# Nutrient Composition, Sensory, and Functional Properties of Complementary Foods Developed from Local Staples for Young Children (6-23) Using Linear Programming

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## ABSTRACT

***Background:*** *The introduction of complementary foods is a critical stage in infant and young child development, as growth as well as physiological and cognitive functions depend on adequate nutrition.*

***Objective:*** *This study evaluated the nutrient composition, sensory, and functional properties of complementary food made from maize, cowpea, peanut, carrot, and dried fish flour blends.*

***Methodology:*** *Raw ingredients (6 kg) were procured, sorted, cleaned, and dried using a cabinet dryer (Model HR 6200, UK) at 50 °C for 8 hours, except peanuts, which were roasted. Samples were milled and sieved through a 500 µm mesh. Ingredient optimization was performed using Nutri-survey software (version 2007) at varying ratios (maize:cowpea:peanut:carrot:fish). Proximate and functional properties were analyzed using AOAC. Sensory evaluation was conducted using a 9-point hedonic scale by semi-trained and untrained panelists. Data were analyzed using ANOVA.*

***Results:*** *The result revealed that the moisture content ranged from 8.47–10.10 g/100 g, protein 11.73–14.61 g/100 g, fat 16.93–22.11 g/100 g, crude fiber 4.00–4.34 g/100 g, ash 2.07–3.28 g/100 g, carbohydrate 50.72–53.82 g/100 g, and beta-carotene 0.73–1.12 µg/100 g. The 6–8 months formulation exhibited the highest water absorption and foaming capacity, while the 9–11 and 12–23 months formulations showed lower bulk density. Sensory evaluation indicated that the 12–23-month formulation achieved the highest scores for taste, texture, and overall acceptability*

**Keywords:** Local staples, Linear programming, Formulation, Infant feeding, and Nutritional optimization

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## INTRODUCTION

Infancy is a period of rapid physical growth as well as physiological, immunological, and mental development when nutritional requirements are at their highest per unit body weight, higher than in later childhood and adulthood (1). Most infants are first fed with breast milk that provides adequate nutrition and materials for most resistance to diseases (2). Adequate nutrition during infancy and childhood is fundamental to the development of a child to their full potential. The infancy period (0-2 years) is a critical window for promotion of optimal growth, health, and behavioural development. After two years of the child's life, it is difficult to reverse stunting that has occurred earlier (3). In sub-Saharan Africa, as in other developing countries, protein deficiency in the diet is common, and it is usually associated with deficiencies in calories and micronutrients, leading to endemic protein-energy malnutrition with its attendant health consequences, particularly during infancy. In Nigeria, the traditional complementary foods (gruel) are mainly porridges from either maize, sorghum, or millet, which do not satisfy the energy and other nutrient needs of infants (4).

Complementary feeding in developing countries requires affordable, protein-rich, locally available food for low-income parents (5). Traditional complementary foods, such as cereal-based alternatives like maize and guinea corn, are low in nutritive value and have low protein, high energy density, and bulk (6). These cereals, often low in lysine and tryptophan amino acids, contribute to severe acute malnutrition in children during the complementary period (7).

Maize, a staple crop, is primarily composed of carbohydrates, with starch being the primary carbohydrate (8). It is also a source of plant-based protein with 9% content, but lacks essential amino acids like lysine and tryptophan (9). Maize contains both soluble and insoluble fibre, aiding digestion and gut health. Additionally, it is also a source of vitamins like $B_6$, thiamin, and folate, and minerals like magnesium, phosphorus, and potassium (10). The nutritional quality of maize depends on the processing method used.

Cowpea is a valuable complementary feeding ingredient because its high protein content and favorable amino acid profile improve the nutritional quality of cereal-based foods. It provides essential micronutrients, including iron, zinc, and folate, which support hematological development, immune function, and rapid growth in infancy (11). Its dietary fiber supports gastrointestinal function, while its affordability, local availability, and cultural acceptability make it suitable for plant-based complementary food formulations (12).

Peanut oil contains mainly unsaturated fatty acids and therefore affects lipid oxidation. Peanut oil mainly contains less linoleic acid than other seed oils. Oleic, linoleic, and palmitic acids account for a total of 90 % the fatty acid profile of peanuts, although there are five other fatty acids in the ratios of at least 1% (13). Peanut oil is a rich source of monounsaturated and polyunsaturated fatty acids. It contains about 48% monounsaturated fatty acids, 34% polyunsaturated fatty acids, and 18% saturated fatty acids. Monounsaturated and polyunsaturated fatty acids have been associated with a lower risk of heart disease and other chronic conditions (5).

