Development and Nutritional Evaluation of Snack Bars Formulated from Sorghum, Fonio, Groundnut and Soybean Flours for Adolescents

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Abstract
This study evaluated the proximate composition, energy values, mineral profile, anti-nutrient content, and sensory acceptability of snack bars formulated from composite flours of sorghum, fonio, soybean, and groundnut. Four formulations were prepared: a 100% refined wheat flour control and three composite formulations (SB1, SB2, and SB3) containing varied proportions of the non-wheat flours. Analytical procedures were performed in triplicate, and data were subjected to analysis of variance ($p < 0.05$). Results of analysis showed that snacks from the composite formulations showed higher crude protein (6.89–9.86 g/100 g), crude fat (18.08–20.48 g/100 g), crude fibre (3.88–5.00 g/100 g), and calculated energy values (423.88–439.00 kcal/100 g) compared to the control which had 7.82 g/100g (protein), 11.09 g/100 g (fat), 0.38 g/100 g (fibre), and 407.21 kcal/100 g(energy). Sample SB1 recorded the highest energy value (439.00 kcal/100 g) and crude protein (9.86 g/100 g) which represent 26.1% increase comparative to the control. For mineral content, calcium, magnesium, potassium, iron and zinc concentrations were also higher in the composite formulations. The sample coded SB1 recorded the highest calcium (77.10 mg/100 g), magnesium (125.00 mg/100 g), potassium (243.70 mg/100 g) and zinc (4.13 mg/100 g), whereas SB2 had the highest iron concentration (9.82 mg/100 g). Anti-nutritional factors in the finished composite snack bars ranged from 0.12% to 0.23% for oxalate and 0.12% to 0.13% for phytate, while remaining undetected in the control. Sensory evaluation showed that while the control received the highest overall acceptability score (7.43), SB3 recorded the highest numerical score among the composite formulated with a score of 6.80, showing no statistically significant difference from SB2 which had a score of 6.68. The findings from this study revealed that incorporation of sorghum, fonio, soybean and groundnut flours can improve the nutritional composition and mineral content of cereal-based snack bars while maintaining acceptable sensory quality as shown among the panelist. Based on its overall nutritional and sensory profile, SB3 represents a promising formulation for further product development.

Keywords: *adolescent nutrition; composite flour; fonio; groundnut; sorghum; soybean; snack bar; sensory evaluation*

1. Introduction

Adolescence is a transitional phase of physical and physiological change that spans between childhood and adulthood which according to the world health organization is put as 10 to 19 years. During this critical developmental space, adolescents experience a massive surge in their physical growth, gaining up to 45% and 50% of their total adult skeletal mass and body weight, respectively. This rapid accumulation of bone and muscle increase the daily physiological demands, requiring consistent high supply of energy, high-biological-value protein, iron, zinc, calcium, and dietary fiber to fuel the changing bodies (NCD-RisC, 2020; WHO, 2023).

Despite these keen nutrient demands, the diets of many adolescents within city and the rural areas in Nigeria are increasingly dominated by commercial street foods which consist mainly of refined wheat pastries, sugar-sweetened drinks, and extruded maize products full of refined carbohydrates and Trans fats (Akinyemi *et al*., 2022). While these snacks gives up to 30% of daily caloric intake among secondary school students according to research, their nutritional contribution may be limited by low levels of dietary fibre and some essential micronutrients which could lead to anemia, zinc deficiency, calcium inadequacy, stunting and even adolescent overweight and obesity common in the cities (Onyeneke *et al*., 2023; FAO, 2024).

One way to improving the nutritional contribution of snacks is the incorporation of locally available cereals and legumes into familiar food products. Composite flour formulations are particularly useful because ingredients with different nutritional and functional attributes can be combined to produce products with improved nutrient profiles. For this study the raw material selected includes: Sorghum, fonio, groundnut, and soybean; these are suitable contenders for such applications because they differ in their major nutrient contributions and can potentially complement one another nutritionally. Their use in value-added foods may also encourage greater utilization of locally produced crops while reducing exclusive dependence on refined wheat-based ingredients (Adebo, 2020).

