Nutritional, Functional, Microbiological and Sensory Quality of Wheat Crackers Fortified with Sprouted Pearl Millet and Soybean Flour

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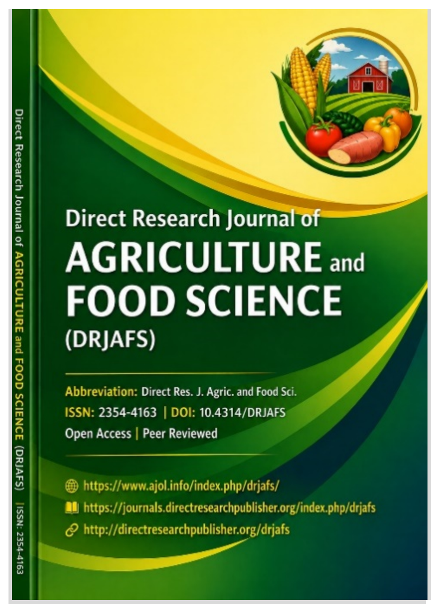
ABSTRACT

Wheat-based crackers generally have low nutritional quality due to limited protein, dietary fibre, and mineral contents from refined-grade wheat flour. There has been wide-ranging research on cereal-based composite flours, but few studies have focused on the effect of replacing refined wheat flour with sprouted pearl millet- and soybean-milled flour on the quality of wheat-based crackers. The effect of sprouted pearl millet and soybean flour supplementation on the nutritional and sensory quality of wheat crackers was studied using five formulations by substituting the wheat flour with different levels of sprouted flour of pearl millet and soybean flour. The formulations were designated as F1, F2, F3, F4 and F5. Proximate composition, functional properties, mineral composition, physical properties, microbial quality, and organoleptic evaluation (hedonic scale of five points) by 100 untrained panellists of the crackers were determined and the data analysed for one-way analysis of variance (ANOVA) and Tukey's HSD test with $p < 0.05$. Increasing the substitution improved protein (10.42-15.36%), fibre (1.46-3.82%), ash (1.42-2.91%), calcium (38.42-71.36 mg/100 g) and iron (2.84-5.76 mg/100 g). The effect of formulation on quality characteristics was important ($p < 0.001$). Sensory analysis showed that increased levels of substitution in fortified formulations negatively affected overall acceptability, with the fortified formulation of F3 (70% wheat flour, 20% sprouted pearl millet flour and 10% soybean flour) scoring the highest acceptability at 4.16 out of 5. Moderate supplementation of sprouted pearl millet and soybean flour improved nutritional quality with acceptable sensory acceptability.

Keywords: *Composite flour formulation; Cereal-legume blend; Protein enrichment; Dietary fibre; Mineral composition; Proximate composition; Antinutritional factors; Food acceptability; Product development; Bakery products*



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INTRODUCTION

Crackers are usually convenience foods with a long shelf life and a low cost suitable for modern convenience-eating habits. On the other hand, conventional crackers are largely made with refined wheat flour, a low source of dietary fibre, minerals, and other nutrients compared to whole-grain and composite flour crackers. This has led to the development of wheat-based snacks that are fortified with biofortified underutilised cereals, legumes, and other plant-based ingredients that maintain desirable technological and sensory characteristics (Zupo *et al*., 2026; Ramashia *et al*., 2026). The use of composite flour technology has attracted great attention as a way to improve the nutritional quality of wheat based products, partially substituting wheat flour with locally grown nutrient rich crops. Cereal-legume composite flour is of particular interest because legumes provide high quality proteins and complementary amino acids and cereals provide carbohydrates, dietary fibre, minerals and desirable processing properties. However, high substitution ratios of alternative flours can also affect the functional properties, structure, color, texture, flavour, and acceptability of dough. It is, therefore, necessary to find the optimal substitution ratio that does not compromise product quality while maximising nutritional advantages (Neji *et al*., 2023; Ramashia *et al*., 2026).

Pearl millet (Pennisetum glaucum) is an underutilised climate-smart food cereal crop with high scope for additional product development, owing to the crop's distinctive nutrient profile and capacity for growth in harsh agroecological conditions. The grains are considered a good source of dietary fibre, minerals and health functional components that can be used to improve cereal-based food products. In addition to nutritional value, adoption of pearl millet can further contribute to food system diversity through the use of locally adapted food crops. Despite these benefits, however, there have been limited attempts to use pearl millet in bakery products. Barriers to use of pearl millet in baked goods include the coarse particle properties of pearl millet flour, its flavour, and its antinutritional properties (various phytochemicals), which can impact processing and consumer acceptance (Al-Khaleel *et al*., 2025; Cheung *et al*., 2025).

Sprouting is another method of processing cereal grains to improve their functionality as human food. Enzymatic activity during germination may bring about changes in the biochemical characteristics of the proteins, starch, mineral bioavailability, and functional characteristics of the grain-based food ingredient. Based on previous studies, it was apparent that sprouted millet ingredients improve the nutritional and technological characteristics of formulated food products, allowing for the possibility of their use in composite flour systems (Majzoobi *et al*., 2023; Bachate *et al*., 2025; Chauhan & Gupta, 2025). To further increase protein content of cereal-based products, soybean flour has been extensively studied. It has a high protein content and balanced amino acid composition. Soybean flour appears to increase the protein density and the nutritional quality of the wheat-based food product but too much soybeans changes the product in a way that the dough structure, sensory and organoleptic characteristics, the texture, the taste, the functionality, and the acceptability are negatively affected. Therefore, an optimal level of soybean inclusion is meaningful to maximise nutrition, while ensuring that the desired product quality is achieved (Neji *et al*., 2023; Long *et al*., 2025).

Recent studies on cereal-legume composite crackers have contributed to protein, fibre, mineral, and overall quality enhancement. Crackers that include cereal, legume, and other nutrient-rich plant ingredients can have their nutritional quality improved in an acceptable sensory profile through proper control of formulation and product process parameters (Akoijam *et al*., 2026; Jabbar *et al*., 2026). Although reports of supplementation of single ingredients or other cereal-legume combinations are available, to the best of our knowledge, this is the first report on the combined supplements of sprouted pearl millet and soybean flour in the wheat cracker matrix. The correlation between the substitution levels of sprouted pearl millet and soybean flour and nutritional profile, functional behaviour, physical properties, microbial quality and consumer acceptability of the composite flour products is unexplored. More wide-ranging study of these parameters is needed as the fortification of composite flour with superior nutritional components may be at the cost of structural properties, processing and consumer acceptability. For this reason, the present study evaluated the effect of gradual incorporation of sprouted pearl millet and soy composite flour on the characteristics of crackers. While most studies have only considered the addition of flour derived from cereal and legume sources, the present study broadly analyses the nutritional, functional, mineral, physical, microbiological quality, and sensory evaluation of crackers prepared from sprouted pearl millet-soy composite flour. The study aimed to: 1. Determine the effect of increasing levels of sprouted pearl millet and soybean flour substitution on the proximate composition of wheat crackers. 2. Evaluate the functional properties of wheat-sprouted pearl millet-soybean composite flour blends. 3. Assess the effect of the substitution on the mineral composition on cracker properties. 3. Determine the microbiological quality characteristics of the developed crackers. 4. Evaluate the sensory acceptability of developed cracker formulations with consumer panellists.

MATERIALS AND METHODS

Research Design

The effect of replacing wheat flour with blends of sprouted pearl millet and soybean flour on the physicochemical properties of crackers was conducted in a controlled-laboratory based on a completely randomised design. Composite flour formulations were prepared by partially replacing wheat flour with sprouted pearl millet flour and soybean flour at different levels. Five formulations (F1-F5) were prepared, where F1 with 100% wheat flour was considered control, while F2, F3, F4, and F5 represented samples with increasing levels of composite flour. Experimental design formulation parameters were used to analyse the nutritional, functional, mineral, physical, microbiological, and sensory quality attributes of the resultant crackers based on variations of the formulation. Similar experimental design evaluations have been conducted on other cereal-legume crackers to investigate the effect of composite flour addition on the product's quality attributes (Akoijam *et al*., 2026; Jabbar *et al*., 2026). All formulations were made three times to account for variability between batches. Standard methods were used for analysis and results were recorded as mean values with associated variability estimates. Standardised analytical methods have been applied to improve reproducibility and comparisons with other food composition studies (AOAC, 2023).

Raw materials and reagents

Food grade pearl millet grains, soybean seeds, wheat flour, and other ingredients for the cracker preparation were procured from food grade Suppliers. Raw materials were visually inspected, and manually picked to remove foreign materials, damaged grains, and stones before processing. The crackers were formulated with the following ingredients: wheat flour, sprouted pearl millet flour, soybean flour, vegetable shortening, sugar, salt, baking powder, vanilla essence, and potable water. Cereal-legume constituents were selected based on their complementary nutritional profiles and their known ability to improve the characteristics of wheat products (Neji *et al*., 2023; Ramashia *et al*., 2026). Analytical-grade reagents used in the chemical analyses, such as solvents and assay reagents, were obtained from certified laboratory suppliers and were prepared using standard laboratory procedures.

