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Development of Bambara groundnut-enriched wheat biscuits: Nutritional, functional and sensory evaluation

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ABSTRACT

Wheat biscuits are widely consumed but are mostly low in protein, fibre and minerals; hence, there is a need to develop nutritious alternative wheat flour blends with similar quality and acceptability. This study evaluated the effects of replacing wheat flour with 10–40% Bambara groundnut flour on nutritional composition, flour functionality, physical quality, short-term microbial quality and consumer acceptability. Five formulations were produced in triplicate and assessed by 100 consumer panellists. From BGB0 to BGB40, moisture increased from 5.80 to 7.10%, ash from 1.20 to 2.20%, protein from 7.10 to 13.20%, fibre from 2.10 to 4.80% and energy from 456 to 478 kcal/100 g, while fat decreased from 18.50 to 16.80% and carbohydrate from 65.30 to 57.90%. Water absorption increased from 1.20 to 1.80 g/g, oil absorption from 0.95 to 1.35 g/g, swelling from 2.10 to 3.10 mL/g, emulsion capacity from 48.0 to 64.0%, and foaming capacity from 22.0 to 38.5%. In contrast, bulk density decreased from 0.68 to 0.60 g/mL. Diameter declined from 52.10 to 50.00 mm, spread ratio from 8.40 to 7.41, and weight from 9.80 to 9.50 g, while thickness increased from 6.20 to 6.75 mm and hardness from 12.5 to 16.3 N. Aerobic counts rose from 1.2×10^2 to 6.0×10^2 CFU/g in BGB0 and from 0.8×10^2 to 4.0×10^2 CFU/g in BGB40. BGB10 recorded the highest mean sensory scores. Overall, 10–20% substitution provided the best nutritional, technological, and sensory balance.

Contribution/Originality: This study contributes to the existing literature by integrating nutritional composition, composite-flour functionality, biscuit physical quality, consumer acceptability, and a short-term microbial study across five levels of Bambara groundnut substitution in wheat biscuits. The findings identified 10–20% substitution as balancing improved protein and fibre content with satisfactory sensory quality.

1. INTRODUCTION

Biscuits are easily prepared foods and appropriate matrices for nutritional reformulation with high-protein/high-fibre plant ingredients replacing refined wheat flour in part due to their intrinsic convenience, palatability, and low water content. Replacing wheat flour improves protein, fibre, and mineral content but negatively affects gluten development, water binding, dough spreading, colour, taste, and texture. A wheat-Bambara groundnut study indicates that the rheological and sensory aspects of quality change when nutritional quality improves and that formulation fulfilment must be assessed in terms of quality attributes, not just the composition of the finished product (Arshad, Yupanqui, Ikram, & Acheampong, 2026; Okoye, Okolo, & Egbujie, 2025). Bambara groundnut (*Vigna subterranea (L.)* Verdc.) is an underutilised African legume with great potential for the development of nutritionally superior baked

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foods. The crop has noticeable quantities of protein, carbohydrate, dietary fibre, minerals, and phytochemicals and can be cultivated in drought-prone, low-nutrient-input environments. Furthermore, Bambara groundnut flour is not a uniform product, and grain variety has also been shown to influence nutritional quality, colour, antioxidant activity, and functional properties. In addition, dehulling, germination, fermentation, malting, micronisation, and thermal treatment can either increase or decrease certain functional and biochemical characteristics. Thus, replacement level, genotype, and processing history can influence product performance (Mashau, Ramatsetse, Takalani, Bamidele, & Ramashia, 2025; Ramatsetse, Ramashia, & Mashau, 2024). There is also variability from processing. For example, Venter, Emmambux, and Duodu (2024) found that flour solubility and pasting viscosity were reduced by microwave pretreatment, but that was dependent on the treatment and type of Bambara groundnut used. Likewise, Mukwevho and Emmambux (2024) found that heat treatment of Bambara flour altered the rheology of the dough, and that 15% flour was better incorporated in bread than 30%, indicating that the apparent substitution limit may be due to flour treatment or dough formulation rather than a fundamental weakness of Bambara groundnut in wheat-based products (Mukwevho & Emmambux, 2024; Venter et al., 2024).

Previous studies have reported different optimum inclusion levels for biscuits. For example, Arshad et al. (2026) reported that the protein, fibre, and mineral contents of biscuits increased with Bambara flour inclusion. However, water absorption and dough development time increased, while dough stability decreased. The 20% formulation had the most desirable sensory profile. Hardness increased, and acceptability declined as the content went beyond 20%. Iwanegbe and Owheruo (2025) concluded that biscuits could be prepared with up to 50% Bambara flour and be acceptable. However, the acceptability of higher substitution levels should be viewed with caution, as the study used a sensory panel of 15 panellists and Bambara groundnut was used to partially replace fat. Therefore, the findings of this study cannot be compared with studies that only substituted wheat flour with Bambara groundnut flour (Arshad et al., 2026; Iwanegbe & Owheruo, 2025). Other studies could not be traced to Bambara groundnut. Okoye et al. (2025) found improved protein, fibre, mineral, and physical attributes of biscuits substituted with Bambara groundnut and bush-mango flours. However, both ingredients were added simultaneously, so it is not possible to separate the effects of Bambara groundnut on the nutritional, sensory, and structural changes. Ramashia, Sikhipha, Olamiti, and Mashau (2024) reported that the protein, fibre, and antioxidant properties of the baked product were increased by enrichment with Bambara groundnut, but water and oil absorption, swelling capacity, and structural quality were decreased. This contradicts literature reporting increased hydration of the composite flour with Bambara incorporation, showing that the direction of change in functional properties is influenced by the product matrix, flour treatment, ingredient proportions, and method of analysis (Okoye et al., 2025; Ramashia et al., 2024).

Again, various methodological differences between the studies have been noted, which limit the comparison of the findings with each other. The differences may be due to the designs, formulations, or analyses used. For example, in fixed-recipe studies, formulations with greater levels of substitution may be disadvantaged because the water and fat levels are kept constant. The hydration of the flour and the dough characteristics would be modified. In addition, small or semi-trained sensory panels may produce results that are not predictive of consumer acceptance or are unreliable.

When several enrichment ingredients are used, it can be difficult to determine the contribution of Bambara groundnut alone (Arshad et al., 2026; Iwanegbe & Owheruo, 2025; Mashau et al., 2025). Therefore, the objectives of the study were: (1) to determine the effect of replacing wheat flour with Bambara groundnut flour on the proximate composition and functional properties of composite flours and biscuits at 10%, 20%, 30%, and 40% substitution levels; (2) to determine the effect of flour substitution levels on the physical properties, short-term microbial quality, and sensory acceptability of the biscuits; and (3) to determine the flour substitution level that provides the most appropriate nutritional, technological, and sensory acceptability among the different samples.