Sorghum (*Sorghum bicolor* [L.] Moench) is an important African cereal adapted to semi-arid environments that has enhanced its widespread cultivation. Its grain comprising a pericarp, prominent endosperm, and germ, sorghum contains 64.0–80.0% starch, 7.0–15.0% crude protein, 2.0–4.5% lipids, and 1.5–3.5% ash (Oyeyinka & Ma, 2020). The carbohydrate fraction is controlled by amylose and amylopectin (slow-digesting) fixed within a dense protein matrix; this structural organization, together with starch-protein-tannin interactions, delays enzymatic hydrolysis, providing a low glycemic index and sustained glucose release (Rao et al., 2021). Kafirins constitute the major storage proteins in sorghum but poor in lysine. This limitation makes it important for combining sorghum with legumes that contain greater proportions of lysine (Xiong et al., 2019). Fonio (*Digitaria exilis* [Kippist] Stapf) an ancient West African small-millet cereal, that flourishes in marginal, nutrient-depleted soils. The grain is predominantly carbohydrate-based but also provides protein, fibre, and minerals, including magnesium, phosphorus, and potassium (Giamperi et al., 2022). Its protein (glutelins and prolamins) is notable for its contribution of sulphur-containing amino acids, particularly methionine and cysteine, which can complement the amino acid composition of other plant ingredients (Kanoussi et al., 2023). Fonio is also naturally gluten-free, further increasing its potential application in diversified cereal-based food products.

Groundnut (*Arachis hypogaea* L.) contributes a significantly different nutritional profile to the cereal components. The seed is rich in protein and lipid and contains considerable amounts of energy-dense nutrients, with oleic and linoleic acids representing important components of its lipid fraction (Nautiyal *et al*., 2020). Its globulin proteins (arachin and conarachin) are rich in bioavailable lysine, arginine, and aspartic acid that can complement the amino acid limitations of cereals, while its lipid profile is dominated by monounsaturated oleic acid (18:1, 40.0–65.0%) and polyunsaturated linoleic acid (18:2, 20.0–35.0%), boosting energy density and cardiovascular health (Surono *et al*., 2021). Processing, particularly roasting, also has implications for product quality because it initiates non-enzymatic Maillard reactions, generating volatile alkylpyrazines, pyridines, and furans that generate flavour and aroma compounds associated with the characteristic sensory properties of roasted groundnut critical for snack palatability (Liu et al., 2022). Groundnut therefore has both nutritional and sensory relevance in the development of snack products. Soybean (*Glycine max* [L.] Merr.) Provides an additional source of plant protein; containing 36.0–44.0% crude protein, 18.0–22.0% lipids, and 5.0–6.0% ash (Espinosa-Ramírez *et al*., 2021) and is particularly relevant to cereal-legume complementation Soybean typically contains substantially more protein than cereal grains and also supplies lipid and minerals (Espinosa-Ramírez *et al*., 2021). The major storage proteins contribute essential functional properties such as water binding, gelation, and emulsification. High lysine bioavailability in soy complements cereal amino acid limitations, while thermal processing deactivates heat-labile antinutrients (trypsin inhibitors and lectins), elevating *in vitro* protein digestibility (Vagadia *et al*., 2018).

The combination of the four ingredients is therefore based not only on their individual nutritional characteristics but also on the possibility of achieving complementary effects within the final product. Cereal proteins are commonly constrained by their relatively low lysine content, whereas legumes provide greater amounts of this essential amino acid. At the same time, the inclusion of different cereal sources can contribute amino acids and other nutrients that complement those supplied by legumes. A sorghum-fonio base supplemented with soybean and groundnut may consequently provide a broader nutritional profile than a formulation based predominantly on a single cereal.

Nutritional improvement, however, does not necessarily translate into a superior food product. Altering the proportions of cereal and legume flours can affect water absorption, dough characteristics, starch behaviour, product structure, texture, and density (Offiah et al., 2019). These changes may subsequently influence consumer perception. Soybean can be particularly challenging at higher inclusion levels because lipoxygenase-mediated reactions may generate volatile compounds responsible for undesirable beany or grassy notes (Guo et al., 2021). Groundnut inclusion may likewise influence the colour, aroma, flavour, and texture of the finished product. The proportion of each ingredient must therefore be carefully selected to obtain nutritional enhancement without compromising sensory quality.

The evaluation of antinutritional factors is also relevant to the nutritional assessment of cereal-legume products. Phytate and oxalate occur naturally in plant foods and can form complexes with minerals, potentially reducing the availability of calcium, iron, magnesium, and zinc for absorption (Castro-Alba et al., 2019). Their nutritional significance depends on both concentration and the characteristics of the food matrix. Processing operations, including thermal treatment, can alter the levels of these compounds and may consequently influence the nutritional quality of the final product. Determining their concentrations before and after processing therefore provides useful information on the nutritional implications of the