Preparation of Sprouted Pearl Millet Flour

Pearl millet grains were cleaned and washed with tap water to remove the adhered impurities from the grains. After that, the grains were soaked in tap water at the grain: water ratio 1:3 (w/v) for 12 h at room temperature. The grains were drained, placed in moist trays and germinated for 48 h at 28 ± 2 °C. Throughout germination, the grains were periodically soaked and washed in fresh water to ensure moisture content and prevent microbial contamination. The germination was terminated by drying the sprouted grains to below 10% moisture content in a hot-air tray dryer at 50 ± 2 °C. The dry sprouts were milled, passed through a 500 µm screen to obtain sprouted pearl millet flour, packed in moisture barrier polyethylene bags, and stored at 4°C until use. Controlled germination and drying conditions were selected based on previous studies that demonstrated the effect of sprouting on the nutritional profile and functional characteristics of cereal grains (Majzoobi *et al*., 2023; Bachate *et al*., 2025).

Preparation of soybean flour

Soybean seeds were sorted, washed and subjected to blanching for 10 min in boiling water to inactivate unwanted flavouring compounds and partially inactivate antinutritional enzymes. These were then cooled, manually dehulled and dried at 55 ± 2 °C to a moisture content of less than 10%. The beans were dried, ground, and passed through a 500 µm sieve. Prepared soybean flour was packed in airtight polyethylene polybags and stored at 4 °C for use in preparation of composite flour when required. The addition of soybean was chosen because cereal-legume blends are known to improve the protein quality and food value of baked goods, while excessive proportions of soybean might lead to adverse effects on the sensorial and textural qualities (Neji *et al*., 2023; Long *et al*., 2025).

Composite Flour Formulation

Five composite flour formulations were prepared from wheat flour, sprouted pearl millet flour, and soybean flour, with the proportion of sprouted pearl millet flour and soybean flour rising and wheat flour falling in each successive formulation. Each formulation consisted of a 500 g composite flour blend for cracker preparation. The composition of the formula with progressive substitution of composite flour allows for the assessment of nutritional, technological, and sensory parameters for a gradual increase in the mix, consistent with the methodologies used in recent studies on the optimization of cereal-legume formulated products (Akoijam *et al*., 2026; Jabbar *et al*., 2026). Table 1 presents the ingredient formulation for the wheat-sprouted pearl millet- soybean composite crackers.

Table 1: Ingredient formulation wheat-sprouted pearl millet-soybean composite crackers.

Ingredient	F1	F2	F3	F4	F5
Wheat flour (g)	500	400	350	300	250
Sprouted pearl millet flour ((g)	0	75	100	125	150
Soybeanflour (g)	0	25	50	75	100
Cook-brand margarine (g)	200	200	200	200	200
Sugar (g)	100	100	100	100	100
Salt (g)	2	2	2	2	2
Vanilla Essence (mL)	10	10	10	10	10
Water(mL)	35	35	35	35	35

*Values are per 500 g of blended composite flour used in the dough. **F1** (Wheat flour 100%, Control), **F2** (Wheat flour 80%, Millet flour 15% and Soybean flour 5%), **F3** (Wheat flour 70%, Millet flour 20% and Soybean flour 10%), **F4** (Wheat flour 60%, Millet flour 25% and Soybean flour 15%) and **F5** (Wheat flour 50%, Millet flour 30% and Soybean flour 20%)

Production of Composite Crackers

Composite crackers were prepared by modifying the procedures for manufacturing instant cereal-legume composite flour products (Akoijam *et al*., 2026; Jabbar *et al*., 2026). In the preparation of composite crackers, sprouted pearl millet flour and soybean flour were added to wheat flour in varying ratios, and nutritional and functional properties, physical dimensions, microbiological characteristics, and sensory attributes were analysed. All the ingredients were weighed according to the formulations in Table 1. Margarine and sugar were creamed for 3 min in a laboratory mixer to obtain a uniform mix. Salt was added, followed gradually with the composite flour blend, and lastly, 35mL water was added until the dough formed and a proper consistency was achieved. The dough was rested at 25 ± 2 °C for 10 min to allow moisture equilibration and to improve processability. The dough was sheeted to a thickness of 2.5 mm, and discs having a diameter of 45 mm were cut from the sheeted dough. The discs were uniformly docked to control excessive dough expansion during the baking process. The crackers were baked in a preheated forced-air oven at 160 ± 3 °C for 12-15 min. After baking, the crackers were cooled at room temperature for 30 min, and then placed into laminated, moisture-barrier pouches. Each formulation was made in three independent production batches to assess the processing variability. Physical and sensory analysis samples were analysed within 48 h of manufacture whereas chemical analysis samples were ground, packed in airtight containers and stored at −20 °C until analysis. The controlled processing conditions used in this study are similar to other recent cereal-legume cracker studies, where formulation levels, dough mixing and resting, baking conditions, and post-baking handling can greatly affect product quality attributes (Akoijam *et al*., 2026; Jabbar *et al*., 2026).

Proximate Composition Analysis of wheat-sprouted pearl millet-soybean crackers

The proximate composition of the formulated wheat-sprouted pearl millet-soybean crackers was determined as per the standard analytical methods of AOAC (2023) and included determination of moisture content, crude protein, crude fat, ash, total dietary fibre, carbohydrates and estimated energy value. The data were analysed by triplicate assays, and presented with statistical values as mean ± standard deviation.

Moisture Content

Moisture content was determined by the gravimetric oven-drying method as described by AOAC (2023). Approximately 5 g of the homogenised cracker sample was placed in pre-dried moisture dishes and dried in a hot-air oven at 105 °C until a constant weight was obtained. Moisture content was calculated asthe loss of weight during drying.

Formula: $\text{Moisture (\%)} = \dfrac{\text{(initial sample weight - final sample weight)}}{\text{Initial sample weight}} \times 100$

Ash Content

The ash content was determined according to the AOAC (2023) dry ashing method. Pre-weighed crucibles were filled with approximately 2 g of ground cracker samples and heated in a muffle furnace at 550 ± 5 °C until the weight of the ash was constant to determine the respective ash content.

Formula: $\text{Ash (\%)} = \dfrac{\text{Weight of ash} \times 100}{\text{Weight of original sample)}}$

Crude Protein Content

The crude protein content was determined with the Kjeldahl nitrogen determination method as described by AOAC (2023) , requiring digestion, distillation, and titration of nitrogen, and this number was multiplied by the factor of 6.25 to obtain the crude protein content.

Formula: Protein (%) = Nitrogen (%) × 6.25

Crude Fat Content

Crude fat was determined by AOAC (2023) gravimetric solvent extraction: the lipid extract was collected and weighed after removal of the petroleum ether, with the fat mass recorded.

Formula: $\text{Fat (\%)} = \dfrac{\text{Weight of extracted fat}}{\text{Weight of sample)}} \times 100$

Total Dietary Fibre

Total dietary fibrewas measured by an enzymatic gravimetric method (AOAC, 2023) where the digestible components were removed enzymatically and the fibre portion reconstituted as a and weighing ,drying ,ter filtrationresidue af.

Formula: $\text{Dietary Fibre (\%)} = \dfrac{\text{Weight of dried fibre residue}}{\text{Weight of sample}} \times 100$

Carbohydrate

Available carbohydrate content was calculated from moisture, protein, fat, ash and dietary fibre content by difference.

Formula: Carbohydrate (%) = 100 − (Moisture + Protein + Fat + Ash + Dietary Fibre)
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Energy Value Calculation

Energy of the cracker samples was estimated using Atwater conversion factors.

Formula: Energy (kcal/100 g) = (4 × Protein) + (4 × Carbohydrate) + (9 × Fat)

To ensure the accuracy, reproducibility, and comparability to other cereal legume food formulations, all analyses to determine nutritional composition were performed following AOAC (2023) procedures.

Functional Properties of Composite Flour Blends

The functional properties of wheat-sprouted pearl millet-soybean composite flour blends and suitability for crackers' production were evaluated by ascertaining the bulk density, water absorption capacity, oil absorption capacity, swelling power and water solubility index. These properties also gave information on the hydration behaviours of the flour, processing abilities, and their possible impact on the quality of the final products (Neji *et al*., 2023; Ramashia *et al*., 2026). All measurements were taken three times and expressed as a mean ± standard deviation.

Bulk Density

Bulk density was calculated by packing a known weight of flour into a graduated cylinder and gently tapping it until its volume became constant.

Formula: $\text{Bulk Density (g/mL)} = \dfrac{\text{Weight of flour sample (g)}}{\text{Final flour volume (mL)}}$

Bulk density indicates a flour's particle arrangement, packing ability and suitability for later processing.

Water Absorption Capacity (WAC)

One gram of the flour sample was mixed with 10 mL of distilled water using a vortex mixer and allowed to stand for 30 min. Centrifugation was done at approximately 3000 × g for 15 min. The remaining water was then measured.

Formula: $\text{WAC (g/g)} = \dfrac{\text{Weight of hydrated flour sediment (g)}}{\text{Weight of flour sample (g)}}$

Water absorption capacity refers to the ability of individual flour components (proteins, starch, fibre) to absorb water during preparation.

Oil Absorption Capacity (OAC)

Oil absorption capacity was determined by mixing 1 g of the flour sample with 10 mL of refined vegetable oil, allowing it to stand for 30 min, centrifuging at 3000 × g for 15 min, and measuring the remaining oil.