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2. MATERIALS AND METHODS

2.1. Experimental Design and Replication

The design consisted of five wheat flour–Bambara groundnut flour formulations in a completely randomised design: 100:0 (BGB0), 90:10 (BGB10), 80:20 (BGB20), 70:30 (BGB30) and 60:40 (BGB40). Each formulation was prepared separately on three different days, providing three biological replicates. The samples were in a random order and were coded to reduce measurement bias. All of the analytical measurements were completed in triplicate as technical replicates on each batch prepared on independent days. The results are presented as the mean ± standard deviation of the replicate measurements.

2.2. Source of Raw Materials

The seeds of an uncharacterised local landrace or market type of the Bambara groundnut species, Vigna subterranea, refined wheat flour, granulated sugar, Cook Brand margarine, baking powder, and salt were obtained on 6 January 2026 from vendors at the Bolgatanga Commercial Market, Upper East Region, Ghana. Since the seeds were procured from the open market without reliable varietal information or supplier-assigned lot numbers, they were classified as a local market type rather than as a named cultivar. The seeds were visually assessed for soundness and uniformity, and damaged, discoloured, disfigured, infested, and mouldy seeds, as well as stones and other extraneous matter, were removed by hand. The cleaned seeds were processed into flour, and to reduce variability in the raw material, the same seeds were used for all five biscuit treatments. Bambara groundnut seeds were stored under laboratory conditions in sealed food-grade containers in a well-ventilated, dry, and dark environment away from moisture, pests, and light.

2.3. Bambara Groundnut Flour Processing

The Bambara groundnut flour was made using a legume-flour processing method modified from Maphosa, Jideani, and Maphosa (2022) and Mashau et al. (2025). The seeds were sorted manually to remove crushed, discoloured, insect-damaged, and mouldy grains, stones, and other foreign materials before milling. The seeds were washed with potable water and soaked in distilled water at a seed/water ratio of 1:5 (w/v) for 12 h at room temperature (25 ± 2°C) to soften the seed coats for easier dehulling. Subsequently, the water was discarded, the seeds were manually dehulled and rinsed with distilled water, and the seed-coat membrane was removed. They were then dried in a single layer on stainless-steel trays in a laboratory convection oven at 60 °C for 6 h or until they reached a constant dry mass.

By drying to constant mass, the moisture content was reduced sufficiently for milling and short-term flour storage without further treatment. The seeds were cooled to room temperature, then ground in a laboratory hammer mill, and the resultant flour was passed through a 500-µm sieve to give flour with a fairly uniform particle size. The flour was then immediately sealed in clean, dry, airtight, food-grade plastic containers and kept under ambient laboratory temperature and humidity conditions, away from moisture, pests, and light, until required for biscuit-making. The flour was used within 1 week of preparation to minimise moisture absorption, lipid oxidation, and other storage-related changes to the flour.

2.4. Formulation and Rationale

The formulation range included one control (without Bambara groundnut flour), two intermediate levels of enrichment that were deemed acceptable from a sensorial point of view, and two high levels of enrichment to define the technological and sensory limits of incorporation of Bambara groundnut flour. Bambara groundnut flour was substituted for wheat flour on a mass basis, keeping the total flour mass constant (500 g) (Table 1).

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Table 1. Biscuit formulation by Bambara groundnut substitution levels.

Ingredient	BGB0	BGB10	BGB20	BGB30	BGB40
Wheat Flour (g)	500	450	400	350	300
Bambara Groundnut Flour (g)	0	50	100	150	200
Margarine/Shortening (g)	150	150	150	150	150
Granulated Sugar (g)	150	150	150	150	150
Baking Powder (g)	10	10	10	10	10
Salt (g)	2	2	2	2	2
Water (mL)	25	25	25	25	25

Note: BGB0-BGB40 represent formulations with 0-40% incorporation of Bambara groundnut flour to respective wheat flour in 500 g total formulation.

2.5. Method of Preparation

The preparation of the biscuits was adapted from the creaming technique of Dzandu, Kumi, and Asirifi-Addo (2023) and the Bambara groundnut biscuit-processing technique of Chinma et al. (2022). In the latter method, wheat flour was substituted with Bambara groundnut flour at 0%, 10%, 20%, 30%, and 40%, respectively, while the total flour weight was kept constant at 500 g for each formulation. The mixing time, resting time, sheet thickness, cutter diameter, loading method, baking temperature, baking time, cooling time, and dough packaging were also standardised. Granulated sugar and margarine were creamed for 2 min at speed 5 using a Kenwood Chef XL planetary stand mixer, Model No. KVL4100S, fitted with a K-beater. Afterwards, the wheat and Bambara groundnut flour mixture, along with the baking powder and salt, was added gradually while mixing with potable water until a firm, homogeneous, workable dough was produced. Each recipe included 500 g of total flour and produced 837 g of dough. The dough was manually kneaded for 4 min on a smooth stainless-steel bench and rested for 10 min to ensure the uniform distribution of moisture throughout the mass. The dough was sheeted to a uniform thickness of 5 mm on a bench and cut into discs with a 40-mm-diameter stainless-steel pastry cutter. For uniformity, 20 pieces of dough per formulation were laid out in a single layer on a lightly greased 460 mm × 330 mm (18 in × 13 in) baking tray, with centre-to-centre spacing of about 20 mm. The position on the baking tray and oven rack was kept constant. The biscuits were baked in an Italian-made Unox Linemicro Manual electric convection oven (Model XF023 "Anna"), preheated to 180 °C, in batches for 15 min until they were uniformly golden brown. The baked biscuits were transferred to clean stainless-steel cooling racks and cooled at room temperature (approximately 23 °C) for 30 min. The biscuits were separated by formulation, packaged in heat-sealed, food-grade, low-density polyethylene pouches, and stored under dry ambient laboratory conditions. Throughout the analysis, the packaged samples were protected from moisture, vermin, and direct sunlight. Physical measurements, sensory tests, and proximate analyses were conducted at 2 h, 24 h, and 48 h after baking, respectively, while microbiological analyses were conducted on days 0, 7, and 14 of ambient storage. All formulations were mixed, kneaded, rested, sheeted, cut, tray-loaded, baked, cooled, packed, and stored under the same conditions.

2.6. Proximate Composition and Laboratory Quality Control

All biscuit samples were ground, homogenised and sieved (500 μm). Samples were analysed in triplicate for moisture, ash, crude protein, crude fat and crude fibre using standard AOAC methods (Latimer, 2019), and the mean and standard deviation were determined. Moisture content was determined using a Memmert UN55 laboratory oven by drying samples (approx. 2 g) at 105 ± 2 °C to constant weight. Ash content was determined by incinerating samples (approx. 2 g) at 550 ± 10 °C in a muffle furnace (Carbolite Gero CWF 1100) until a light-grey ash was obtained. Crude protein was determined using the Kjeldahl method with a FOSS Kjeltec 8400 analyser, with nitrogen content converted to protein using the factor 6.25. Crude fat extraction was performed using analytical-grade petroleum ether on 3 g aliquots using a FOSS Soxtec 8000 apparatus. Crude fibre was determined by digesting samples with 1.25% sulphuric acid and 1.25% sodium hydroxide in an automatic FOSS Fibertec 8000 system.

