ability of starch molecules, especially amylose, to re-associate during cooling. Sample E again showed the highest (4526.50 RVU), suggesting strong retrogradation potential and gel strength. Sample G had the lowest (3519.50 RVU), implying reduced amylose reassociation and better paste stability upon cooling (Salata et al. 2014). Setback viscosity is the difference between final and trough viscosity and it

ranged between 1241-1522.00 RVU, with Sample E showing the highest (1522.00 RVU). The setback involves the retrogradation of the starch molecules particularly the amylase component. The higher the setback value, the lower the retrogradation during cooling and the lower the staling rate of the products made from the flour. Setback relates to gel firmness and staling potential. According to Sobowale et al. (2012), higher setback in cassava-rich blends is linked to rapid retrogradation, which may reduce shelf stability. Setback has been correlated with texture of various products and also, an index of the tendency of the cooked flour to harden on cooling due to amylose retrogradation. High setback is also associated with syneresis, or weeping, during freeze-thaw cycles for example and substituted starches are commonly used where this presents a quality defect. There is a relationship between amylose content and set back; high amylose indicates high leaching hence high setback. The rate of starch breakdown depends on the nature of the materials, the temperature and the degree of mixing and shear applied to the mixture. The peak time across all samples ranged from 5.00 to 5.13 min, with no significant differences ($p>0.05$), indicating similar cooking durations. The pasting temperature of the flour is lower than the boiling temperature; hence the flour can form a paste in hot water below boiling point. This means at a commercial level, there is a remarkable cost saving. Viscosity also depends on the shape and swelling power of the granule and amylopectin granules interaction (Sobowale et al. 2021). However, pasting temperature significantly varied. Sample G exhibited the highest (83.10°C), significantly higher ($p<0.05$) than others, suggesting that increasing Bambara flour raised gelatinization thresholds due to protein-starch competition (Kaur et al. 2023b). High pasting temperature in Sample G may enhance product stability but require more energy during processing, an important consideration for industrial extrusion (Nehemail et al. 2016). Pasting temperature is a measure of the minimum temperature required to cook a given food sample and also gives an indication of the gelatinization time during processing. It is temperature at which the first detectable viscosity is measured and an index characterized by initial change due to the swelling of starch, it can have implications for the stability of other components in a formula and also indicate energy costs. Pasting temperature has been reported to relate to water binding capacity, a higher pasting temperature implies higher water binding capacity property of starch due to high degree of association between starch granules. Although Sample C had the highest value in starch and protein respectively, there was no significant difference ($p>0.05$) among the samples, indicating that increasing the level of bambara groundnut flour did not significantly reduce phytate content. The observed phytate levels fall within acceptable limits for human consumption (Ogunmuyiwa et al. 2017; Sarka et al., 2021).

Phytates, while known to chelate divalent minerals like calcium and zinc, can be reduced by extrusion cooking due to the thermal degradation of phytic acid complexes (Salata et al. 2014). The decreasing trend from Sample C to Sample G could be attributed to the higher proportion of bambara groundnut, which has been shown to contain lower phytate levels than cassava flour (Ogunmuyiwa et al. 2017). This finding is consistent with the report of Ogunmuyiwa et al. (2017) and Sarka et al. (2021), who found lower phytate concentrations in legume enriched extruded snacks. The phytate content of the samples ranged from 0.12 mg.g-1 (Sample G) to 0.24 mg.g-1 (Sample C).

Tannins are known to bind to proteins, including digestive enzymes thereby causing decrease in the protein and dry matter digestibility tannin levels ranged from 0.71 $mg.g^{-1}$ in Sample E to 0.87 $mg.g^{-1}$ in Sample G, with significant differences ($p<0.05$) across all samples. The highest value observed in Sample G (50:50 blend) may be due to the concentration of tanninrich polyphenols in Bambara groundnut, which increased with its substitution level (Umoh and Iwe 2022). Tannins have both anti-nutritional and antioxidant functions. However, excessive tannins can bind to proteins and inhibit enzymatic activity, especially trypsin and amylase (Ogunmuyiwa et al. 2017; Sarka et al. 2021). Extrusion processing has been reported to reduce tannin levels through the breakdown of polyphenolic complexes (Ogunmuyiwa et al. 2017; Itrat et al. 2024), but the persistence of significant differences suggests that raw material composition still plays a key role postprocessing. The oxalate content of the samples ranged from 0.15 $mg.g^{-1}$ (Sample E) to 0.20 $mg.g^{-1}$ (Sample G). Statistically