formulation. For an adolescent-targeted snack, nutritional composition must be considered alongside sensory appeal. Adolescents are likely to evaluate a product on the basis of attributes such as appearance, colour, aroma, flavour, texture, mouthfeel, and overall acceptability. A nutritionally improved formulation may have limited practical value if its sensory characteristics discourage consumption. The development of an acceptable product consequently requires an appropriate balance between ingredient composition, nutritional value, processing behaviour, and sensory quality. The present study therefore evaluated snack bars formulated from sorghum, fonio, groundnut, and soybean flours, with a snack bar prepared from refined wheat flour serving as the control. The study assessed the proximate composition and energy value of the products, determined their calcium, magnesium, potassium, iron, and zinc contents, and quantified selected antinutritional factors, particularly phytate and oxalate, in the raw materials and formulated products. Changes in these antinutritional factors following processing were also examined. In addition, the sensory properties of the snack bars were evaluated in terms of appearance, colour, aroma, taste/flavour, texture/mouthfeel, and overall acceptability. The ultimate aim was to determine whether a suitable combination of these locally available ingredients could produce a nutritionally improved snack with acceptable sensory characteristics for potential incorporation into adolescent diets.

2. Materials and Methods

2.1 Study design

The study involved formulation and laboratory evaluation of snack bars prepared from sorghum, fonio, soybean and groundnut flours. A 100% wheat-flour formulation served as the control.

2.2 Raw materials Procurement

Sorghum (*Sorghum bicolor* [L.] Moench), fonio (*Digitaria exilis* [Kippist] Stapf), soybean (*Glycine max* [L.] Merr.), and groundnut (*Arachis hypogaea* L.) were purchased from Masaka Market, Nasarawa State, Nigeria. Refined wheat flour and other ingredients used in the preparation of the snack bars, including date syrup, tiger nut milk, vegetable oil, baking powder, and natural spices, were obtained from local commercial markets. Aluminium foil and low-density polyethylene (LDPE) pouches were used for packaging the finished products.

2.3 Preparation of raw materials

2.3.1 Preparation of Sorghum Flour

Sorghum grains were sorted, cleaned, washed with potable water, and dried in an oven at 60°C. The dried grains were milled using an industrial disc mill and passed through a 250-µm sieve. The resulting flour was stored in clean, airtight containers until use.

2.3.2 Preparation of Fonio Flour

Fonio grains were thoroughly washed to remove adhering sand, grit, and other foreign materials. The cleaned grains were dried at 50°C, milled, and passed through a 250-µm sieve. The flour was stored in airtight containers until formulation.

2.3.3 Preparation of Soybean Flour

Soybean seeds were cleaned and soaked in potable water for 10 h at room temperature. The soaked seeds were manually dehulled and dried before roasting at 120°C for 15 min. The roasted soybean was cooled, milled, and passed through a 250-µm sieve. The flour was stored in airtight

containers until use. The heat treatment was intended to reduce heat-sensitive antinutritional factors and improve the processing and sensory characteristics of the soybean flour.

2.3.4 Preparation of Groundnut Meal

Groundnut seeds were cleaned and roasted at 130°C for 15 min. The roasted seeds were cooled, dehulled, and milled into a relatively uniform meal. The groundnut meal was stored in airtight containers until formulation.

2.4 Formulation of snack bars

Four snack bar formulations were prepared: a refined wheat flour control and three composite formulations designated SB1, SB2, and SB3. The composite formulations contained different proportions of sorghum, soybean, groundnut, and fonio flours. Vegetable oil and date syrup were incorporated at the levels specified in Table 1, while tiger nut milk, spices, and baking powder were maintained also at specified levels across the formulations.

Table 1: Formulation of snack bars

Ingredient	Control (g)	SB1 (g)	SB2 (g)	SB3 (g)
Refined wheat flour	75.0	–	–	–
Sorghum flour	–	20.0	25.0	30.0
Soybean flour	–	30.0	25.0	20.0
Groundnut meal	–	20.0	15.0	15.0
Fonio flour	–	15.0	20.0	20.0
Vegetable oil	10.0	5.0	5.0	5.0
Date syrup	15.0	10.0	10.0	10.0

Source: Experimental formulation design

2.5 Preparation of snack bars

The required quantities of the dry flour ingredients were weighed according to the formulations in Table 1 and thoroughly mixed. Baking powder and spices were incorporated into the dry mixture and uniformly dispersed. Date syrup, vegetable oil, and tiger nut milk were subsequently incorporated into the flour mixture, water was added as required to form firm dough. The dough was covered with a clean damp cloth and allowed to rest for 30 min at ambient temperature (28 ± 2°C). It was then rolled into sheets approximately 1.0 cm thick and cut into rectangular bars measuring approximately 3 × 8 cm. The pieces were arranged on baking trays and baked in a preheated electric oven at 180°C for 15–20 min until a uniform light-brown colour was obtained. After baking, the snack bars were cooled to room temperature on racks and packaged in aluminium foil/LDPE pouches pending laboratory analysis

2.6 Packaging

Aluminum pouches were used for packaging the developed snack bars.