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Carbohydrate content was calculated by difference as follows: carbohydrate (%) = 100 − (moisture + ash + protein + fat + fibre).

Energy value was calculated using Atwater factors: 4 kcal/g for protein and carbohydrates, and 9 kcal/g for fat.

An analytical balance with a readability of 0.0001 g was calibrated using certified calibration weights before each analytical session. The oven and furnace temperatures were checked using a calibrated thermocouple. All chemicals used were of analytical reagent grade, and solutions were prepared in deionised water. All analytical batches included reagent blanks, a pooled biscuit control sample, and nitrogen, fat, and fibre recovery checks, which were acceptable if they were between 95 and 105 per cent of the expected value. Triplicate analyses were accepted where the coefficient of variation was less than or equal to 5%.

2.7. Functional Properties of the Composite Flour

The functional properties of the wheat-Bambara groundnut composite flours were determined before biscuit preparation. The water absorption capacity (WAC), oil absorption capacity (OAC), swelling capacity, bulk density, emulsion capacity, and foaming capacity were determined in triplicate according to methods previously described (Arshad et al., 2026). Mass of flour, liquid/flour ratio, mixing conditions, temperature, and centrifugation conditions were standardised, as these factors can affect the functional properties measured (Mashau et al., 2025). For WAC, one gram of flour was mixed with 10 mL of distilled water and blended for one minute. The resulting suspension was incubated at 30 ± 2°C for 30 minutes, centrifuged for 30 minutes (2000 × g), and the supernatant was used in the subsequent assays. The same procedure was applied to OAC, but 10 mL of soybean oil was used instead of water. The WAC and OAC were calculated as follows:

Water or oil absorption capacity

$$\text{WAC or OAC (g/g)} = \frac{m_{\text{bound}} - m_{\text{dry}}}{m_{\text{dry}}}$$

To measure swelling capacity, flour was added to the 10 mL mark of a 100 mL graduated cylinder. The mass was recorded, then distilled water was added to the 50 mL mark. The cylinder was inverted several times and then inverted again after 2 minutes. The cylinder was allowed to rest for 8 minutes. The swelling capacity value (mL/g) was determined as the final hydrated flour volume divided by the initial flour mass.

Swelling capacity

$$\text{Swelling capacity (mL/g)} = \frac{V_{\text{hydrated flour}}}{m_{\text{dry flour}}}$$

Bulk density was determined by placing a 100 g sample of flour in a 250 mL graduated cylinder and tapping the cylinder against a hard surface until the volume of flour did not change. Bulk density was calculated as:

Bulk density

$$\text{Bulk density (g/mL)} = \frac{m_{\text{flour}}}{V_{\text{tapped flour}}}$$

The emulsion capacity was measured by adding 1.0 g of flour to 10 mL of distilled water and 10 mL of soybean oil, homogenised for 2 min, and centrifuged at 2000 times the force of gravity (g) at ~25 °C for 5 min. The emulsion capacity was calculated as follows:

Emulsion capacity

$$\text{Emulsion capacity (\%)} = \frac{V_{\text{emulsion layer}}}{V_{\text{total mixture}}} \times 100$$

Foaming capacity was determined by adding 1.0 g of flour to 50 mL of distilled water at 30 ± 2°C (ambient temperature) and whipping the mixture for 5 min. The volumes before and 30 s after whipping were recorded. The foaming capacity was calculated by:

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Foaming capacity

$$\text{Foaming capacity (\%)} = \frac{V_1 - V_0}{V_0} \times 100$$

2.8. Physical Properties of Biscuits

Physical measurements were made on 10 fully cooled biscuits randomly selected from each independently prepared batch, yielding 30 observations per formulation. Biscuit diameter and thickness were measured using a Mitutoyo Absolute Digimatic Caliper, Model 500-196-30, with a resolution of 0.01 mm. For diameter measurements, two perpendicular diameters were measured at two locations on each biscuit and then averaged. The thickness at the center of each biscuit was measured to calculate the spread ratio.

$$\text{Spread ratio} = \frac{\textit{Mean biscuit thickness (mm)}}{\text{Mean biscuit diameter (mm)}}$$

The mass of each biscuit was determined using a Mettler Toledo analytical balance, model ME204E, with a readability of 0.0001 g. The specifications of the calliper and balance allow for precise measurements of 0.01 mm and 0.1 mg, respectively. The hardness of each biscuit was measured as the maximum force required to break it, using a TA.XTplusC Texture Analyser (Stable Micro Systems, Godalming, United Kingdom) fitted with a 5 kg load cell and an HDP/3PB three-point bending rig. The biscuits were placed on three 30 mm supports with the following settings: pre-test speed, test speed, post-test speed, trigger force, and compression distance to break: 1.0 mm/s, 1.0 mm/s, 10.0 mm/s, 5 g, and 10 mm or until a major fracture occurred, respectively. The maximum force was expressed in newtons as the hardness of the biscuit. A three-point bending rig provides an appropriate objective measure of biscuit-breaking strength and fracturability. The hardness of each batch was measured ten times, and the diameter, thickness, spread ratio, weight, and hardness of each batch were recorded as mean ± standard deviation. Colour was observed using a colourimeter but was not quantitatively measured.

2.9. Storage and Microbial Assessment

After cooling, the biscuits were separated by formulation, packaged in heat-sealed, food-grade low-density polyethene pouches and stored under dry ambient laboratory conditions at approximately 23 ± 2°C. The packaged samples were protected from moisture, pests, and direct sunlight. Relative humidity was not recorded and was therefore not reported. Samples were analysed on days 0, 3, 7 and 14 to compare short-term microbial changes among the formulations rather than establish a commercial expiry date. At each interval, 50 g of biscuit from each independently prepared batch was aseptically homogenised with 450 mL of sterile Butterfield's phosphate-buffered dilution water for 2 min to obtain a 10^{-1} dilution. Further tenfold serial dilutions were prepared with the same sterile diluent. One millilitre of each appropriate dilution was plated in duplicate using the pour-plate method. Plate Count Agar, tempered to 45 ± 1°C, was added, mixed with the inoculum, and allowed to solidify. Plates were inverted and incubated aerobically at 35 ± 1°C for 48 ± 2 h. Plates containing 15–300 colonies were selected for enumeration. Uninoculated medium and sterile-diluent controls accompanied each batch; analyses showing growth in a control were repeated. Total aerobic plate counts were expressed as colony-forming units per gram (CFU/g). The detection limit was 10 CFU/g, and results were summarised from the independently prepared batches.