Formula: $\text{OAC (g/g)} = \dfrac{\text{Weight of oil retained by flour (g)}}{\text{Weight of flour sample (g)}}$

One property that might have a role in flavour retention and texture formation is flour components' capacity for lipid binding.

Swelling Power

Suspensions of flour were heated to a temperature of 90 °C for 30 minutes, cooled and centrifuged, and then the sediment weighed.

Formula: $\text{Swelling Power (g/g)} = \dfrac{\text{Weight of hydrated sediment (g)}}{\text{Weight of flour sample (g)}}$

Swelling power is the hydrated and swollen state of starch.

Water Solubility Index (WSI)

The soluble extract from heating and centrifugation was dried and weighed to determine the amount of dissolved solids.

Formula: $\text{WSI (\%)} = \dfrac{\text{Weight of dried soluble solids (g)}}{\text{Weight of flour sample (g)}} \times 100$

Soluble species released during hydration are covered in the WSI section. These properties are associated with the capability of flour proteins and other components to stabilise oil-water emulsions.

Mineral Composition Analysis

The mineral levels of the formulated baked crackers were determined with the view to studying the contribution of sprouted pearl millet and soybean flour to the mineral levels of the formulated crackers. The baked cracker samples were dried, ground to a fine powder, acid-digested and analysed to determine their mineral content. About 0.50 g of powdered cracker sample was weighed into the digestion vessels and digested with concentrated nitric acid (HNO_3) in accordance with the AOAC (2023) suggested method, and digestion was continued with heating until a clear solution was obtained. The samples were then cooled, filtered, and the resulting solutions diluted to known volumes with deionised water for instrumentation. Calcium (Ca), iron (Fe), zinc (Zn), magnesium (Mg), and phosphorus (P) concentrations were determined by atomic absorption spectrophotometry (AAS). Mineral concentrations were determined by direct calibration using corresponding certified standard solutions for each element analysed (Table 2).

Table 2: The analytical wavelengths used for mineral

Mineral	Analyticalwavelength (nm)
Calcium (Ca)	422.7
Iron(Fe)	248.3
Zinc(Zn)	213.9
Magnesium(Mg)	285.2
Phosphorus(P)	Confirm analytical wavelength/method

A series of calibration standards was prepared from the certified stock solutions at appropriate concentration ranges for each mineral. The prepared standards were used to establish calibration curves, which were subsequently applied to determine the mineral concentrations in the samples, as presented in (Table 3).

Linearity of the calibration curves was assessed prior to sample analysis. Quality control procedures (reagent blanks, calibration verification standards, and duplicate samples) were used to monitor analytical accuracy and precision. Mineral analyses were performed in triplicate, and concentrations were calculated based on calibration curves and expressed as mg/100 g cracker sample on a dry weight basis. Mineral composition was selected as a nutritional response variable because cereal-legume composite formulations containing nutrient dense cereals and legumes have been found to improve mineral density of processed foods while maintaining desirable sensory quality (Jabbar *et al*., 2026; Akoijam *et al*., 2026).

Table 3: Calibration standards within appropriate concentration ranges for each mineral.

Mineral	Calibration range
Calcium (Ca)	0-10 mg/L
Iron (Fe)	0-5 mg/L
Zinc (Zn)	0-2 mg/L
Magnesium(Mg)	0-5 mg/L
Phosphorus(P)	0-10 mg/L

Physical Characteristics of Crackers

Physical characteristics of the formulated crackers were studied to evaluate the effect of the inclusion of sprouted pearl millet and soybean flour on the product quality characteristics. The weight, diameter, thickness, spread ratio, surface colour, texture characteristics and baking loss of the crackers were determined. All measurements were performed in triplicate and results were expressed as mean values ± standard deviation. Weights of individual crackers were determined using a calibrated digital weighing balance. The diameter and thickness of the crackers were measured using a calibrated digital Vernier calliper. The diameter and thickness values at different portions of each cracker were averaged, and the spread ratio (diameter/thickness of the cracker) was taken as a measure of dough expansion. The degree of structure formation compared to dough spread was estimated using a spread ratio (i.e. a higher spread ratio indicates lateral spread of the dough upon baking, while a lower spread ratio could imply a higher resistance to the dough spread due to differences in flour composition and water binding capacity) (Jabbar *et al*., 2026).

The colour of the crackers was measured with a colorimeter based upon the CIE Lab colour space, which includes measurements of lightness (L), redness/greenness (a), and yellowness/blueness (b). The instrument was calibrated according to manufacturer's instructions, and the color determinations were repeated three times for each formulation. The average scores of each formulation were subjected to statistical analysis. The CIE Lab* system provided an objective method for analysing the appearance variations introduced by the addition of cereal and legume flours in the baked products (Akoijam *et al*., 2026). The hardness, breaking strength, and the crispness of the crackers were measured using a texture analyser. The samples were compressed uniformly in a controlled manner until the structure of the crackers broke, and the maximum compressive force that causes the structural failure was taken as the index of the structural strength. Texture determination is required since adding sprouted pearl millet and soybean flour may alter the behaviour of starch, the behaviour of proteins, the fibre content, and thus the mechanical properties of the baked goods. Baking loss was calculated as the difference between the weight of the dough before baking and the weight of the baked cracker, divided by the weight of the dough before baking, multiplied by 100.

The formula to calculate the Baking Loss is:

$$\text{Baking Loss (\%)}\} = \frac{\text{Weight of unbaked dough-Weight of baked cracker}}{\text{Weight of unbaked dough} \ \text{x} \ 100}$$

The composition of composite crackers affects their physical properties. The rheological properties of the dough, moisture absorption, structure of the dough, sensory properties and consumer acceptability are affected by the nature of the flour used. While alternative cereal and legume flours can improve the nutrition of composite crackers, they may also affect the gluten dilution, hydration behaviour and matrix structure, and therefore require the optimization of the formulation (Akoijam *et al*., 2026; Jabbar *et al*., 2026).

Microbiological Analysis of Crackers

Microbiological analyses of the formulated wheat-sprouted pearl millet-soybean crackers were used to assess the microbial status of the product developed. These microbiological analyses were performed according to standard food microbiology test procedures as established by internationally recognised microbiology guidelines such as ISO Standard No. 4833-1:2013). All microbiological analyses were done under aseptic conditions. In brief, 10 g of each cracker sample was aseptically weighed and homogenised with 90 mL of sterile peptone water, thus obtaining a 10^{-1} dilution of the sample. Serial ten-fold dilutions were prepared in sterile peptone water and appropriate dilutions were used for enumerations of the microorganisms in triplicate for each of the samples. The total viable count (TVC) of the bacteria was estimated by the plate count method using Plate Count Agar. The samples were diluted in suitable proportions and inoculated on media and incubated aerobically. After the incubation period, the number of colonies per sample was then counted and expressed as $\log_{10}$ CFU/g (colony-forming units per gram). Yeast and mould counts were carried out on Potato Dextrose Agar (PDA) by inoculating prepared dilutions onto Potato Dextrose Agar plates and incubating under conditions for fungal growth. These colonies were counted and reported as $\log_{10}$ CFU/g. Coliform counts, an indicator of hygienic quality, were measured using the Violet Red Bile Agar method. Dilutions were performed and aliquots were spread onto Violet Red Bile Agar plates. Plates were incubated under suitable conditions, and the number of characteristic colonies was counted and expressed as $\log_{10}$ CFU/g. Colony levels from dilutions were converted to CFU per gram of sample, with the limit of detection being the dilution at which colonies could be counted given the methodology used in the experiment. Quality control included aseptic handling, the use of sterile media controls, and good laboratory practices during the analysis. Data are expressed as mean ± standard deviation for triplicate tests.

Sensory Evaluation of Crackers

The consumer acceptability of the developed crackers was evaluated according to a five-point hedonic scale, as is the standard sensory evaluation of other cereal-based bakery products (Akoijam *et al*., 2026; Jabbar *et al*., 2026). For this purpose, 100 untrained consumer panellists were selected from the Department of Hospitality Management, Bolgatanga Technical University, Ghana. The panellists were chosen for their propensity to regularly consume baked snack products such as crackers. They were informed of the purpose and procedures of the experiment and provided written informed consent. Individuals were excluded from becoming panellists if they had known allergies or intolerances to any of the ingredients of the formulation, such as soybean and sesame. To lower the risk of bias from sample identification and arrangement, each cracker formulation was assigned a random three-digit code and the samples were presented in random order. The samples were equal in size, served at room temperature, and drinking water was offered between each sample to cleanse the palate before sampling the next sample. Sensory evaluation took place in a room with optimal light and minimal external interference. The sensory parameters evaluated were appearance, color, aroma, taste, texture/crispness, mouth feel, and overall acceptability. The panellists used a five-point hedonic scale to rate each sensory parameter where 1 = dislike very much, 2 = dislike, 3 = neither like nor dislike, 4 = like, 5 = like very much. Since all of the sensory data was collected from the same consumer panellists for all cracker formulations, the data represented repeated measures rather than independent observations. Therefore, to determine important differences between cracker formulations, a linear mixed-effects model was used, where the cracker formulation was considered a fixed effect, and the panellist identity was considered a random effect. Statistical importance was set at $p < 0.05$, and formulations were compared using estimated marginal means.