2.7 Analysis

2.7.1 Proximate Composition

The proximate composition of the snack bars was determined using standard analytical procedures of the Association of Official Analytical Chemists (AOAC, 2023). Moisture, crude protein, crude fat, crude fibre, and ash were determined experimentally, while carbohydrate content was calculated by difference.

Moisture: Five grams (5.0 g) of each sample were weighed into previously dried and weighed moisture cans and dried at 105°C until constant weight was obtained. Moisture content was calculated from the loss in sample mass during drying. The formula below was used for the calculation

$$\% \text{ Moisture content} = \frac{W2-W3}{W2-W1} \times 100 \quad \text{Eq.(1)}$$

Where;
W_1 = weight of the empty moisture can
W_2 = weight of the can + sample before drying
W_3 = weight of the can + sample dried to constant weight.

Crude protein: Protein content was determined by the Kjeldahl method. The nitrogen content was converted to crude protein using a factor of 6.25.
%Protein content = % N_2 x 6.25

$$\% N_2 = \frac{100}{W} X \frac{14}{100} X N X 0.02 X \frac{Vt}{Va} X T - B \quad \text{Eq.(2)}$$

Where;
N = concentration (Normality) of titrant
V_t = Total vol of digest
V_a = vol of digest distilled
T = Titre value of sample
B = Titre value of reagent blank

Crude fat: Fat content was determined by Soxhlet extraction using petroleum ether with a boiling range of 40–60°C as the extraction solvent.
The fat content was given by weight loss due to oil removed by the solvent. The formula below was used:

$$\% \text{ of fat} = \frac{W3-W2}{W2-W1} \quad \text{Eq.(3)}$$

Where;
W_1 = Weight of empty filter paper
W_0 = Weight of filter paper ± sample before defatting
W_3 = Weight of filter paper ± sample, defatted and dried.

Crude fibre: Crude fibre was determined by sequential acid and alkaline digestion using 1.25% sulphuric acid and 1.25% sodium hydroxide, respectively. The residue obtained was dried and incinerated at 550°C, and crude fibre was calculated from the loss in mass after ignition.
The crude fiber content was calculated as shown below.

$$\% \text{ of Crude fiber} = \frac{W2-W3}{\text{weight of sample}} \; x \; 100 \quad \text{Eq.(4)}$$

W_2 = Weight of crucible and the boiled dried sample
W_3= weight of crucible and ash from the sample.

Ash: Ash content was determined by incinerating a known quantity of sample in a muffle furnace at 550°C until a constant weight of greyish-white ash was obtained.

The formula below was used for ash content.

Ash content= $\frac{W2-W1}{W} X100$

Eq.(5)

Where:
W_1 = weight of empty crucible
W_2 = weight of crucible + ash
W = weight of sample analyzed.

Carbohydrate: Carbohydrate content was calculated by difference:
Carbohydrate (%)} = 100 - (Moisture + Protein + Fat + Fibre + Ash) Eq. (6)
Energy value was calculated using the Atwater factors:
Energy (kcal/100 g) = (protein × 4) + (carbohydrate × 4) + (fat × 9). Eq. (7)

2.8 Mineral Analysis

The concentrations of calcium (Ca), magnesium (Mg), potassium (K), iron (Fe), and zinc (Zn) were determined using standard mineral analytical procedures. Iron and zinc were quantified by atomic absorption spectrophotometry following wet-acid digestion. Calcium and magnesium were determined by EDTA complexometric titration, while potassium was determined using flame photometry. Mineral concentrations were expressed as mg/100 g of sample.

2.9 Determination of Antinutritional Factors

Phytate: Phytate content was determined using a colorimetric method based on the reaction of phytate with iron-containing reagents. Absorbance was measured at 510 nm and phytate concentration was calculated from the appropriate calibration procedure.

Oxalate: Oxalate was determined by acid extraction followed by precipitation as calcium oxalate and titration of the recovered oxalate with standardized potassium permanganate solution. The concentration was calculated from the titre value and expressed as a percentage of the sample.

2.10 Sensory Evaluation

The sensory characteristics of the snack bars were evaluated using a nine-point hedonic scale, where 9 represented “like extremely” and 1 represented “dislike extremely.” The attributes assessed were appearance, colour, aroma, taste/flavour, texture/mouthfeel, and overall acceptability. The snack bar samples were coded and presented to the panelists in randomized order. Potable water was provided for palate cleansing between samples. Sensory scores were summarized as mean ± standard deviation of panelist responses.