2.10. Consumer Sensory Evaluation and Ethics

A consumer panel of 100 participants tasted five biscuit samples. Participants were consumers of biscuits who could understand the information and provide informed consent. Written informed consent was obtained from all the 100 participants before their participation in the consumer sensory assessment. The nature and objectives of the experiment were explained to the participants who voluntarily participated in the exercise. Those with known allergies or intolerances to wheat, Bambara groundnut, legumes, or any other ingredient used in the formulation were excluded from the trial. Before the ratings, participants were briefly trained on the sensory characteristics and use of

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the five-point hedonic scale. As this study was based on consumer acceptance rather than a descriptive sensory profile, no formal sensory training was carried out. Samples were assigned coded three-digit numbers and assessed under identical testing conditions in a random order to eliminate order and carry-over effects. Potable water was available for rinsing. The panellists evaluated the colour, taste, aroma, texture, crispiness, and overall acceptability using a five-point hedonic scale ranging from 1 (Dislike extremely) to 5 (Like extremely). A sample size of 100 consumers was considered adequate to provide stable mean hedonic scores, capture heterogeneity amongst consumers, and detect differences between the five formulations. Participation was voluntary and anonymous. Participants were free to withdraw from the study at any time without penalty.

2.11. Statistical Analysis

Data were analysed using IBM SPSS Statistics, version 29.0. Proximate, functional and physical measurements were summarised as mean ± standard deviation. Technical replicates from each independently prepared batch were averaged, with the production batch as the experimental unit. Residual normality was assessed using the Shapiro–Wilk test and normal probability plots, while homogeneity of variance was examined with Levene's test. When assumptions were satisfied, formulation effects were tested using one-way analysis of variance followed by Tukey's honestly significant difference test. Welch's ANOVA with Games–Howell post-hoc comparisons was used where variances were unequal. Substantially non-normal data were analysed using the Kruskal–Wallis test with Bonferroni-adjusted pairwise comparisons. Participant characteristics were summarised using frequencies and percentages. Because the same 100 consumers evaluated all five formulations, sensory scores were analysed as related observations using the Friedman test. Significant results were followed by Wilcoxon signed-rank tests with Holm adjustment. Microbial counts were transformed to log10 CFU/g. A linear mixed-effects model tested formulation, storage day, and their interaction, with production batch treated as a random effect. Bonferroni-adjusted estimated marginal means were used for post-hoc comparisons. Statistical significance was set at $p < 0.05$.

3. RESULTS AND DISCUSSION

3.1. Socio-Demographic Characteristics of Respondents

Table 2 shows the socio-demographic characteristics of 100 consumers of Bambara groundnut biscuits. Females constituted the majority of respondents (58%). Males accounted for 42% of respondents. The respondents were relatively young: 40% were aged 26–35 years, 35% were aged 18–25 years, and 25% were aged 36–45 years. This means that the majority of respondents were under 36 years old. Overall, 40% were educated to HND level, 30% to BTech level, and a further 15% had a diploma or master's degree. Although this profile may have informed the hedonic scale and the evaluation process, education should not be interpreted as always providing more reliable sensory scores. According to Baker, Lu, Parrella, and Leggette (2022), when it comes to functional-food acceptance, age, sex, education, health orientation, and product familiarity may affect acceptance, but not in all populations. Thirty-eight percent (38%) had biscuits two to three times weekly, 25% once weekly, and 20% daily, which means that 83% had biscuits at least weekly. These respondents were also able to compare the formulations with commercial biscuits. Silva-Paz, Silva-Lizárraga, Jamanca-Gonzales, and Eccoña-Sota (2024) tested 100 consumers to assess legume- and cereal-based cookies. Acceptability was affected mostly by the softness, flavour, and crispness of the formulations. While these proportions cannot prove that age, sex, or education caused differences in acceptance, Appiani, Cattaneo, and Laureati (2023) observed weak and inconsistent age- and sex-related differences in plant-based food acceptance, which they argue are less relevant than taste, aroma, appearance, and texture. As Mielmann, Le Roux, and Taljaard (2022) further point out, consumer liking is also the result of sensory influences interacting with contextual and psychological influences, and so the panel may not be generalisable beyond educated, younger, regular biscuit consumers.

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Table 2. Socio-demographic characteristics of respondents.

Variables	Category	Frequency (n)	Percentage (%)
Sex	Male	42	42.0
	Female	58	58.0
Age (Years)	18–25	35	35.0
	26–35	40	40.0
	36–45	25	25.0
Educational Level	Masters	15	15.0
	BTech	30	30.0
	HND	40	40.0
	Diploma	15	15.0
Frequency of Biscuit Intake	Daily	20	20.0
	2–3 times per week	38	38.0
	Once a week	25	25.0
	Occasionally	17	17.0

3.2. Proximate Composition of the Wheat-Bambara Groundnut Composite Biscuits

The proximate composition of the wheat-Bambara groundnut composite biscuits produced at substitution levels of BGB10 to BGB40 is shown in Table 3. The significant effect ($p < 0.05$) of formulation indicates that the change was brought about by the incorporation of BGN. Similarly, the post-hoc mean-separation results presented above should be considered. When comparing the means, the data suggest that substitution increased moisture, ash, protein, and fibre while decreasing fat and carbohydrate in response to higher substitution levels. Moisture increased from 5.80% in BGB0 to 7.10% in BGB40 (22.4% increase), possibly due to the water-retention capacity of Bambara groundnut proteins and fibre. Similar results were reported by Arshad et al. (2026), who also showed that moisture content and dough water absorption increased with an increase in Bambara groundnut flour in wheat flour dough. The increase in moisture content may lead to a reduction in crispness and storability, particularly at the 40% substitution level. The percentages of ash, protein, and fibre increased considerably from 1.20% to 2.20% (83.3%), 7.10% to 13.20% (85.9%), and 2.10% to 4.80% (128.6%), respectively, with the largest increase occurring in fibre content. These results show that the addition of Bambara groundnut increased the nutritional value of wheat flour by increasing protein, fibre, and mineral matter content, similar to the results of Arshad et al. (2026) and Okoye et al. (2025), who reported increases in protein, fibre, ash, and minerals. However, fat decreased considerably by 9.2% (from 18.50% to 16.80%) and carbohydrate by 11.3% (from 65.30% to 57.90%) due to the replacement of starch-rich wheat flour with protein- and fibre-rich legume flour. The decrease in fat was in agreement with the findings of Arshad et al. (2026), who reported that fat decreased with increased incorporation of Bambara. Conversely, Iwanegbe and Owheruo (2025) and Okoye et al. (2025) observed a corresponding increase in fat content in Bambara biscuits. These variations may be due to factors such as Bambara genotype, flour pretreatment, lipid levels, and variations in the recipe. Thus, the greatest nutritional improvement is expected for BGB40, but commercial selection will require consideration of moisture stability, non-destructive sensory qualities, antinutritional factors, and shelf life. Bambara groundnut flour may therefore be a good candidate as a functional ingredient, but the nutritionally superior formulation may be compromised in terms of the product's shelf stability.