Data Analysis Technique

The physicochemical, functional, minerals, physical, microbiological, and sensory properties of the wheat-sprouted pearl millet-soybean composite crackers were statistically analysed. All experimental analyses were performed in triplicate and the results are expressed as mean ± standard deviation (SD). The differences in physicochemical, functional, mineral, physical and microbiological properties among crackers' formulations F1, F2, F3, F4 and F5 were compared using one-way analysis of variance (ANOVA) after checking the requirements of normality and equality of variances. The normality of the residuals was analysed by the Shapiro-Wilk test and the homogeneity of the variance by Levene's test. Should normality and homoscedasticity assumptions be met, important differences between formulation means were calculated using Tukey's HSD post hoc test at the 95% confidence level, with $p < 0.05$ considered statistically important. Since all of the formulations were tasted by all of the consumer panellists, sensory data were treated as repeated measurements and analysed by a linear mixed-effects model with formulation specified as a fixed effect and panellist identity as a random effect to allow for panellist-to-panellist variation. Differences between the formulations were assessed using estimated marginal means with $p < 0.05$. Where substantial differences were found, effect sizes were reported in order to assess the magnitude of formulation effects and, where possible, confidence intervals were calculated to support the interpretation of the practical importance of differences observed. Statistical analyses were performed using the IBM SPSS Statistics (version 26.0, IBM Corp., Armonk, NY, USA) software package, and results were presented as means, standard deviations, importance levels, and estimates.

RESULTS AND DISCUSSION

Demographic characteristics of sensory evaluation panellists

Socio-demographic data of 100 untrained panellists who sensory evaluated the crackers made from the optimised formulation of wheat, sprouted pearl millet and soybean flour are shown in (Table 4). Age, sex, education and previous experience with the product are very important in sensory assessment of food products to understand perception, acceptance and purchase intent of the functional food. Consumer awareness of health benefits and nutritional properties has been reported to shape

Table 4: Demographic Characteristics of Sensory Evaluation Panelists (n = 100)

Demographic variable	Category	Frequency (n)	Percentage (%)
Sex	Male	46	46.0
	Female	54	54.0
Age (years)	18–25	38	38.0
	26–35	32	32.0
	36–45	20	20.0
	Above 45	10	10.0
Educational level	Basic education	12	12.0
	Secondary education	28	28.0
	Tertiary education	60	60.0
Frequency of cracker consumption	Daily	18	18.0
	Weekly	42	42.0
	Occasionally	32	32.0
	Rarely	8	8.0
Total		100	100.0

Source: Field study, 2026

attitudes toward innovative food products (Ponte *et al*., 2025). The gender of the panel members was 46% male and 54% female. While the gender composition was not balanced as such, balancing the gender of the panel members provided for an adequate reflection of the overall consumer preference and minimised any potential gender-related biases in the sensory responses of the panel members. Gender is also relevant because it may affect food choice, health issues, and the purchase of functional products (Zuruk *et al*., 2026). Panellists were 18 to 25 years old (38%) or 26 to 35 years old (32%). Younger consumers may have been more likely to accept the crackers, due to preconceived familiarity with novel foods, acceptance of alternative grains, and the use of health benefits as a basis for food choice. On the other hand, older adults were only 10% of our sample so our findings might not generalise to older adults because the taste, texture and familiarity with traditional foods might be different. Respondents who completed tertiary education made up 60% of respondents, 28% secondary education and 12% basic education. It could be due to the relatively higher education level of respondents that the nutritional advantages of sprouted pearl millet and soybean flour were acknowledged. However, sensory acceptance may differ between consumers with high and low nutritional knowledge. Cracker use is weekly (42%), sometimes (32%), daily (18%) or rarely (8%). Past exposure and experience of eating similar products is likely to account for some of the sensory judgement differences due to prior expectations around taste, mouth feel and acceptability. Although the panel was reasonably diverse overall, future studies could benefit from including a wider range of demographic groups to improve the applicability to future market adoption and potential commercialisation.

Proximate composition of wheat-sprouted pearl millet-soybean functional crackers

As shown in (Table 5), the proximate composition of functional crackers is considerably ($p < .05$) affected by the gradual replacement of wheat flour with sprouted pearl millet flour and soybean flour. Increasing the levels of F1 to F5 led to higher levels of protein, fat, fibre, ash, and moisture, but lower carbohydrate and energy.

This indicates the nutritional potential of incorporating nutrient-dense cereal-legume ingredients into a wheat-based snack food product. Likewise, Amponsah *et al*. (2026) documented similar improvements in the nutritional profile of composite foods developed from cereals and legumes, illustrating the potential for combining complementary plant-based ingredients to improve the nutritional profile of existing products. The protein content of the bread increased considerably from 10.42% in F1 (100% wheat flour) to 15.36% in F5 (50% wheat, 30% sprouted pearl millet and 20% soybean flour). This increase was largely due to plant protein concentration of soybean flour and pearl millet flour. These results are in agreement with the finding of Amponsah *et al*. (2026) which showed that the protein content of the cereal-legume blends increased with the incorporation of soybean which is more protein-dense than other cereals. In conclusion, the addition of soybean was an effective way to improve the protein quality of wheat-based snack foods. The fibre content of the dough increased from 1.46% to 3.82% with increasing substitution. The presence of a higher level of fibre in sprouted pearl millet flour, and the loss of fibre when wheat flour is refined, account for this increase. Dietary fibre, resistant starch and bioactive compounds are some of the components in pearl millet that contribute to its improved functional properties (Kokisi *et al*., 2026). As observed in previous studies, the millet-based formulations increased dietary fibre levels considerably, but the higher concentration may have affected dough properties and textural qualities of the resulting crackers.

The ash content (minerals) of F1 was 1.42% and increased to 2.91% for F5. Pearl millet and soybean increased minerals, the former has more bran layers and retained more bran than refined wheat flour. In addition, soybean is a source of minerals that are typically associated with legume seeds. Millet-supplemented composite foods have also shown similar increases in ash content (Amponsah *et al*., 2026), with which this observation is consistent. The impact of soybean addition on lipid content is another improvement, from 8.64% (control) to 10.86%, because legumes have intrinsically higher lipid content than wheat flour. Higher lipid levels may agree to the deterioration of storage stability of the crackers through lipid oxidation. Nevertheless, soybean oil containing high amounts of unsaturated fatty acids, could improve the nutritional value. This observation agrees with Chiacchio *et al*. (2026), who observed higher lipid content in the legume-enriched crackers. However, the carbohydrates decreased from 73.21% to 61.63%. This is due to the replacement of wheat flour with other ingredients that provide protein, fibre, and minerals rather than the loss of carbohydrates during processing. Similarly, Jabbar *et al*. (2026) found a decrease in the carbohydrate contents of the products when they replaced refined wheat flour with multigrain and legume flour. The energy content decreased from 408.32 to 399.84 kcal/100 g. However, this decline in starch content

Table 5: Proximate Composition of Wheat–Sprouted Pearl Millet–Soybean Functional Cracker

Code	Moisture (%)	Ash (%)	Protein (%)	Fat (%)	Fibre (%)	Carbohydrate (%)	Energy (kcal/100g)
F1	4.85 ± 0.12^{e}	1.42 ± 0.05^{e}	10.42 ± 0.18^{e}	8.64 ± 0.21^{e}	1.46 ± 0.09^{e}	73.21 ±0.42^{a}	408.32 ±2.14^{a}
F2	4.97 ± 0.10^{d}	1.78 ± 0.06^{d}	11.86 ± 0.22^{d}	9.12 ± 0.18^{d}	2.05 ± 0.11^{d}	70.22 ±0.36^{b}	407.84 ± 1.95^{a}
F3	5.08 ± 0.13^{c}	2.15 ± 0.08^{c}	13.24 ± 0.25^{c}	9.68 ± 0.24^{c}	2.68 ± 0.14^{c}	66.98 ±0.41^{c}	404.76 ± 2.08^{b}
F4	5.25 ± 0.11^{b}	2.54 ± 0.07^{b}	14.42 ± 0.29^{b}	10.24 ± 0.26^{b}	3.26 ± 0.16^{b}	64.29 ±0.38^{d}	402.56 ± 2.21^{c}
F5	5.42 ± 0.14^{a}	2.91 ± 0.09^{a}	15.36 ± 0.31^{a}	10.86 ± 0.29^{a}	3.82 ± 0.18^{a}	61.63 ±0.45^{e}	399.84 ± 2.36^{d}

Note. Data are expressed as mean ± SD where applicable. Different superscript letters within the same column indicate significant differences at p < .05. Key: F1 (100% Wheat flour), F2 (80% Wheat, 15% Sprouted Millet flour, and 5% Soybean Flour, F3 (70% Wheat + 20% Sprouted Millet flour and 10% Soybean Flour), F4 (60% Wheat flour, 25% Sprouted Millet flour and 15% Soybean Flour) and F5 (50% Wheat flour, 30% Sprouted Millet flour and 20% Soybean Flour)

Table 6: Functional Properties of Wheat–Sprouted Pearl Millet–Soybean Composite Flour.