significant differences ($p<0.05$) were observed among the samples. The lowest oxalate content was recorded in Sample E, indicating a possible dilution effect due to the intermediate proportion of bambara groundnut. Conversely, Sample G had the highest oxalate concentration, potentially due to cumulative contributions from both cassava and bambara groundnut (Korkered et al. 2016). Oxalates can bind to calcium and magnesium, forming insoluble salts that may lead to kidney stones when consumed in high amounts. However, all values obtained were within the tolerable limits reported by WHO (2021) and corroborated by Lotfi et al. (2020), who stated that extrusion cooking significantly reduces oxalate content in legume-based flour blends. Cyanide levels ranged from 0.83 $mg.g^{-1}$ (Sample G) to 0.94 mg/g (Sample F), with significant differences ($p<0.05$) among the samples. The increasing cyanide content from Sample G to Sample F corresponds with higher cassava content, as cassava is known to naturally contain cyanogenic glycosides, particularly linamarin (Nur Adibah et al. 2024). Bambara groundnut, by contrast, does not produce cyanide, and its inclusion likely contributed to the observed reduction in Sample G. Although cyanide levels below 10 $mg.g^{-1}$ (0.01 $mg.g^{-1}$) are considered safe by FAO/WHO standards, further detoxification methods (e.g., soaking or fermentation) prior to extrusion could enhance safety (Kaur et al. 2023b).

High pasting temperature in Sample G may enhance product stability but require more energy during processing, an important consideration for industrial extrusion (Nehemail et al. 2016). Pasting temperature is a measure of the minimum temperature required to cook a given food sample and also gives an indication of the gelatinization time during processing. It is temperature at which the first detectable viscosity is measured and an index characterized by initial change due to the swelling of starch, it can have implications for the stability of other components in a formula and also indicate energy costs. Pasting temperature has been reported to relate to water binding capacity, a higher pasting temperature implies higher water binding capacity property of starch due to high degree of association between starch granules. The results of as phytate, tannins, oxalates, and cyanide, which the anti-nutrient composition of the extruded flour must be within acceptable limits for safe blends are presented in Table 4.

Table 4. Anti-nutrients composition of extruded breakfast products from cassava- bambara groundnut flour

Sample	Phytate, $mg.g^{-1}$	Tannin, $mg.g^{-1}$	Oxalate, $mg.g^{-1}$	Cyanide $mg.g^{-1}$
C	0.24 ± 0.02^{a}	0.73 ± 0.02^{b}	0.17 ± 0.00^{c}	0.89 ± 0.01^{b}
E	0.14 ± 0.00^{a}	0.71 ± 0.01^{a}	0.15 ± 0.00^{a}	0.93 ± 0.00^{c}
F	0.14 ± 0.00^{a}	0.85 ± 0.01^{c}	0.16 ± 0.00^{b}	0.94 ± 0.00^{c}
G	0.12 ± 0.00^{a}	0.87 ± 0.00^{d}	0.20 ± 0.01^{a}	0.83 ± 0.05^{a}

Sample C - 90% CF and 10% BGF; Sample E - 70% CF and 30% BGF; Sample F - 60% CF and 40% BGF; Sample G - 50% CF and 50% BGF.

Texture analysis of the extruded breakfast samples. Texture is one of the most important quality attributes influencing consumer acceptability of extruded ready-to-eat products. Mechanical texture parameters such as peak force, chewiness, springiness, adhesiveness, gumminess, and cohesiveness are widely used to determine the physical properties of extruded products (Omoba et al. 2024, Jakkanwar et al.2018). Table 5a and 5b present the results of the texture profile analysis (TPA) of the extruded breakfast samples. Peak force, which measures the maximum force required

Table 5a. Texture profile analysis of extruded breakfast products from cassava flour and bambara groundnut flour

Sample	Peak force, g	Height, mm	Area, J	Weight, g	Gumminess	Stringiness
C	18696.00±4.68^{a}	11.47±0.04^{a}	39754.59±7.51^{a}	1.00±0.00^{a}	6823.00±9.22^{a}	0.26±0.26^{a}
E	20450.25±9.82^{a}	12.89±0.16^{c}	47454.26±6.29^{a}	0.50±0.71^{ab}	7508.50±2.17^{a}	1.08±1.39^{a}
F	23284.75±7.31^{a}	12.33±0.31^{c}	62058.92±7.69^{a}	0.00±0.00^{ab}	7536.00±3.07^{a}	0.08±0.00^{a}
G	20193.25±6.23^{a}	11.71±0.07^{ab}	52760.99±9.73^{a}	0.50±0.71^{a}	7169.50±9.26^{a}	0.20±0.01^{a}