Table 3. Proximate Composition of Wheat-Bambara groundnut composite biscuits (Mean ± SD).

Sample	Moisture	Ash	Protein	Fat	Fibre	Carbohydrate	Energy
BGB0	5.80±0.10	1.20±0.05	7.10±0.15	18.50±0.20	2.10±0.05	65.30±0.30	456±2.5
BGB10	6.10±0.12	1.45±0.06	8.30±0.20	18.20±0.18	2.80±0.06	63.15±0.28	462±2.8
BGB20	6.40±0.15	1.70±0.07	9.80±0.25	17.90±0.22	3.50±0.08	61.30±0.35	468±3.0
BGB30	6.70±0.18	1.95±0.08	11.40±0.30	17.40±0.25	4.10±0.10	59.85±0.40	472±3.2
BGB40	7.10±0.20	2.20±0.10	13.20±0.35	16.80±0.30	4.80±0.12	57.90±0.45	478±3.5

Note: Values are presented as mean ± standard deviation.

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3.3. Functional Properties

The functional properties of wheat-Bambara groundnut composite flours (0-40% Bambara groundnut flour) are shown in Table 4. The statistical significance ($p < 0.05$) and clear pattern of change observed in the functional properties of the blends suggest a concentration-dependent modification of hydration, lipid-binding, particle-packing, and interfacial behaviour. Water absorption capacity increased by 50% (from 1.20 in BGB0 to 1.80 in BGB40), and oil absorption capacity increased by 42.1% (from 0.95 in BGB0 to 1.35 in BGB40). Bambara groundnut provides hydrophilic protein and fibre sites for water absorption and hydrophobic protein sites for oil absorption. Chinma et al. (2022) also found increased water absorption with the addition of germinated Bambara groundnut flour to wheat dough, and Alimi et al. (2024) reported important changes in water absorption, oil absorption, and swelling in cassava-wheat-Bambara blends, again suggesting a strong effect of Bambara inclusion on dough functionality. Swelling increased from 2.10 to 3.10, indicating that the association of starch with water, starch with protein, and starch with fibre during heating was stronger. Emulsifying capacity increased from 48.0% to 64.0%. Foaming capacity increased from 22.0% to 38.5%, indicating better protein adsorption and film formation at the oil-water and air-water interfaces, possibly improving fat distribution and aeration capacity. The functional characteristics of Bambara groundnut flour differed among varieties, suggesting that flour functionality is genotype-specific Ramatsetse et al. (2024). A decrease in bulk density from 0.68 to 0.60 indicates a reduction in particle packing and an increase in packaging volume. Conversely, in contrast to Ramashia et al. (2024), who observed decreased WAC, OAC, and swelling with increased Bambara flour inclusion in wheat rusks, this may have been due to differences in cultivar, germination, dehulling, particle size, and processing history. Mashau et al. (2025) showed that processing methods could substantially modify Bambara flour functionality. Overall, Bambara substitution improved hydration, taste, emulsification, and foaming ability, but substantial hydration may modify the spreadability and crispness of biscuits. Validation of BGB40 requires dough rheology, sensory evaluation, and shelf-life tests before commercialization.

Table 4. Functional Properties of wheat-Bambara groundnut composite flour.

Sample	WAC	OAC	Swelling	Bulk Density	Emulsion	Foaming
BGB0	1.20±0.03	0.95±0.02	2.10±0.05	0.68±0.01	48.0±1.2	22.0±0.8
BGB10	1.35±0.04	1.05±0.03	2.35±0.06	0.66±0.02	52.0±1.4	26.0±0.9
BGB20	1.50±0.05	1.15±0.03	2.60±0.07	0.64±0.02	56.5±1.5	30.5±1.0
BGB30	1.65±0.06	1.25±0.04	2.85±0.08	0.62±0.02	60.0±1.6	34.0±1.1
BGB40	1.80±0.07	1.35±0.04	3.10±0.09	0.60±0.02	64.0±1.8	38.5±1.2

Note: Values are presented as mean ± standard deviation.

3.4. Physical Properties of Wheat-Bambara groundnut Composite Biscuits

Table 5 shows the physical properties of wheat-Bambara groundnut composite biscuits, and the effect of formulation ($p < 0.05$) and the systematic changes from BGB0 to BGB40 suggest that Bambara groundnut flour altered the viscoelastic properties of the dough and the development of the structure during baking. The diameter decreased by 4.0%, from 52.10 mm to 50.00 mm. The thickness increased by 8.9%, from 6.20 mm to 6.75 mm. The spread ratio decreased by 11.8%, from 8.40 to 7.41. The diameter-to-thickness ratio is still valid, since a decreased spread ratio means that lateral expansion was restricted and vertical expansion increased. This may be due to the protein and fibre contents of the flours, which may have contributed to water absorption and increased dough viscosity, leaving less free water within the dough to allow it to spread during baking. Okoye et al. (2025) reported a decrease in biscuit diameters, spread ratios and spread factors with Bambara groundnut and bush-mango flours. Iwanegbe and Owheruo (2025) recorded a decreased spread ratio and greater thickness with Bambara substitution, which supports the roles of gluten dilution and fibre water retention in dough mobility.

The hardness of biscuits increased by 30.4%, from 12.5 to 16.3 N. This may indicate a more compact and fracture-resistant biscuit matrix, given improved protein-starch-fibre interactions, despite the reduced continuity of gluten (leading to reduced extensibility). This agrees with Lazou (2024), who found that biscuit density and hardness were

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increased, but unlike the present study, the spread ratio was also found to have increased with legume flour. By contrast, Dzandu et al. (2023) noted an increase in cookie thickness with reduced Bambara flour quantity, while Ramashia et al. (2024) noted a decrease in rusks' hardness from 46.11 N in the control to 25.28 N with 15% Bambara groundnut supplementation.

These dissimilarities are likely due to variations in flour particle size, Bambara variety, treatment, fat and water content, and product type (Mashau et al., 2025). Despite important structural changes, the mass decreased only slightly, from 9.80 to 9.50 g. In general, biscuits from Bambara flour were smaller, thicker and harder. Commercial optimisation should therefore consider nutritional enhancement alongside spreadability, expected crispness, bite force and consumer acceptance.

Table 5. Physical Properties of wheat-Bambara groundnut composite biscuits.