2.11 Ethical Considerations

Ethical considerations were observed throughout the sensory evaluation involving adolescent participants. Participation in the sensory evaluation was voluntary, and the purpose and

procedures of the study were explained to the participants. Participants were informed that they could decline participation or withdraw from the evaluation at any time without penalty. Confidentiality and anonymity of participants were maintained throughout the study, and the sensory data were used solely for research purposes.

2.12 Statistical Analysis

Determinations were performed in triplicate and the results were expressed as mean ± standard deviation. Data were subjected to one-way analysis of variance (ANOVA) using Minitab version 22.0. Where significant differences followed among formulation means, Duncan's multiple range test (DMRT) was used for mean separation. Differences were considered statistically significant at $p < 0.05$

3.0 Results

3.1 Proximate composition and energy value

Results of analysis obtained for proximate composition and calculated energy values of the control and composite snack bars are presented in Table 2.

Moisture content ranged from 6.85 to 7.21 g/100 g. the highest value of 7.21 g/100 g was obtained in the control sample while samples SB1, SB2 and SB3 each recorded 6.85 g/100 g.

In table 2, the crude protein result differed significantly ($p<0.05$) among the formulated samples. The highest protein content (9.86 g/100 g) was found in sample SB1, followed by the control (7.82 g/100 g), SB2 (7.18 g/100 g) and SB3 (6.89 g/100 g).

The crude fat content was higher in all formulated samples than that of the control. Again sample with SB1 recorded the highest value of 20.48 g/100 g followed by SB2 (18.43 g/100 g) and SB3 (18.08 g/100 g), compared with 11.09 g/100 g obtained in the control sample.

Crude fibre content increased from 0.38 g/100 g in the control to a range of 3.88 to 5.00 g/100 g in the composite formulations, with sample SB3 having the highest value.

Ash content ranged from 4.48 to 5.18 g/100 g. Although values obtained in samples SB1 and SB2 are numerically different, they had statistically similar values, and SB3 recorded a lower value than SB1 and SB2 but higher numerical value than the control. Carbohydrate content calculated by difference was highest in the control (69.03 g/100 g) but decreased to 53.81, 57.50 and 58.40 g/100 g, respectively, in samples SB1, SB2 and SB3,.

Calculated Energy values showed that the control had 407.21 kcal/100 g, SB1 (439.00 kcal/100 g), SB2 (424.59 kcal/100 g) and SB3 (423.88 kcal/100 g).

Table 2. Proximate composition (g/100 g) and calculated energy value (kcal/100 g) of the snack bars

Formulation	Moisture	Crude protein	Crude fat	Crude fibre	Ash	Carbohydrate	Energy
Control	$7.21^{a} \pm 0.02$	$7.82^{c} \pm 0.10$	$11.09^{d} \pm 0.06$	$0.38^{d} \pm 0.00$	$4.48^{c} \pm 0.09$	$69.03^{a} \pm 0.03$	407.21
SB1	$6.85^{b} \pm 0.20$	$9.86^{a} \pm 0.10$	$20.48^{a} \pm 0.44$	$3.88^{c} \pm 0.07$	$5.12^{a} \pm 0.04$	$53.81^{d} \pm 0.62$	439.00
SB2	$6.85^{b} \pm 0.01$	$7.18^{d} \pm 0.00$	$18.43^{b} \pm 0.06$	$4.95^{b} \pm 0.03$	$5.18^{a} \pm 0.06$	$57.50^{c} \pm 0.31$	424.59
SB3	$6.85^{b} \pm 0.01$	$6.89^{e} \pm 0.01$	$18.08^{c} \pm 0.13$	$5.00^{a} \pm 0.05$	$4.78^{b} \pm 0.23$	$58.40^{b} \pm 0.29$	423.88

Values are mean ± standard deviation of triplicate determinations. Means within a column with different superscript letters differ significantly at $p<0.05$. Energy was calculated using 4 kcal/g (protein), 9 kcal/g (fat) and 4 kcal/g (carbohydrate).

3.2 Mineral Content

The mineral content of the formulated snacks is presented in Table 3.

Calcium content ranged from 31.18 mg/100 g in the control sample to 77.10 mg/100 g in SB1 which recorded the highest calcium concentration, followed by SB2 with 68.03 mg/100 g and SB3 (67.17 mg/100 g).

Magnesium content increased from 11.64 mg/100 g in the control to 125.00, 116.93 and 109.43 mg/100 g in SB1, SB2 and SB3, separately. Likewise, Potassium content ranged from 226.56 mg/100 g in the control to 243.70 mg/100 g in SB1.