Sample C - 90% CF and 10% BGF; Sample E - 70% CF and 30% BGF; Sample F - 60% CF and 40% BGF; Sample G - 50% CF and 50% BGF

Table 5b. Textural properties of extruded breakfast products from cassava flour and bambara groundnut flour

Sample	Adhesiveness	Resilience	Chewiness	Springiness	Cohesiveness
C	0.08±0.09^{a}	0.12±0.01^{a}	1972.00±45.25^{a}	0.29±0.01^{ab}	0.35±0.04^{a}
E	0.48±0.55^{a}	0.18±0.07^{a}	1994.00±552.96^{a}	0.26±0.02^{b}	0.34±0.02^{a}
F	0.06±0.00^{a}	0.12±0.00^{a}	2435.00±298.40^{a}	0.33±0.01^{b}	0.30±0.01^{a}
G	0.02±0.01^{a}	0.27±0.21^{a}	2807.00±666.09^{a}	0.39±0.01^{c}	0.33±0.00^{a}

Sample C - 90% CF and 10% BGF; Sample E - 70% CF and 30% BGF; Sample F - 60% CF and 40% BGF; Sample G - 50% CF and 50% BGF

to compress the sample, ranged from 18696.00 g (Sample C) to 23284.75 g (Sample F). Hardness is the amount of force needed by molar teeth to crush the extruded snacks. Despite numerical variations, the differences were statistically insignificant ($p>0.05$). The increased peak force in Samples E and F suggests a firmer structure likely due to optimal protein–starch interactions (Kaur et al., 2023c). Higher area under the curve (J) observed in Sample F (62058.92) also correlates with more work required to compress the sample, indicating enhanced structural integrity. The height of the samples after extrusion was highest in Sample E (12.89 mm) and lowest in Sample C (11.47 mm), showing significant differences ($p<0.05$). This increase in height may result from gas retention caused by increased protein content which improves expansion and cell structure during extrusion (Omoba et al. 2024). Gumminess, which represents the energy required to disintegrate a semi-solid food before swallowing, ranged from 6823.00 g (C) to 7536.00 g (F) with no significant difference ($p>0.05$). High gumminess indicates a more cohesive and resilient texture. Stringiness and weight also did not show significant variations. However, the low values observed (0.08-1.08 g for stringiness) are advantageous for ready-to-eat cereals, which should not be overly sticky or elastic, as noted by Alonso et al. (2021). Adhesiveness indicates the work necessary to overcome attractive forces between the food and other surfaces (e.g., palate or spoon). Sample E recorded the highest adhesiveness (0.48), though statistically not different from others. Increased adhesiveness could be associated with higher protein or lipid content (Sobowale et al. 2021). Resilience, which measures how quickly a sample recovers after deformation, ranged from 0.12 (C) to 0.27 (G). No significant difference was noted ($p>0.05$), implying that extrusion at the set parameters did not drastically

affect elasticity properties. Chewiness, an energy parameter associated with mastication, was highest in Sample G (2807.00) and lowest in Sample C (1972.00). Although differences were statistically insignificant, the gradual increase with Bambara inclusion may reflect denser structures due to added protein and fibre, enhancing bite resistance (Paesani et al. 2020). Springiness, defined as the degree to which a sample returns to its original shape, was significantly different ($p<0.05$) among samples. Sample G recorded the highest (0.39) and Sample E the lowest (0.26). High springiness is desired in extruded snacks to avoid crumbling during packaging and handling. Cohesiveness, which quantifies the internal bonding strength, ranged between 0.30-0.35 with no significant differences. These values reflect acceptable structural binding typical of cereal - legume extruded products (Nehemaih et al. 2016**)**.

Colour properties of the extruded products. Colour is one of the most critical sensory attributes influencing consumer preference and marketability of food products, especially breakfast cereals. It serves as a visual cue for freshness, processing conditions, and the presence of bioactive components like Maillard browning products or pigments such as carotenoids (Olatoye, and Arueya 2023). Colour plays a very important quality role in snacks. It shows the extent to which cooking and chemical reactions have occurred (Ojo et al. 2016). The colour of food products is usually determined using the CIE Lab colour space*, where *L** indicates lightness (0 = black, 100 = white), a* represents the red-green spectrum (+*a** = red, −*a** = green), and *b** signifies the yellow-blue axis (+*b** = yellow, −*b** = blue) (Alonso et al. 2021; Ali et al. 2024). The results are presented in Table 6 revealed that Lvalues ranged from 25.46 in Sample C (90:10 cassava: bambara) to 26.51 in Sample F (60:40).