Code	Bulk Density (g/mL)	Water Absorption Capacity (g/g)	Oil Absorption Capacity (g/g)	Swelling Power (g/g)	Water Solubility Index (%)
F1	0.72 ± 0.02^{e}	1.62 ± 0.05^{e}	1.24 ± 0.04^{e}	8.42 ± 0.21^{a}	5.86 ± 0.18^{e}
F2	0.75 ± 0.02^{d}	1.74 ± 0.06^{d}	1.36 ± 0.05^{d}	8.15 ± 0.24^{b}	6.42 ± 0.20^{d}
F3	0.78 ± 0.03^{c}	1.88 ± 0.04^{c}	1.49 ± 0.06^{c}	7.86 ± 0.18^{c}	7.05 ± 0.22^{c}
F4	0.81 ± 0.02^{b}	2.04 ± 0.07^{b}	1.62 ± 0.05^{b}	7.54 ± 0.20^{d}	7.68 ± 0.25^{b}
F5	0.84 ± 0.03^{a}	2.18 ± 0.08^{a}	1.74 ± 0.07^{a}	7.21 ± 0.19^{e}	8.24 ± 0.28^{a}

Note. Data are expressed as mean ± SD where applicable. Different superscript letters within the same column indicate significant differences at p < .05. Key: F1 (100% Wheat flour), F2 (80% Wheat, 15% Sprouted Millet flour, and 5% Soybean Flour, F3 (70% Wheat + 20% Sprouted Millet flour and 10% Soybean Flour), F4 (60% Wheat flour, 25% Sprouted Millet flour and 15% Soybean Flour) and F5 (50% Wheat flour, 30% Sprouted Millet flour and 20% Soybean Flour)

may have been compensated by an increase in protein and fat content. The addition of sprouted pearl millet and soybean flour considerably improved the nutrient quality, and F5 had the highest protein, fibre and mineral content. It appears likely that functional crackers can be developed using cereals and legumes, but the nutritional attributes of such products must be balanced with sensory and technological properties to achieve consumer acceptance.

Functional Properties of Wheat-Sprouted Pearl Millet-Soybean Composite Flour

Functional properties of wheat-sprouted pearl millet-soybean composite flour are given in (Table 6). These properties determine the flour's suitability for cracker making because they affect the ability of the flour to absorb water, its handling properties, the formation of structure, and the quality of the final product. Bulk density, water absorption capacity (WAC), oil absorption capacity (OAC), swelling power and water solubility index (WSI) of the flour were considerably affected ($p < .05$) by substituting wheat flour with sprouted pearl millet and soybean flour, indicating addition of protein- and fibre-rich ingredients affected the flour matrix interactions and physicochemical characteristics. Bulk density increased from 0.72 g/mL (F1, 100% wheat flour) to 0.84 g/mL (F5, 50% wheat flour: 30% sprouted pearl millet flour: 20% soybean flour); this is linked to higher fibre, protein and mineral concentrations in the pearl millet and soybean ingredients, which change the packing and reduce void volume. An increase in bulk density is viewed as an increase in mass, per unit volume. This phenomenon can support the transfer of nutrients appointed in food formulation. Comparable elevations in bulk density values of cereal-legume composite flours have been recorded owing to an increase in the proportional amounts of nutrient-dense ingredients which altered particle packing and flour structure (Amponsah *et al*., 2026). In fact, high levels of substitution have been shown to influence not only dough expansion, but also the cracker texture (matrix density), providing an incentive for optimization of substitution levels.

The water absorption capacity increased from 1.62 g/g of F1 to 2.18 g/g of F5 due to the increased protein and dietary fibre of sprouted pearl millet and soybeans. Protein contains hydrophilic functional groups that easily absorb water. Moreover, the fibrous component has a porous structure that possesses a higher water absorption capacity. Increased WAC results in high hydration capacity which can improve dough handling, moisture retention, and processing stability. Similar trends have been observed in millet- and soybean-based composite flour systems, where improved hydration properties were attributed to improved interactions between the water and protein/fibre (Kokisi *et al*., 2026). It indicates that the composite flour developed in this study is suitable for baked products with controlled moisture absorption. The oil absorption capacity was increased from 1.24 g/g for F1 to 1.74 g/g for F5. This may be because of the higher contribution of soybean proteins with their hydrophobic properties that interact with lipid molecules. Improved OAC may also increase the flavour retention and mouthfeel of crackers. Similar oil binding capacity has been found in legume-enriched bakery products due to the increased availability of proteins (Chiacchio *et al*., 2026). Some studies report a meaningful reduction in OAC with increased soybean addition. The high lipid level of soybean may reduce the number of sites for oil absorption.

The effect of soybean flour on OAC may depend on the level of inclusion, as well as its protein structure and interactions with other flour components. Increase in WAC, OAC and bulk density indicated improvement in functional properties of composite flour. This shows the water absorption and structural properties of flour improved due to sprouted pearl millet and soybean. These findings reinforced the observations that cereal/legume blends can improve the functional performance of bakery products and highlighted the potential to develop functional crackers with improved nutritional profiles (Jabbar *et al*., 2026; Kokisi *et al*., 2026).

Mineral Content of Wheat-Sprouted Pearl Millet-Soybean Functional Crackers

The mineral content of the wheat-sprouted pearl millet-soybean functional crackers is given in (Tables 7 and 8), and the ANOVA results for mineral content of the wheat-sprouted pearl millet-soybean functional crackers are shown in Table 6. The one-way ANOVA demonstrated that the formulation has a meaningful effect on the mineral content (calcium, iron, zinc, magnesium, and phosphorus; $p < .001$). The large F-values for Ca ($F = 212.24$), Fe ($F = 148.83$), Zn ($F = 174.99$), Mg ($F = 326.18$) and P ($F = 161.83$), showed that wheat flour substitution with sprouted pearl millet and soybean flour was the most influencing factor for mineral content among all formulations. These very large effect sizes ($\eta^2 = 0.983, 0.988, 0.990, 0.992$) showed that formulation explained most of the variation in minerality and indicated the possible contribution of pearl millet and soybean flour in mineral fortification of the crackers.

The micronutrient contents of the crackers improved from F1 (100% wheat flour) to F5 (Wheat 50% + sprouted pearl millet flour 30% + soybean flour 20%), indicating the retentiongood cereal-legume complementation for improving the micronutrient density of wheat-based crackers. The Calcium contents of crackers improved from 38.42 mg/100 g (F1) to 71.36 mg/100 g (F5), whichan increase of 85.7%. Thismainly attributable to the mineral concentrations found in pearl millet when compared to refined wheat flour. Mostof pearl millet are concentrated in the outer layer of the grain. This finding corroborates the earlier findings of Kokisi *et al*. (2026) that millet-based functionalare more mineral-rich than those from more conventional cereal grains. However, the amount of minerals in millet-based functional foods is affected by factors like millet genotype, soil mineral content, processing method, and formulation ratio of ingredients. The iron concentration increased from 2.84 mg/100 g for F1 to 5.76 mg/100 g for F5, showing an increase of 103% in iron concentration because of high concentration of iron in pearl millet and soybean compared to refined wheat flour. These findings are in agreement with those of Amponsah *et al*. (2026) who found that millet-based ingredients improved iron content and overall nutrient profile of cereal blends. However, higher total iron content does not necessarily imply higher bioavailability, because cereal and legume components contain antinutritional factors such as phytates and tannins that can inhibit mineral bioavailability.bThecontent of zinc and magnesium was found to increase from 1.12 mg/100 g to 2.68 mg/100 g and 46.38 mg/100 g to 97.54 mg/100 g from F1 to F5, respectively. The increase in zinc and magnesium contents may be attributed to the presence of pearl millet and soybean, which are known sources of phytominerals andbioactive compounds. Zinc is essential for immunity, growth, and cellular metabolism, while magnesiumis important for enzymatic reactions and energy metabolism. These findings were consistent with Kokisi *et al*. (2026), who observed that millet andsoybean ingredients were mineral-rich. The phosphorus content of F1 was 182.64 mg/100 g and that of F5 was 284.52 mg/100 g. These increases may have been due to the higher phosphorus content of whole grains and legumes than white wheat flour. Jabbar *et al*. (2026) have reported similar results for minerals in cereal-legume composite products. From the results it can be concluded that the wheat flour of crackers can be replaced with sprouted pearl millet and soybean flour to design functional crackers with higher mineral content. The cracker F5 formulation (with highest minerals content) can be used for designing functional food as a snack food product. However, studies on bioavailability of minerals and the effects of processing on antinutritional factors would indicate the true nutritional benefit of these minerals.

Physical Characteristics of Wheat–Sprouted Pearl Millet–Soybean Functional Crackers

Physical parameters of crackers developed from wheat, sprouted pearl millet and soybean flour blends are presented in (Table 9). The quality of the product can be reflected by these physical parameters as they play an important role in determining consumer acceptability, handling stability, behaviour under packaging and appearance of the product. The effect of formulation on all physical characteristics was statistically meaningful ($p < 0.001$), indicating that the structure of the crackers was affected by the gradual substitution of wheat flour with sprouted pearl millet and soybean flour. Cracker weight increased from 8.42 g in F1 to 9.36 g in F5 (11.2%). This could be attributed to the higher protein, fibre and minerals contributed by pearl millet and soybean flour resulting in more solids and lesser loss of moisture during baking of cracker. Yet, the increased retention of non-starch components in the bakery products from composite flour was said to lead to increased product weight and density (Jabbar *et al*., 2026). On the other hand, horizontal diameter decreased from 46.82 mm (F1) to 41.52 mm (F5), i.e. by 11.3%, and thickness increased from 5.12 mm (F1) to 6.12 mm (F5). This may be due to the dilution of wheat gluten that lowers dough's extensibility, thereby decreasing horizontal expansion. It may also be due to increased fibre protein content from

Table 7: Mineral Composition of Wheat–Sprouted Pearl Millet–Soybean Functional Crackers.