Iron content was highest in SB2 (9.82 mg/100 g), followed by SB3 (8.62 mg/100 g) and SB1 (8.23 mg/100 g), compared with 0.87 mg/100 g recorded in the control. As shown in the table, Zinc content increased from 0.35 mg/100 g in the control sample to, respectively, 4.13, 3.50 and 3.55 mg/100 g in SB1, SB2 and SB3.

Table 3. Mineral composition of the snack bars

Formulation	Calcium (mg/100 g)	Magnesium (mg/100 g)	Potassium (mg/100 g)	Iron (mg/100 g)	Zinc (mg/100 g)
Control	$31.18^{d} \pm 0.57$	$11.64^{d} \pm 0.04$	$226.56^{d} \pm 0.20$	$0.87^{d} \pm 0.01$	$0.35^{d} \pm 0.03$
SB1	$77.10^{a} \pm 0.22$	$125.00^{a} \pm 1.23$	$243.70^{a} \pm 1.74$	$8.23^{c} \pm 0.31$	$4.13^{a} \pm 0.35$
SB2	$68.03^{b} \pm 0.72$	$116.93^{b} \pm 0.95$	$241.03^{b} \pm 0.38$	$9.82^{a} \pm 0.11$	$3.50^{b} \pm 0.13$
SB3	$67.17^{c} \pm 0.23$	$109.43^{c} \pm 0.40$	$227.73^{c} \pm 0.81$	$8.62^{b} \pm 0.08$	$3.55^{b} \pm 0.04$

Values are mean ± standard deviation of triplicate determinations. Means within a column with different superscript letters differ significantly at $p<0.05$.

3.3 Anti-nutrient content

Oxalate and phytate concentrations are presented in Table 4. Oxalate was not detected in the control but ranged from 0.12 to 0.23% in the formulate snacks. the highest oxalate content was found in sample SB2 (0.23%), while SB1 recorded the lowest (0.12%).

Similarly, Phytate was not detected in the control but ranged from 0.12 to 0.13% in the formulated snacks. There was no significant difference ($p<0.05$) amongst samples SB1, SB2 and SB3.

Table 4. Oxalate and phytate contents of the Formulated snack bars

Formulation	Oxalate (%)	Phytate (%)
Control	ND	ND
SB1	$0.12^{b} \pm 0.01$	$0.13^{a} \pm 0.00$
SB2	$0.23^{a} \pm 0.01$	$0.12^{a} \pm 0.01$
SB3	$0.20^{a} \pm 0.01$	$0.12^{a} \pm 0.00$

Values are mean ± standard deviation of triplicate determinations. Means within a column with different superscript letters differ significantly at $p<0.05$. ND= below the limit of detection (LOD)

3.4 Sensory evaluation

The sensory scores are presented in Table 5. The highest sensory scores were recorded in the control for all the measured attributes. For the appearance attribute, scores ranged from 6.36 in SB1 to 7.25 in the control sample.

Likewise, colour scores were highest in the control (7.25), while SB1, SB2 and SB3 recorded 6.48, 6.57 and 6.32, respectively. Aroma ranged from 6.30 in SB1 to 6.91 in the control.
Taste/flavour scores were highest in the control (7.11). Nevertheless, among the formulated snacks SB3 had the highest numerical value (6.39), followed by SB2 (6.14) and SB1 (5.66). Texture/mouthfeel scores were 7.43, 5.61, 5.93 and 6.27 for the control, SB1, SB2 and SB3, respectively. The control sample had the highest score while SBI had the lowest score.
Overall acceptability was highest for the control (7.43). However, among the composite formulations, SB3 had the highest numerical value (6.80), followed by SB2 (6.68) and SB1 (6.09). There was no significantly ($p<0.05$) different between SB2 and SB3.

Table 5. Sensory characteristics and overall acceptability of the snack bars

Formulation	Appearance	Colour	Aroma	Taste/ Flavour	Texture/ Mouthfeel	Overall acceptability
Control	$7.25^{a} \pm 1.56$	$7.25^{a} \pm 1.28$	$6.91^{a} \pm 1.25$	$7.11^{a} \pm 1.28$	$7.43^{a} \pm 1.28$	$7.43^{a} \pm 1.13$
SB1	$6.36^{b} \pm 1.60$	$6.48^{b} \pm 1.36$	$6.30^{b} \pm 1.68$	$5.66^{c} \pm 2.07$	$5.61^{c} \pm 1.91$	$6.09^{c} \pm 1.65$
SB2	$6.55^{b} \pm 1.45$	$6.57^{b} \pm 1.28$	$6.68^{ab} \pm 1.72$	$6.14^{b} \pm 1.96$	$5.93^{bc} \pm 1.76$	$6.68^{b} \pm 1.34$
SB3	$6.70^{ab} \pm 1.44$	$6.32^{b} \pm 1.34$	$6.55^{ab} \pm 1.81$	$6.39^{ab} \pm 1.79$	$6.27^{b} \pm 1.76$	$6.80^{b} \pm 1.47$

Values are mean ± standard deviation of panelist scores. Means within a column with different superscript letters differ significantly at $p<0.05$. Sensory evaluation used a nine-point hedonic scale: 1 = dislike extremely, 5 = neither like nor dislike and 9 = like extremely.