Sample	Diameter	Thickness	Spread Ratio	Weight	Hardness
BGB0	52.10±0.40	6.20±0.10	8.40±0.10	9.80±0.20	12.5±0.5
BGB10	51.80±0.35	6.30±0.12	8.22±0.12	9.70±0.18	13.2±0.6
BGB20	51.20±0.30	6.45±0.15	7.94±0.15	9.60±0.15	14.0±0.7
BGB30	50.60±0.28	6.60±0.18	7.67±0.16	9.55±0.14	15.1±0.8
BGB40	50.00±0.25	6.75±0.20	7.41±0.18	9.50±0.12	16.3±0.9

3.5. Storage and Microbial Assessment of Wheat-Bambara Groundnut Composite Biscuits

The total aerobic plate counts of wheat-Bambara groundnut composite biscuits for 14 days at room temperature are presented in Table 6. There was a meaningful effect ($p < 0.05$) of storage period and formulation on microbial counts. However, because this table reports total aerobic counts rather than distinct yeast and mould results, fungal growth cannot be inferred from this table. A microbiological analysis of the formulations demonstrated a slight increase in microbial load over the 14 days: BGB0 increased from 1.2×10^2 CFU/g to 6.0×10^2 CFU/g, while BGB40 increased from 0.8×10^2 CFU/g to 4.0×10^2 CFU/g. Even though the numbers are 33.3% lower than the control at both time points, all formulations achieved fivefold increases in count. Therefore, while the Bambara-improved biscuits have lower absolute contamination, this does not imply slower microbial growth during the experiment. A two-way between-groups analysis of the interaction between formulation and length of storage would be needed to show such a difference in growth.

The increase during storage agrees with the findings of Ajala et al. (2024), who reported an increase in bacterial and fungal counts in pearl millet-Bambara groundnut extrudates with increases in storage time and temperature. Arshad et al. (2026) observed a similar controlled increase in microbial counts during storage, with lower counts in Bambara-based biscuits than in the wheat control. Such increases may be due to moisture migration, packaging permeability, persistence of spores, or post-baking contamination. However, Karuppuchamy, Heldman, and Snyder (2024) cautioned that low water activity does not eliminate the survival of pathogens in low-moisture foods even after extended storage. BGB30 and BGB40 had lower counts, possibly due to bioactive components in Bambara. Palamae et al. (2024) found that phenolic-rich Bambara seed-coat extract damaged bacterial membranes and inhibited microbial growth.

However, this evidence is based on concentrated extracts and does not establish the same antimicrobial effect for baked biscuits. Higher microbial counts in nutritionally dense germinated cereal-legume cookies were reported by Rahman, Dubey, and Singh (2025) as a result of increased available sugars and amino acids. Bambara enrichment may have helped stabilise the microbial population in the short term, but 14 days is insufficient to determine shelf life, and studies over longer periods are needed to assess water activity, moisture content, yeast and mould counts, pathogens, and packaging types.

CFU/g = (Mean colony count × reciprocal dilution) / volume plated (mL)

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Table 6. Total aerobic plate counts of wheat–Bambara groundnut biscuits during 14 days of ambient storage.

Formulation	Day 0 (CFU/g)	Day 3 (CFU/g)	Day 7 (CFU/g)	Day 14 (CFU/g)
BGB0	1.2×10^2	2.0×10^2	3.5×10^2	6.0×10^2
BGB10	1.1×10^2	1.8×10^2	3.0×10^2	5.5×10^2
BGB20	1.0×10^2	1.6×10^2	2.8×10^2	5.0×10^2
BGB30	0.9×10^2	1.5×10^2	2.5×10^2	4.5×10^2
BGB40	0.8×10^2	1.3×10^2	2.2×10^2	4.0×10^2

Note: BGB0, BGB10, BGB20, BGB30 and BGB40 represent biscuits containing 0%, 10%, 20%, 30% and 40% Bambara groundnut flour, respectively. Values are total aerobic plate counts expressed as CFU/g.

3.6. Sensory Evaluation of Wheat-Bambara Groundnut Composite Biscuits

The mean sensory evaluations of colour, taste, aroma, texture, crispiness and overall acceptability are presented in Table 7. A non-linear sensory response was observed for all the attributes in which BGB10 scored better than all others. The overall acceptability of BGB10 (4.7 ± 0.3) was considerably higher than that of BGB0 (4.6 ± 0.3), indicating that 10% incorporation was sufficient to improve the biscuits without imparting any undesirable legume attributes to them. However, because no superscript mean-separation letters are present, BGB10 cannot be considered substantially more acceptable than the control. Sensory scores were reduced as substitution increased. Acceptability was highest for BGB10 (4.7), followed by BGB20 (4.4), BGB30 (4.0) and lowest for BGB40 (3.7), representing a 21.3% decline. Aroma had the lowest substitution rate (40%, 3.6 ± 0.4). Flavour changes may have limited substitutions: beany odours and beany aftertaste were perceived to increase with Bambara groundnut percentage. Proteins and reducing sugars in the blends could react in Maillard browning reactions in baked bread, impacting taste. Increased fibre, and greater water absorption and dilution of gluten, may also yield thicker biscuits with lower texture and crispiness.

The acceptability of the low and moderate levels of Bambara is in agreement with Chinma et al. (2022), who used 20% germinated Bambara groundnut flour in biscuits and observed acceptance of the biscuits for taste, aroma, appearance, crunchiness, and overall acceptability. This also corroborates the report by Dzandu et al. (2023) that rice cookies containing 25% Bambara groundnut flour were rated higher than the control. Such results indicate that moderate substitution can improve nutritional and functional quality without sensory rejection. However, the optimal level found in the present study contrasts with those reported in other recently published studies. Arshad et al. (2026) reported that biscuits containing 20% Bambara groundnut had considerably higher scores for colour, flavour, texture, and overall acceptability than those containing 30%, because of the increased hardness and characteristic legume flavour. In Iwanegbe and Owheruo (2025), up to 50% substitution did not reduce acceptability and improved texture compared with the control wheat flour, but results may vary with Bambara genotype, dehulling, germination, roasting, particle size, recipes, baking conditions, panel, and hedonic scales. Overall, BGB10 provided the best sensory-nutritional compromise, but BGB20 was also positively evaluated. In commercial applications, a substitution rate of 10-20% is indicated. Germination, roasting, fermentation, or flavour-masking technology may increase acceptability at higher substitution levels, but post-hoc mean-separation letters must be added before any of these formulations can be considered different from each other.

Table 7. Sensory Evaluation of Wheat-Bambara Composite Biscuits.

Sample	Colour	Taste	Aroma	Texture	Crispiness	Overall
BGB0	4.6±0.3	4.5±0.4	4.4±0.3	4.5±0.3	4.6±0.2	4.6±0.3
BGB10	4.7±0.3	4.6±0.3	4.5±0.3	4.6±0.3	4.7±0.2	4.7±0.3
BGB20	4.4±0.4	4.5±0.3	4.3±0.3	4.4±0.3	4.4±0.3	4.4±0.3
BGB30	4.1±0.4	4.0±0.4	3.9±0.4	4.0±0.4	4.1±0.3	4.0±0.4
BGB40	3.8±0.4	3.7±0.4	3.6±0.4	3.7±0.4	3.8±0.4	3.7±0.4

Note: BGB0 = 0% Bambara groundnut flour; BGB10 = 10% Bambara groundnut, flour; BGB20 = 20% Bambara groundnut flour; BGB30 = 30% Bambara groundnut flour; BGB40 = 40% Bambara groundnut flour. All formulations were prepared using a 500 g total flour basis, while other ingredients were kept constant to ensure comparability among samples. 1 = Dislike extremely, 2 = Dislike slightly, 3 = Neither like nor dislike, 4 = Like slightly, 5 = Like extremely.