Code	Calcium (mg/100g)	Iron (mg/100g)	Zinc (mg/100g)	Magnesium (mg/100g)	Phosphorus (mg/100g)
F1	38.42 ± 1.26^{e}	2.84 ± 0.11^{e}	1.12 ± 0.05^{e}	46.38 ± 1.42^{e}	182.64 ± 4.21^{e}
F2	46.85 ± 1.38^{d}	3.52 ± 0.14^{d}	1.46 ± 0.06^{d}	58.72 ± 1.65^{d}	211.46 ± 5.18^{d}
F3	55.74 ± 1.54^{c}	4.18 ± 0.16^{c}	1.82 ± 0.08^{c}	71.34 ± 1.88^{c}	238.76 ± 5.64^{c}
F4	64.28 ± 1.72^{b}	4.96 ± 0.18^{b}	2.24 ± 0.09^{b}	84.62 ± 2.14^{b}	264.38 ± 6.02^{b}
F5	71.36 ± 1.86^{a}	5.76 ± 0.21^{a}	2.68 ± 0.11^{a}	97.54 ± 2.46^{a}	284.52 ± 6.38^{a}

Note. Data are expressed as mean ± SD where applicable. Different superscript letters within the same column indicate significant differences at $p < .05$.

Table 8. ANOVA Summary for Mineral Composition of Wheat–Sprouted Pearl Millet–Soybean Functional Crackers.

Mineral parameter	F-value	df	p-value	Effect size (η^2)
Calcium	212.24	4.10	<0.001	0.988
Iron	148.83	4.10	<0.001	0.983
Zinc	174.99	4.10	<0.001	0.986
Magnesium	326.18	4.10	<0.001	0.992
Phosphorus	161.83	4.10	<0.001	0.985

Note: Values are based on one-way ANOVA for five cracker formulations (F1–F5) with three replicates per formulation (df between = 4; df within = 10). Effect size is expressed as eta squared (η^2), representing the proportion of variation in mineral content explained by formulation differences.

Table 9: Physical Characteristics of Wheat–Sprouted Pearl Millet–Soybean Functional Crackers

Code	Weight (g)	Diameter (mm)	Thickness (mm)	Hardness (N)	L*	a*	b*
F1	8.42 ± 0.18^{e}	46.82 ±0.62^{a}	5.12 ±0.14^{e}	18.42 ±0.86^{e}	72.64 ± 1.22^{a}	2.14 ± 0.08^{e}	22.36 ± 0.42^{e}
F2	8.66 ± 0.21^{d}	45.38 ±0.58^{b}	5.34 ±0.16^{d}	20.36 ±0.92^{d}	69.42 ± 1.18^{b}	2.58 ± 0.10^{d}	24.18 ± 0.46^{d}
F3	8.84 ± 0.19^{c}	44.16 ±0.55^{c}	5.58 ±0.15^{c}	22.74 ±0.95^{c}	66.28 ± 1.14^{c}	3.04 ± 0.12^{c}	26.42 ± 0.51^{c}
F4	9.12 ± 0.23^{b}	42.86 ±0.51^{d}	5.84 ±0.18^{b}	25.16 ±1.02^{b}	63.74 ± 1.10^{d}	3.46 ± 0.14^{b}	28.16 ± 0.54^{b}
F5	9.36 ± 0.25^{a}	41.52 ±0.48^{e}	6.12 ±0.20^{a}	27.86 ±1.08^{a}	60.86 ± 1.06^{e}	3.92 ± 0.16^{a}	30.24 ± 0.58^{a}

Note. Data are expressed as mean ± SD where applicable. Different superscript letters within the same column indicate significant differences at $p < .05$.

Table 10 Microbiological Quality Indicators of Wheat–Sprouted Pearl Millet–Soybean Composite Crackers.

Formulation	Total Viable Bacterial Count (log CFU/g)	Yeast and Mould Count (log CFU/g)	Coliform Count (log CFU/g)
F1	1.21 ± 0.06^{e}	0.74 ± 0.04^{e}	0.18 ± 0.02^{e}
F2	1.29 ± 0.05^{d}	0.82 ± 0.05^{d}	0.21 ± 0.03^{d}
F3)	1.38 ± 0.07^{c}	0.91 ± 0.06^{c}	0.25 ± 0.02^{c}
F4	1.47 ± 0.06^{b}	1.02 ± 0.05^{b}	0.29 ± 0.03^{b}
F5	1.58 ± 0.08^{a}	1.12 ± 0.06^{a}	0.32 ± 0.02^{a}

Note. Data are expressed as mean ± SD where applicable. Different superscript letters within the same column indicate significant differences at $p < .05$.

pearl millet and soybean that possibly strengthens the dough matrix, restricting its flow and increasing vertical expansion. Similar reductions in spread ratio have also been observed in composite flour crackers due to reductions in gluten availability and increased protein-fibre interactions (Amponsah *et al*., 2026). Hardness increased from 18.42 N in F1 to 27.86 N in F5 (+51.3%). This may be due to the weak gluten development, high dietary fibre and good associations between protein and fibre, which made the dough hard. A similar trend has been observed in the hardness of crackers fortified with millet and legumes (Chiacchio *et al*., 2026). Of course, there is a minus side to this, as certain hardness is required to achieve the appropriate crispness and structure of the cracker, while excessive levels of hardness may make the crackers unacceptable to the consumer due to excessive biting and chewing resistance. Thus, with F5 showing a 51% increase in nutritional value our results suggest that a balance must be struck at higher levels of substitution to maintain eating quality. Lightness (L) decreased from 72.64 to 60.86, redness (a) increased from 2.14 to 3.92 and yellowness (b) from 22.36 to 30.24, from formulation F1 to F5. The difference in color is attributed to the pigments of pearl millet and soybean, and the Maillard reaction between sugars and amino acids occurring during baking, which is increased by the increased protein availability. Similarly, color changes in millet and legume-based functional bakery products have been observed (Kokisi *et al*., 2026). The addition of sprouted pearl millet and soybean flour improved the nutritional quality of the cracker but influenced its physical properties, specifically reducing spread and increasing thickness, hardness and darkening of color. The highest nutritional improvement was in F5, but the increase in hardness and decrease in diameter could negatively affect consumer acceptability.

Therefore, these intermediate formulations (F3 and F4) could maintain an acceptable balance between nutritional enrichment and good characteristics, suggesting the development of functional crackers.

Microbial Quality of Wheat-Sprouted Pearl Millet-Soybean Functional Crackers

Microbial quality of wheat-sprouted pearl millet-soybean functional crackers was determined by total viable bacterial count, yeast and mould count and coliform count (Table 10). Microbial quality of the food is an important factor for determining the food safety, shelf life and marketability of the food. Microorganisms could deteriorate food quality, nutritional value and consumer acceptability of the food. Substitution of wheat flour with sprouted pearl millet and soybean flour increased the microbial counts, but those counts remained low, implying that the developed crackers were microbiologically acceptable. The total viable counts (TVCs) increased from 1.21 log CFU/g (F1) to 1.58 log CFU/g (F5) in a gradual manner. This indicates that the crackers containing more amount of sprouted pearl millet and soybean flour had a marginal increase in microbial load. This is likely due to the nutritional profile of the added ingredients, in terms of protein, minerals and bioactive compounds, as well as the relative concentrations of each of them that may be associated with a better condition for the viability of microorganisms in comparison with white refined wheat flour. Sprouting could also influence this in that germination requires the addition of water and the presence of enzymes, which can favour microbial growth when poorly controlled. Similar observations were made with sprouted cereal-based products, for which microbial interventions are also needed to ensure safety and shelf life, despite having superior nutritional attributes (Kokisi *et al*., 2026). Yeast counts and mould counts also followed the same trend, increasing from 0.74 log CFU/g in F1 to 1.12 log CFU/g in F5, possibly due to the higher content of nutrient and dietary fibre present in pearl millet and soybean flour. These flours also provided substrates for the growth of fungi. Nevertheless, the relatively low levels found in all formulations suggest that baking and drying conditions were effective in reducing fungal growth. Molds are one of the leading causes of spoilage of bakery products and are detrimental to their shelf life and commerciality to consumers.

These recent studies on functional bakery products highlighted that the enrichment with whole grains and legumes should be combined with efficient moisture management and conservation techniques for the maintenance of microbiological safety (Jabbar *et al*., 2026).Coliform numbers were slightly higher at F5, with 0.32 log CFU/g vs. 0.18 log CFU/g at F1. This low coliform level in both cases indicates good handling and processing practices, and provides evidence that sanitary conditions are satisfactory. This is a good sign. Elevated coliform levels are usually indicative of poor sanitation and provide a possible way for contamination. Increasing substitution resulted in increased microbial counts, which attributed to the nutritional-microbial balance being affected by the addition of sprouted, protein-rich ingredients. Pearl millet and soybean improved the nutritional value of the flour-based bread, but needed precise processing conditions to achieve successful incorporation. This aligns with recent reports indicating that functional foods derived from whole grains and legumes require validated drying, packaging, and storage methods to maintain safety and quality (Jabbar *et al*., 2026). The overall results showed that the crackers were microbiologically safe. A lower count of bacteria, fungi and coliform was observed in all the formulations. The highest counts were observed in F5 but this did not affect its safety. This study has shown that the functional crackers could be produced from a composite flour of wheat, sprouted pearl millet and soybean to obtain the desired product quality with proper hygiene, moisture and packaging to increase the shelf-life and marketability.