Table 6. Colour analysis of extruded breakfast products from cassava flour and bambara groundnut flour

Sample	Flour			Extruded snack		
	*L**	*a**	*b**	*L**	*a**	*b**
C	25.46±0.04^{a}	4.66±0.03^{d}	7.93±0.00^{b}	30.55±0.04^{a}	6.78±0.04^{d}	14.30±0.01^{b}
E	26.49±0.02^{b}	3.71±0.00^{a}	6.75±0.00^{a}	31.84±0.02^{b}	5.36±0.01^{a}	11.54±0.01^{a}
F	26.51±0.03^{b}	4.51±0.01^{c}	8.65±0.01^{d}	31.87±0.30^{b}	6.48±0.00^{c}	15.57±0.06^{d}
G	26.29±0.23^{b}	4.39±0.08^{a}	8.16±0.10^{c}	31.47±0.28^{b}	6.34±0.03^{b}	14.54±0.14^{c}

Sample C - 90% CF and 10% BGF; Sample E - 70% CF and 30% BGF; Sample F - 60% CF and 40% BGF; Sample G - 50% CF and 50% BGF.

A similar trend was observed in the *L** values, with Sample C having the lowest lightness (30.55) and Sample F has the highest (31.87). These significant differences ($p<0.05$) may be attributed to the relative proportion of Bambara groundnut, which tends to lighten the blend due to its naturally beige colour and lower carotenoid content compared to cassava flour. The increase in lightness with bambara groundnut inclusion is consistent with reports by Carmo et al. (2019), who observed improved L-values in cereal-legume blends due to reduced browning intensity from Maillard reactions. Also, extrusion may cause some caramelization and pigment degradation, influencing the final colour outcome (Nehemaih et al. 2016). Significant variations ($p<0.05$) were also observed in the a-values and *a** values, ranging from 3.71 in Sample E to 4.66 in Sample C. The lowest redness in Sample E suggests less nonenzymatic browning or pigment degradation. The increasing redness in Sample C may result from higher cassava content, which contains more reducing sugars that can intensify browning under high-temperature extrusion (Mohammed et al. 2024) values are within the range reported for similar extruded composite flours. According to Cecilia et al. (2006), *a** value is also influenced by the Maillard reaction during extrusion, especially

in carbohydrate- and protein-rich materials like cassava and Bambara groundnut. Therefore, increased cassava ratio (Sample C) may have promoted higher *a** values due to its high sugar content. The b-values ranged from 6.75 in Sample E to 8.65 in Sample F, while the *b** values ranged from 11.54 (Sample E) to 15.57 (Sample F), with significant differences ($p<0.05$) across the samples. This increase in yellowness is possibly due to the synergistic effect of carotenoids from cassava and polyphenolic compounds from Bambara groundnut. Sample F (60:40) had the highest yellowness, likely due to optimal balance between extrusion-induced pigment release and minimal browning interference. Similar findings were reported by Omosebi et al.(2018) who observed that high protein-carbohydrate blends result in enhanced yellow intensity due to thermal pigment interactions during extrusion.

Conclusions

This study demonstrated that extruded readyto-eat breakfast products developed from cassava and bambara groundnut flour blends possess desirable nutritional and functional properties. Increasing bambara groundnut inclusion improved protein content and textural qualities, while moderate blend levels (particularly 70:30 and 60:40) offered a good balance of proximate composition, pasting performance, and minimal anti-nutritional factors. All samples showed acceptable quality attributes for adult consumption. The economic impact of utilization of flour produced from indigenous crops will enhance Gross Domestic Products in Nigeria and bring about reduction in foreign exchange on wheat importation and thus enhance the industrial utilization of local crops. The study's findings contribute to the growing body of research on the utilization of local and underutilized crops in food product development, highlighting the potential for cassava and bambara groundnut to play a significant role in enhancing food security and nutrition.

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Author Contributions

A-O A.O, conceived the experiment. A-O, A.O., O, O.P., A, I.A., A, A.S., A, A.F., I, P.E., A, O.P and

A, T.O designed and performed the experiments. AO, A.O and O, O.P analysed and interpreted the data. A-O, A.O., O, O.P., A, I.A., A, A. S., A, A.F., I, P.E., A, O. P and A, T.O wrote and read the manuscript.

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The original contributions presented in this study are included in the article. Further inquiries can be directed to the corresponding authors.

Conflicts of Interest

The authors declare no conflicts of interest.

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