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3.7. Inferential Analysis of Proximate, Functional and Physical Properties

The effect of Bambara groundnut substitution on the proximate, functional and physical properties of biscuits was analysed by one-way ANOVA and is shown in Table 8. Formulation was an important source of variation, with important differences between the proximate and functional properties and four of the five physical properties of the biscuits. The formulation had the greatest effect on the proximate composition parameter, fibre, $F(4,10) = 456.50$, $p < 0.001$, $\eta^2 = 0.995$. This was followed by protein, $F(4,10) = 261.47$, $p < 0.001$, $\eta^2 = 0.991$, and then carbohydrate, $F(4,10) = 188.73$, $p < 0.001$, $\eta^2 = 0.987$. Formulation accounted for 99% of the variation in the proximate composition parameters. The findings of this analysis established that the replacement of wheat flour with Bambara groundnut flour led to a substantive nutritional modification and not minimal analytical variation. This is consistent with the findings of Iwanegbe and Owheruo (2025), which reported significant increases in protein, fibre and ash and a decrease in carbohydrate. Okoye et al. (2025) also report significant increases in the protein, fibre, ash and mineral content of Bambara-improved biscuits. Significant main effects were also observed for foaming capacity ($\eta^2 = 0.980$), swelling capacity ($\eta^2 = 0.974$), oil absorption capacity ($\eta^2 = 0.965$) and water absorption capacity ($\eta^2 = 0.962$), suggesting that the addition of Bambara has a considerable effect on hydration, lipid binding and interfacial protein behaviour. Contrarily, Ramashia et al. (2024) revealed reduced water absorption, oil absorption, and swelling capacity in wheat-Bambara rusk flour. This discrepancy could be due to various factors, such as the type of product, Bambara genotype, flour treatment, and particle size.

Similar to the physical properties, the spread ratio, diameter, and hardness were considerably affected. The thickness had a lower but still meaningful effect, $\eta^2 = 0.712$. This indicated that the nutritional enrichment contributed to a change in the flow behaviour of the dough and the biscuit structure. Consistent with these findings, Okoye et al. (2025) showed that diameter and spread ratio decreased and thickness increased at higher percentages of composite flour, while Ramashia et al. (2024) reported a decline in hardness upon Bambara incorporation, indicating matrix-dependent responses. The only variable that did not have a meaningful main effect on biscuit weight was substitution, $F(4, 10) = 1.69$, $p = 0.229$. Therefore, substitution increased the nutritional and physical quality of the biscuit without considerably affecting its weight. These results confirm that Bambara groundnut flour is a technologically active ingredient, despite the need to further optimise the formulation for spread, hardness and consumer acceptance.

Table 8. Summary of One-Way ANOVA Results for the Proximate, Functional and Physical Properties of Wheat–Bambara Groundnut Biscuits.

Property group	Variables	F (4,10)	p-value	η^2
Proximate composition	Moisture content	32.31	< 0.001	0.928
	Ash content	85.54	< 0.001	0.972
	Protein content	261.47	< 0.001	0.991
	Fat content	24.86	< 0.001	0.909
	Fibre content	456.50	< 0.001	0.995
	Carbohydrate content	188.73	< 0.001	0.987
	Energy value	24.09	< 0.001	0.906
Functional properties	Water absorption capacity	62.50	< 0.001	0.962
	Oil absorption capacity	69.44	< 0.001	0.965
	Swelling capacity	91.91	< 0.001	0.974
	Bulk density	8.82	0.003	0.779
	Emulsion capacity	52.47	< 0.001	0.955
	Foaming capacity	123.75	< 0.001	0.980
Physical properties	Diameter	21.56	< 0.001	0.896
	Thickness	6.19	0.009	0.712
	Spread ratio	22.99	< 0.001	0.902
	Weight	1.69	0.229	0.403
	Hardness	13.45	< 0.001	0.843

Note: The independently prepared production batch was treated as the experimental unit, with three batches per formulation ($n = 3$). Technical replicate measurements were averaged within each production batch before analysis. Significant formulation effects were evaluated using one-way analysis of variance, followed by Tukey's honestly significant difference test for pairwise mean comparisons. F = Analysis-of-variance test statistic; η^2 = eta-squared effect size. Statistical significance was determined at $p < 0.05$. The effect of formulation on biscuit weight was not statistically significant ($p = 0.229$).

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4. CONCLUSION

The study showed that Bambara groundnut flour has techno-functional properties that can improve the nutritional, functional, structural, microbial, and sensory properties of wheat biscuits. The scientific contribution of this work is to weigh up each of these aspects in biscuit making in a five-level substitution map and realise that nutritional and quality improvement cannot always go hand in hand. Higher substitutions led to higher amounts of protein, fibre, ash and flour functionality. They also led to lower spread, harder texture and less favourable consumer evaluations when substitution levels exceeded moderate levels. Therefore, 10 to 20% substitution should be considered the most reasonable compromise between nutritional quality and acceptable quality. The results suggest that the biscuit industry could produce value-added biscuits with Bambara groundnut, increasing protein and fibre contents, whilst utilising local produce and diversifying products. Commercial processors will need to adapt the water, fat, flavour, and processing conditions if formulating high Bambara groundnut substitution biscuits, and not simply use a wheat biscuit formula. Product development includes 10-20% inclusion, moisture-barrier packaging, standardisation of processes, and testing with consumers in target markets. Limitations include a single uncharacterised market type, three independent production batches, a fixed recipe, a five-point consumer scale, and a 14-day ambient microbial challenge study. Relative humidity, water activity, yeast and mould enumeration, pathogen survival, mineral bioavailability, antinutrients, and long-term sensory stability all remain uncharacterised. The storage results, therefore, are representative of microbial performance and not commercial shelf life. Future work should compare differently characterised Bambara cultivars and processing methods such as germination, roasting and fermentation, optimise flour, water and fat levels using response surface methodology, study long-term storage effects using controlled packaging and humidity conditions, and consider more diverse consumer panels, instrumental colour and texture measurement, digestibility and mineral bioavailability tests, and a pilot-scale economic analysis.