Sensory Evaluation of Wheat-Sprouted Pearl Millet-Soybean Functional Crackers

Sensory evaluation of wheat-sprouted pearl millet-soybean functional crackers was conducted by a panel of 100 untrained panellists using a 5-point hedonic scale (Table 11). Higher hedonic score represents better consumer acceptability of functional food products. Sensory evaluation is also important for any functional food product, and nutritional improvement should not considerably take away from the palatability of the food product. The formulation considerably ($p < 0.05$) influenced the sensory attributes including appearance, colour, aroma, taste, texture/crispness, mouth feel and overall acceptability. Sensory scores of the cracker decreased with an increase in the level of addition of sprouted pearl millet and soybean flour, but the addition of sprouted pearl millet and soybean flour was able to improve the nutritional quality of the cracker and was acceptable; however, the increase in the level of substitution negatively influenced the sensory attributes. The control formulation (F1, 100% wheat flour) gave the highest overall acceptability value of 4.38 ± 0.52, which means that the respondents showed the highest preference for the wheat-based cracker. The composite flour formulations have overall acceptability ratings of 4.16 ± 0.56, 4.12 ± 0.58, 4.02 ± 0.61 and 3.74 ± 0.66 in descending order: F3 (36% composite flour), F2 (12% composite flour), F4 (24% composite flour) and F5 (48% composite flour). The study suggested that moderate use of sprouted pearl millet and soybean flour will not affect sensory properties while improving the micronutrient quality of the composite flour. Despite numerically improved nutritional properties of F5 based on proximate and mineral constituents, the high proportion of millet and soybean flour may adversely affect consumer acceptability.

Table 11 *Sensory Evaluation Scores of Wheat–Sprouted Pearl Millet–Soybean Functional Crackers (n = 100).*

Code	Appearance	Colour	Aroma	Taste	Texture/Crispness	Mouthfeel	Overall Acceptability
F1	4.42 ± 0.51^{a}	4.38 ± 0.54^{a}	4.21 ± 0.58^{a}	4.36 ± 0.55^{a}	4.32 ± 0.57^{a}	4.28 ± 0.56^{a}	4.38 ± 0.52^{a}
F2	4.18 ± 0.62^{b}	4.12 ± 0.60^{b}	4.05 ±0.61^{b}	4.14 ± 0.63^{b}	4.06 ± 0.65^{b}	4.10 ± 0.60^{b}	4.12 ± 0.58^{b}
F3	4.08 ± 0.59^{c}	4.02 ± 0.62^{c}	4.12 ± 0.57^{ab}	4.18 ± 0.60^{b}	4.10 ± 0.61^{b}	4.15 ± 0.58^{b}	4.16 ± 0.56^{b}
F4	3.86 ± 0.64^{d}	3.78 ± 0.67^{d}	3.98 ± 0.62^{b}	4.05 ± 0.64^{c}	3.92 ± 0.66^{c}	4.00 ± 0.63^{c}	4.02 ± 0.61^{c}
F5	3.62 ± 0.70^{e}	3.54 ± 0.72^{e}	3.76 ± 0.68^{c}	3.72 ± 0.69^{d}	3.64 ± 0.71^{d}	3.70 ± 0.68^{d}	3.74 ± 0.66^{d}

Note.Data are expressed as mean ± SD where applicable. Different superscript letters within the same column indicate significant differences at p < .05.

Therefore, a particular substitution level must be optimised to provide nutritional enhancement and sensory acceptability. Most reduction in a higher substitution occurred in color and appearance, changing from 4.38 ± 0.54 in F1 to 3.54 ± 0.72 in F5. Appearance scores decrease from 4.42 ± 0.51 in F1 to 3.62 ± 0.70 in F5. The darker colour of higher substitution formulations could be due to natural colourants, phenolic compounds and peptide/proteins present in pearl millet and soybean flour that exerted a pigment interaction and Maillard reaction during baking, thereby affecting colour intensity of the formulated composite flour products. Similar results were also reported for composite flour bakery products when millet and legume based ingredients were incorporated (Jabbar *et al*., 2026). The taste and aroma score decreased with the increase in replacement level where taste score decreased considerably from 4.36 ± 0.55 (F1 sample) to 3.72 ± 0.69 (F5 sample) and aroma score also decreased from 4.21 ± 0.58 to 3.76 ± 0.68. This could be attributed to characteristic millet and soybean flavours especially beany flavour compounds from the soybean. However, F3 retained acceptable taste (4.18 ± 0.60) and aroma profiles (4.12 ± 0.57) and thus use of millet and soybean could provide decent nutritional benefits with minimal adverse flavour impact if the millets and soybean are used judiciously.

The texture/crispness also showed a similar reduction, from 4.32 ± 0.57 of F1 to 3.64 ± 0.71 of F5. The greater fibre and protein content of sprouted pearl millet and soyabean could have altered the dough structure, which in turn decreased crispness from the wheat-based formulations. Similar patterns have been noted for crackers using composite flours and fortified with fibre/protein ingredients, where such fortification can influence the texture and consumer response (Chiacchio *et al*., 2026).

Despite a gradual decrease in sensory scores with increasing substitution, all formulations were above the mid-point of the hedonic scale. The composite formulation with the best nutritional and sensory values was F3. F2 also showed good sensory acceptability. For the formulation of nutritionally enriched crackers with good sensory properties, moderate levels of wheat flour replacement with sprouted pearl millet and soybean flour can be recommended. However, high levels of replacement such as F5 may be rejected due to changes in colour, flavour and texture.

Analysis of Variance showing the effect of formulation on the quality attributes of wheat-sprouted pearl millet-soybean functional crackers

The effect of replacing wheat flour with sprouted pearl millet and soybean flour on the nutritional, functional, mineral, physical, microbiological and sensory properties of the functional crackers is shown in (Table 12). Results of one-way ANOVA showed that the formulation has an important effect on all the quality parameters ($p < 0.001$). These differences are attributed to the variation in the levels of the ingredients in the different formulations. This is further supported by high partial eta squared (η^2p) values for most of the variables, indicating the effects of formulation on the quality of the crackers were substantial. Mineral composition was statistically important with F-values ranging from 118.42 to 151.26 and large effect sizes (η^2p = 0.979-0.984). The mineral composition of the crackers was considerably influenced by the incorporation of sprouted pearl millet and soybean flour. The observed increase in calcium, iron, zinc, magnesium, and phosphorus contents could be attributed to the mineral content of pearl millet and soybean, suggesting the cereal-legume complementation potential for improving the micronutrient content of functional foods based on wheat (Kokisi *et al*., 2026).

The proximate composition also varied by formulation (F = 28.64-184.76; η^2p = 0.920-0.987), particularly the protein and fibre contents, which increased with increasing levels of soybean and sprouted pearl millet (SPM), while the carbohydrates decreased. This is due to the substitution of starch-based wheat flour with protein and fibre-rich soybean meal and SPM flour, showing the advantage of composite flour technology. Formulation had significant effects (F = 32.18 to 86.94; η^2p = 0.928 to 0.972) on bulk density, water and oil absorption capacities, swelling power and water solubility index, proving that sprouted pearl millet and soybean modify hydration and matrix interaction of flour. These modifications are important in the functional properties, handling, structure, and end-use characteristics of doughs, and products. It significantly influences physical properties (F = 24.86-96.84; η^2p = 0.909-0.975) due to the substitution level affecting the structure of the crackers, especially hardness, and this resulted from fibre-protein interaction and gluten dilution.