4. Discussion

4.1 Nutritional Values of Cereal–Legume Blending

From the results shown in Table 2, it can be seen that addition of sorghum, fonio, soybean, and groundnut clearly changed the nutritional composition of the formulated snack bars when compared with snacks bar produce using refined wheat flour (control). Snacks from the composite formulations had more protein, fat, and crude fibre than the control, showing that the indigenous crops selected modified the nutritional profile of cereal-based snack products.
Crude protein was highest (9.86 g/100 g) in sample SB1, representing a 26.1% increase comparative to the control which showed protein content of 7.82 g/100 g. The higher protein content of SB1 is due to the formulation composition; containing the highest soybean inclusion level of 30%, Soybean is naturally rich in plant protein. The presence of groundnut apart from boosting the lipid content of the snacks also contributed high-quality storage proteins hence, elevating the protein density of the composite formulations. The present finding agrees with previous reports of Olayinka et al. (2022) which showed that incorporating legume flours into cereal-based foods can increase their protein content. Comparable observations were also made by Obasi et al. (2023) and Ogundele & Adoga (2024), who reported increase in protein content after fortifying cereal systems with legume flours. However, the present study measured total protein only; amino acid composition and protein digestibility were not determined, so, these results reflect quantitative protein increases and not overall biological value.
Fat content was also higher in the composite snack bars. The highest value (20.48 g/100 g) was found in sample SB1, followed by SB2 (18.43 g/100 g) and SB3 (18.08 g/100 g) while the control sample had the lowest value. This increase in the fat can be attributed to the addition of groundnut and soybean, both of which are known oilseeds rich in unsaturated fatty acids (Tamangwa et al., 2023). Samples with higher fat content were complemented by higher

calculated energy values. Using the Atwater factors, calculated energy values were 439.00, 424.59, and 423.88 kcal/100 g for SB1, SB2, and SB3, respectively, while the control sample had energy value of 407.21 kcal/100 g. This higher caloric density observed in the formulated snacks supports the findings on legume-enriched snack bars developed for nutrient-dense supplementation (Gbolagade et al., 2024). These findings indicate that selected indigenous crops increased the calculated energy density of snack bars. Energy values were calculated from the proximate composition and not from measured metabolizable energy.

Crude fibre also increased in the formulated snacks. The control contained only 0.38 g/100 g, whereas the composite formulations contained between 3.88 and 5.00 g/100 g, with SB3 showing the highest value. This increase could be related to the amount of cereal and legume in the formulation. Research has shown that this increase is consistent with the higher dietary fibre fractions provided by whole-grain sorghum and fonio proportional to refined wheat flour (Aryee et al., 2026; Janić Hajnal et al., 2024). Higher fibre content is nutritionally relevant because dietary fibre contributes to gastrointestinal function and is associated with several aspects of metabolic health (Norris et al., 2022). On the other hand, the present study did not measure physiological responses such as satiety, glycaemic response, or gastrointestinal effects.

Carbohydrate content decreased in the formulated snacks when compared with the value found in the control sample. The reason is because carbohydrates were calculated by difference, the proportional increases in moisture, protein, fat, fibre, and ash naturally reduced the calculated carbohydrate fraction.

4.2 Mineral Composition

Results from this study showed that incorporation of the indigenous crops in the snack bars formulation gave rise to higher concentrations of essential minerals. Calcium increased from 31.18 mg/100 g in the control to 67.17–77.10 mg/100 g in the composite formulations, with SB1 having the highest concentration. Likewise, Magnesium increased from 11.64 mg/100 g in the control to 109.43–125.00 mg/100 g in the composite snacks. Potassium was also high in the composite formulations with SB1 having the highest value of 243.70 mg/100 g. These results indicate that the cereal–legume combinations significantly improved the mineral content of the formulated snacks. The results are in line with the mineral profiles reported for indigenous West African cereals such as fonio and sorghum (Bassey et al., 2023; Sulaiman et al., 2020).