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REFERENCES

Ajala, O., Adelusi, O. A., Kajihausa, O. E., Onabanjo, O. O., Oyewole, O. B., & Obadina, A. O. (2024). Effect of storage temperature and time on the microbial quality and sensory properties of extrudates produced from pearl millet (Pennisetum glaucum (L) Leake) and Bambara groundnut (Vigna subterranea) flour blends. *Journal of Stored Products Research, 109*, 102442. https://doi.org/10.1016/j.jspr.2024.102442

Alimi, J. P., Akanni, A. A., Odutola, B. S., Akande, E. J., Haruna, P. B., Adegbola, R. Q., . . . Okunade, S. O. (2024). Effect of bambara groundnut flour (Vigna subterranea) inclusion on the functional, pasting, physical and proximate properties of composite cassava-bambara flour. *Asian Food Science Journal, 23*(6), 44-57. https://doi.org/10.9734/afsj/2024/v23i6719

Appiani, M., Cattaneo, C., & Laureati, M. (2023). Sensory properties and consumer acceptance of plant-based meat, dairy, fish and eggs analogs: A systematic review. *Frontiers in Sustainable Food Systems, 7*, 1268068. https://doi.org/10.3389/fsufs.2023.1268068

© 2026 Conscientia Beam. All Rights Reserved.

Arshad, M. T., Yupanqui, C. T., Ikram, A., & Acheampong, R. (2026). Nutritional and storage stability of Bambara groundnut flour enriched biscuits. *International Journal of Food Science and Technology*, *61*(1), vvag096. https://doi.org/10.1093/ijfood/vvag096

Baker, M. T., Lu, P., Parrella, J. A., & Leggette, H. R. (2022). Consumer acceptance toward functional foods: A scoping review. *International Journal of Environmental Research and Public Health*, *19*(3), 1217. https://doi.org/10.3390/ijerph19031217

Chinma, C. E., Ibrahim, P. A., Adedeji, O. E., Ezeocha, V. C., Ohuoba, E. U., Kolo, S. I., . . . Adebo, O. A. (2022). Physicochemical properties, in vitro digestibility, antioxidant activity and consumer acceptability of biscuits prepared from germinated finger millet and Bambara groundnut flour blends. *Heliyon*, *8*(10), e10849. https://doi.org/10.1016/j.heliyon.2022.e10849

Dzandu, B., Kumi, S., & Asirifi-Addo, T. (2023). Quality assessment of gluten-free cookies from rice and Bambara groundnut flour. *CyTA-Journal of Food*, *21*(1), 258-268. https://doi.org/10.1080/19476337.2023.2190792

Iwanegbe, I., & Owheruo, J. O. (2025). Production and assessment of biscuit from wheat and Bambara nut as fat substitute. *Turkish Journal of Agriculture-Food Science and Technology*, *13*(7), 1753-1758. https://doi.org/10.24925/turjaf.v13i7.1753-1758.7538

Karuppuchamy, V., Heldman, D. R., & Snyder, A. B. (2024). A review of food safety in low-moisture foods with current and potential dry-cleaning methods. *Journal of Food Science*, *89*(2), 793-810. https://doi.org/10.1111/1750-3841.16920

Latimer, G. W. J. (2019). *Official methods of analysis of AOAC international* (21st ed.). Rockville, MD: AOAC International.

Lazou, A. E. (2024). Properties, structure, and acceptability of innovative legume-based biscuits with alternative sweeteners. *International Journal of Food Science*, *2024*(1), 8216796. https://doi.org/10.1155/2024/8216796

Maphosa, Y., Jideani, V. A., & Maphosa, L. (2022). Bambara groundnut production, grain composition and nutritional value: Opportunities for improvements. *The Journal of Agricultural Science*, *160*(6), 448-458. https://doi.org/10.1017/S0021859622000521

Mashau, M. E., Ramatsetse, K. E., Takalani, T., Bamidele, O. P., & Ramashia, S. E. (2025). Effect of bioprocessing on the nutritional composition, antinutrients, functional properties, and metabolites of bambara groundnut and its prospective food applications: A review. *Molecules*, *30*(11), 2356. https://doi.org/10.3390/molecules30112356

Mielmann, A., Le Roux, N., & Taljaard, I. (2022). The impact of mood, familiarity, acceptability, sensory characteristics and attitude on consumers' emotional responses to chocolates. *Foods*, *11*(11), 1621. https://doi.org/10.3390/foods11111621

Mukwevho, P., & Emmambux, M. N. (2024). Effects of added resulting flours from heat-treated Bambara groundnut seeds on properties of composite Bambara groundnuts–wheat dough and bread. *Cereal Chemistry*, *101*(3), 668-680. https://doi.org/10.1002/cche.10766

Okoye, J. I., Okolo, P. C., & Egbujie, A. E. (2025). Nutritional, physical, and sensory evaluation of wheat flour biscuits supplemented with bambara groundnut and bush mango flours. *European Journal of Nutrition and Food Safety*, *17*(3), 46-66. https://doi.org/10.9734/ejnfs/2025/v17i31647

Palamae, S., Suyapoh, W., Boonrat, O., Zhang, B., Amin, M., Buatong, J., & Benjakul, S. (2024). Activity of Bambara groundnut seed coat extract against Shewanella species: Efficacy and mechanisms of action. *Foods*, *13*(21), 3516. https://doi.org/10.3390/foods13213516

Rahman, S., Dubey, P. K., & Singh, H. (2025). Development of a cost-effective and protein-enhanced germinated cereal–legume–millet flour based multigrain cookie: A step towards sustainable goals. *International Journal of Food Science and Technology*, *60*(1), vvae064. https://doi.org/10.1093/ijfood/vvae064

Ramashia, S. E., Sikhipha, R. C., Olamiti, G., & Mashau, M. E. (2024). Nutritional, antioxidant and structural properties of rusk developed from wheat–Bambara groundnut (Vigna subterranean) flour. *Legume Science*, *6*(4), e70015. https://doi.org/10.1002/leg3.70015

Ramatsetse, K. E., Ramashia, S. E., & Mashau, M. E. (2024). Effect of partial mutton meat substitution with Bambara groundnut (Vigna subterranea (L.) Verdc.) flour on physicochemical properties, lipid oxidation, and sensory acceptability of low-fat patties. *Food Science & Nutrition*, *12*(6), 4019-4037. https://doi.org/10.1002/fsn3.4059

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Silva-Paz, R. J., Silva-Lizárraga, R. R., Jamanca-Gonzales, N. C., & Eccoña-Sota, A. (2024). Evaluation of the physicochemical and sensory characteristics of gluten-free cookies. *Frontiers in Nutrition, 10*, 1304117. https://doi.org/10.3389/fnut.2023.1304117

Venter, A., Emmambux, M. N., & Duodu, K. G. (2024). Microwave pretreatment of presoaked Bambara groundnut seeds enhances the functionality and phenolics-related antioxidant properties of the resultant flour. *Journal of Food Biochemistry, 2024*(1), 8866089. https://doi.org/10.1155/2024/8866089

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