Table 12: Analysis of Variance showing the effect of formulation on the quality attributes of wheat-sprouted pearl millet-soybean functional crackers

Quality attribute	Variable	df	F-value	p-value	Partial η^2
Proximate composition	Moisture	4.10	28.64	<0.001	0.920
	Ash	4.10	96.54	<0.001	0.975
	Protein	4.10	184.76	<0.001	0.987
	Fat	4.10	72.38	<0.001	0.967
	Fibre	4.10	156.42	<0.001	0.984
	Carbohydrate	4.10	98.26	<0.001	0.975
	Energy value	4.10	45.82	<0.001	0.948
Functional properties	Bulk density	4.10	32.18	<0.001	0.928
	Water absorption capacity	4.10	86.94	<0.001	0.972
	Oil absorption capacity	4.10	64.75	<0.001	0.963
	Swelling power	4.10	51.36	<0.001	0.954
	Water solubility index	4.10	44.28	<0.001	0.947
Mineral composition	Calcium	4.10	118.42	<0.001	0.979
	Iron	4.10	151.26	<0.001	0.984
	Zinc	4.10	129.84	<0.001	0.981
	Magnesium	4.10	143.62	<0.001	0.983
	Phosphorus	4.10	135.48	<0.001	0.982
Physical characteristics	Weight	4.10	24.86	<0.001	0.909
	Diameter	4.10	62.45	<0.001	0.961
	Thickness	4.10	48.72	<0.001	0.951
	Hardness	4.10	96.84	<0.001	0.975
	Spread ratio	4.10	57.32	<0.001	0.958
Microbial quality	Total viable count	4.10	22.38	<0.001	0.899
	Yeast and mould count	4.10	18.46	<0.001	0.881
	Coliform count	4.10	14.26	<0.001	0.851
Sensory attributes	Appearance	4.396	25.86	<0.001	0.208
	Colour	4.396	22.74	<0.001	0.188
	Aroma	4.396	15.84	<0.001	0.139
	Taste	4.396	18.92	<0.001	0.161
	Texture/crispness	4.396	21.35	<0.001	0.179
	Mouthfeel	4.396	16.48	<0.001	0.143
	Overall acceptability	4.396	20.62	<0.001	0.174

Note: df = degrees of freedom. Partial η^2 represents effect size. The reported statistics demonstrate the magnitude of formulation effects on the nutritional, functional, physical, microbial and sensory characteristics of the crackers.

The modified products were more nutrient-dense. However, excessive substitution levels could also negatively affect their texture and public acceptability. Microbial quality parameters showed a meaningful but weak effect (F = 14.26-22.38; η^2p = 0.851-0.899) of formulation on product quality. The microbe counts were within the prescribed limits, clearly indicating that sprouted pearl millet and soybean flour could not adversely affect the safety of the product. The formulation was also meaningful for sensory properties ($p < 0.001$) with moderate effect sizes (η^2p = 0.139 to η^2p = 0.208). The score reductions are assumed to result from the use of millet pigments, the flavour compounds of the soybeans, and the increased fibre content. However, moderate substitution maintained consumer acceptability In a nutshell, formulation ratio was the most important factor determining crackers' nutritional fortification, technological performance, product safety, and sensory quality. Overall, formulation ratios of sprouted pearl millet and soybean need to be optimised to ensure maximum nutritional benefits without compromising product quality and consumer acceptability.

Conclusion

Replacement of wheat flour with sprouted pearl millet and soybean flour improved nutritional, functional, physical, microbiological and sensory characteristics of wheat-sprouted pearl millet-soybean crackers. There was also an increase in protein, dietary fibre, ash and minerals as the level of composite flour increased. The results indicate that the incorporation of sprouted pearl millet and soybean flour could be a feasible alternative for improving the nutritional quality of wheat-based crackers.

The changes in nutritional composition were complemented by changes in functional properties, physical properties, and sensory properties. With increasing amounts of starch substitution, hardness increased, while scores on color, flavour, texture and overall acceptability decreased. The overall sensory characteristics of all the composite blends were quite acceptable, but amongst them, F3 (70% wheat flour, 20% sprouted pearl millet flour and 10% soybean flour) had the maximum ratio of improved nutritional composition to sensory evaluation. Although F1 (control) was rated highest for sensory evaluation, F3 had a slightly lower sensory acceptability but a more superior nutritional composition. The microbial analyses showed that, between formulations, there were differences, but the values were low in all the circumstances studied. However, more studies using wide-ranging microbial standards, targeted pathogen detection, and shelf-life studies are needed to confirm microbiological safety in the future. definitively Overall, substitution with sprouted pearl millet and soybean flour, at the F3 substitution level, provides a method to improve the nutritional quality of wheat-based crackers without negatively impacting sensory quality. The novel nutrient fortified cereal-legume-based cracker presented in this study has potential; however, additional research is needed on nutrient bioavailability, consumer acceptability among different ethnic populations, shelf-life stability, and cost for marketing before health benefits, affordability or other functional food claims can be made for the product.

REFERENCES

Akoijam, R., Bhutia, D. D., Jena, S., & Said, P. P. (2026). Quality characterization, optimization and consumer acceptance of enriched gluten-free crackers through valorization of chayote tuber and sprouted paheli dal flour. Sustainable Food Technology, 4, 1083–1098. https://doi.org/10.1039/D5FB00622H

Al-Khaleel, R.I., Chellapilla, T. & Siddaiah, C.N. (2025). Pearl Millet: A Sustainable Source of Food and Nutrition in the Age of Climate Change. Anthr. Sci. 4, 1–13. https://doi.org/10.1007/s44177-025-00090-2

Amponsah, A. S., Kyere, G. Prempeh, K. B. & Adinkrah-Appiah, K. (2026). Valorization of Spent Millet Flour in Composite Bread: Characterization, Predictive Modeling, and Multi-Objective Optimization for Nutritional Enhancement. Food Science & Nutrition 14, no. 5: e71843. https://doi.org/10.1002/fsn3.71843.

AOAC International. (2023). Official Methods of Analysis of AOAC International (22nd ed.). Oxford University Press. https://doi.org/10.1093/9780197610145.001.0001

Bachate, A. H., Pawar, V. S., Pawar, G. S., Rodge, S. M., & Joshi, M. M. (2025). Effect of soaking, roasting and germination on nutritional quality and colour properties of pearl millet flour. Asian Journal of Dairy and Food Research, 44(6), 962–967. https://doi.org/10.18805/ajdfr.DR-2371

Chauhan, P., & Gupta, M. (2025). Characterization of sprouted pearl and finger millet incorporated spreads for enhanced nutrition. Food and Humanity, 4, 100610. https://doi.org/10.1016/j.foohum.2025.100610

Cheung, M. M., Miller, L., Deutsch, J., Sherman, R., Katz, S. H., & Wise, P. M. (2025). Sensory properties and acceptability of fermented pearl millet, a climate-resistant and nutritious grain, among consumers in the United States—A pilot study. Foods, 14(5), 871. https://doi.org/10.3390/foods14050871

Chiacchio, M. F., Tagliamonte, S., Blaiotta, G., Pazzanese, A., Juan, C., Juan-García, A., & Vitaglione, P. (2026). Functional potential of crackers formulated with an innovative fermented cooked chickpea flour. Food & function, 17(7), 3275–3290. https://doi.org/10.1039/d5fo05351j.

International Organization for Standardization. (2013). Microbiology of the food chain—Horizontal method for the enumeration of microorganisms—Part 1: Colony count at 30 °C by the pour plate technique (ISO Standard No. 4833-1:2013). International Organization for Standardization.

Jabbar, S., Waqar, M., Urooj, S., Sharif, M. K., Abidin, N. S. A., Benabdelmoumene, D., Dahmouni, S., & Ali, S. (2026). Development of chickpea-based multigrain gluten-free crackers: Formulation optimization and evaluation of nutritional, antioxidant, and quality attributes. Legume Science, 8(2), e70122. https://doi.org/10.1002/leg3.70122

Kokisi P., Nchu F., Kambizi L.& Bvenura C. (2026). Finger millet and soybean as functional ingredients in next-generation fermented foods: a review of nutritional, technological, and health-promoting perspectives. Front. Nutr. 13:1718090. doi: 10.3389/fnut.2026.1718090

Long, D. Q., Trinh, M. T. T., Nguyen, V. H., Tran, T. T. T., Ton, N. M. N., & Le, V. V. M. (2025). Use of transglutaminase at different concentrations and incubation times for quality improvement of high-fibre crackers fortified with soybean hulls. Applied Food Research, 5(2), 101298. https://doi.org/10.1016/j.afres.2025.101298

Majzoobi, M., Wang, Z., Teimouri, S., Pematilleke, N., Brennan, C. S., & Farahnaky, A. (2023). Unlocking the Potential of Sprouted Cereals, Pseudocereals, and Pulses in Combating Malnutrition. Foods, 12(21), 3901. https://doi.org/10.3390/foods12213901

Neji, C., Semwal, J., Máthé, E., & Sipos, P. (2023). Dough Rheological Properties and Macronutrient Bioavailability of Cereal Products Fortified through Legume Proteins. Processes, 11(2), 417. https://doi.org/10.3390/pr11020417

Ponte, L. G. S., Ribeiro, S. F., Pereira, J. C. V., Antunes, A. E. C., Bezerra, R. M. N., & da Cunha, D. T. (2025). Consumer Perceptions of Functional Foods: A Scoping Review Focusing on Non-Processed Foods. Food Reviews International, 41(6), 1738–1756. https://doi.org/10.1080/87559129.2025.2453030

Ramashia, S. E., Ratau, M. A., & Olamiti, G. (2026). Cereal–Legume Food Matrices as Functional Systems: Processing-Driven Synergies in Nutrition, Bioactive Compounds and Sensory Acceptability. Molecules, 31(12), 2033. https://doi.org/10.3390/molecules31122033

Zupo, R., Castellana, F., Crupi, P., Annunziato, A., Corbo, F., & Clodoveo, M. L. (2026). Nutritional, functional, and technological outcomes of fortification strategies in unleavened bakery products: A systematic review. Journal of Food Process Engineering, 49(1), e70310. https://doi.org/10.1111/jfpe.70310

Żurek, J., Rudy, M., & Dziki, D. (2026). Consumer Choices in the Functional Food Market: A Review of Determinants of Purchasing Behavior. Foods, 15(8), 1319. https://doi.org/10.3390/foods15081319.