Iron concentration increased from 0.87 mg/100 g in the control to 8.23–9.82 mg/100 g in the composite formulations with SB2 recording the highest value. Zinc similarly increased from 0.35 mg/100 g in the control to 3.50–4.13 mg/100 g in the composite formulations. The increases are nutritionally important because adolescents experience increased nutrient demands during periods of rapid growth (Abubakar et al., 2024; Gabriel et al., 2024). The findings therefore suggest that incorporating sorghum, fonio, soybean, and groundnut can increase the absolute mineral content of snack bars compared with refined wheat alone. However, these values represent absolute mineral content rather than fractional bioavailability.

4.3 Anti-nutrient composition

Table 4 shows low level of anti-nutrients in the formulated snacks. The finished snack bars contained relatively low concentrations of the anti-nutritional factors evaluated. Oxalate ranged from 0.12 to 0.23%, while phytate ranged from 0.12 to 0.13%. Oxalate and phytate wa not detected in the control sample. Raw cereals and legumes naturally contain phytates and oxalates that can chelate divalent cations including interaction with mineral elements, thereby possibly

affecting their bioavailability (Castro-Alba et al., 2019). However, the relatively low values observed in the finished products may partly reflect the effects of processing operations used in the preparation of the ingredients included soaking, dehulling, roasting and baking, and other treatments may influence the concentration of some anti-nutritional factors (Obayomi et al., 2024). Since the present study did not determine anti-nutrient levels in the raw ingredients before processing, it is not possible to quantify the contribution of each processing step to the final values. Thus, the results provide an indication of the residual phytate and oxalate present in the finished snack bars rather than a direct measure of processing-related reductions. Future studies could strengthen these findings by analysing the raw materials at different stages of processing and by determining the in-vitro bioavailability of the minerals.

4.4 Sensory Characteristics and Acceptability

The sensory results showed that the flour composition had a clear influence on how the snack bars were perceived by the panelists. The refined wheat control received the highest overall acceptability score (7.43). However, among the composite snack products, SB3 had the highest overall acceptability score (6.80), followed by SB2 (6.68), while SB1 had the lowest score (6.09). The scores for SB2 and SB3 were comparable statistically ($p > 0.05$), this means that the numerical difference perceived between these two formulations was not significant

As against the proximate analysis result where SB1 recorded the highest protein density (9.86 g/100 g), SB1 received the lowest sensory scores among the composite treatments. This inverse relationship between high soybean substitution and sensory acceptance is well-documented by some researchers; higher inclusion levels of soy in a product often introduce off-flavours, grassy notes, or undesirable textural changes caused by lipoxygenase activity as reported by Guo et al., (2021); Haș et al., (2023).

Among the composite formulated snack products, SB3 had the highest numerical acceptability and also recorded the highest crude fibre concentration. This equilibrium between sensory palatability and nutritional improvement makes it the major candidate for further product development, storage stability evaluation, and textural boost (Dietrich et al., 2025).

5.0 Conclusion

The study established the possibility of producing snack bars from composite flours of sorghum, fonio, soybean and groundnut. Results showed that snacks from the composite formulations exhibited higher crude protein, crude fat, crude fibre and measured minerals when compared with snack produced from 100% wheat used as control, although the level of improvement varied among formulations. Formulate snack from the composite flour showed that SB1sample recorded the highest crude protein, crude fat, calcium, magnesium, potassium and zinc content, whereas SB2 recorded the highest iron content. SB3 had the highest crude fibre content and the highest numerical overall acceptability among the composite formulated snacks, although SB3 was not significantly different from SB2 sample in overall acceptability.

Additionally, the formulated snacks contained low concentrations of oxalate and phytate. Findings from this study indicate that sorghum, fonio, soybean and groundnut can be incorporated into cereal-based snack bars to modify their nutritional composition while sustaining reasonable sensory acceptance. Based on the combination of its nutritional characteristics and sensory performance SB3 may be considered a likely formulation for further product development. However, further study is needed on mineral bioavailability, protein

quality, fatty-acid composition, microbiological safety and storage stability before making recommendations on commercial applications.

6. Recommendations

1. Among the composite formulations, SB3 recorded the highest numerical overall acceptability it should be considered for further formulation and optimization.
2. Further studies should investigate storage stability, microbial quality, lipid oxidation and changes in sensory quality during storage.
3. Future research on nutritional characterization of this snack should include amino-acid composition, protein digestibility and fatty-acid profile.
4. Possible use of these snack bars in school-feeding or adolescent nutrition programmes should be investigated after looking at the nutrient contribution, food safety, cost and acceptability.
5. Local food-processing enterprises should explore the commercial potential of the snacks using standardized formulations, appropriate packaging and established shelf-life records.

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