Orange carrots are gaining popularity due to their high provitamin A content, which is essential for maintaining health. Carrots are a rich source of vitamins A, C, K, and $B_6$, with a medium-sized carrot providing 22% of the recommended daily value for infants and young children (6-23months) (14). They are also rich in minerals, dietary fiber, and antioxidants, which may reduce the risk of chronic diseases (15).

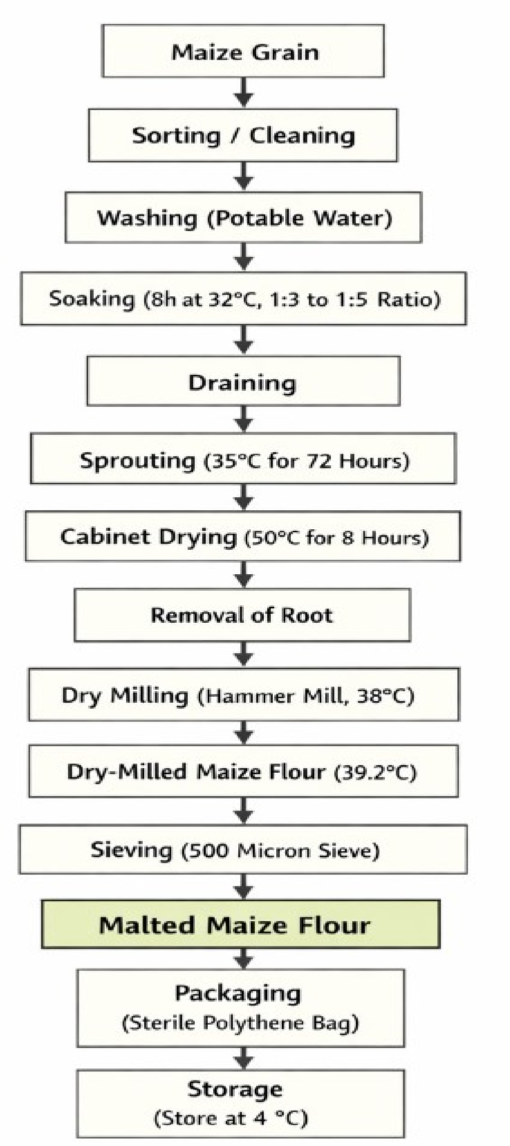
Fish is a highly nutritious food containing a high amount of protein of high biochemical value for humans. In addition, it is a very good source of polyunsaturated fatty acids known to be beneficial in supplying key micronutrients such as iron, zinc, iodine, and calcium that contribute to optimal growth and immune function during the complementary feeding period (16). Fish are a good source of certain vitamins, such as vitamin D, vitamin $B_6$, and vitamin $B_{12}$. Vitamin D is essential for bone health, while vitamin B12 is important for nerve function and DNA synthesis. Fish are also a good source of minerals, such as iodine, selenium, and zinc. Iodine is important for thyroid function, while selenium is an antioxidant that protects against oxidative damage (17).

Maize, cowpeas, peanuts, carrots, and fish were chosen for this study based on their complementary nutritional qualities in order to create a nutrient-dense supplementary food that may satisfy infants' increased dietary needs throughout the complementary feeding period (18). The micronutrient density, protein quality, and overall dietary adequacy of plant-based complementary foods for infants and young children have been shown to be improved by a careful combination of cereals, legumes, oilseeds, vegetables, and foods derived from animals (19; 20). Therefore, the goal of this study was to develop composite supplemental meal blends using these readily available local ingredients in varying quantities, evaluate their nutritional, functional, and sensory attributes, and determine their acceptability.

## MATERIALS AND METHODS

The maize grain, cowpea, carrot, fish and peanut oil used in this study was purchased from a local market (Osiele Market). The maize grain and cowpea were sorted, cleaned to remove dirt and foreign materials, and washed in clean water. Roasted peanut was purchased, sorted, and cleaned as well. The outer part of the carrot was washed and peeled off to remove dirt before dicing. The fish used was cleaned and dried as well. The maize was malted according to (21), cowpea and carrot were packed in sterile polythene bags, and transported to the FUNAAB Nutrition and Dietetics food processing laboratory for cabinet drying.

The processing procedures for cowpea flour are shown in Figure 1. The processing procedures for maize flour are shown in Figure 2. The processing procedures for peanut oil are shown in Figure 3. The processing procedures for carrot flour are shown in Figure 4. The processing procedures for fish flour are shown in Figure 5. The processing procedures for fish flour are shown in Figure 5.



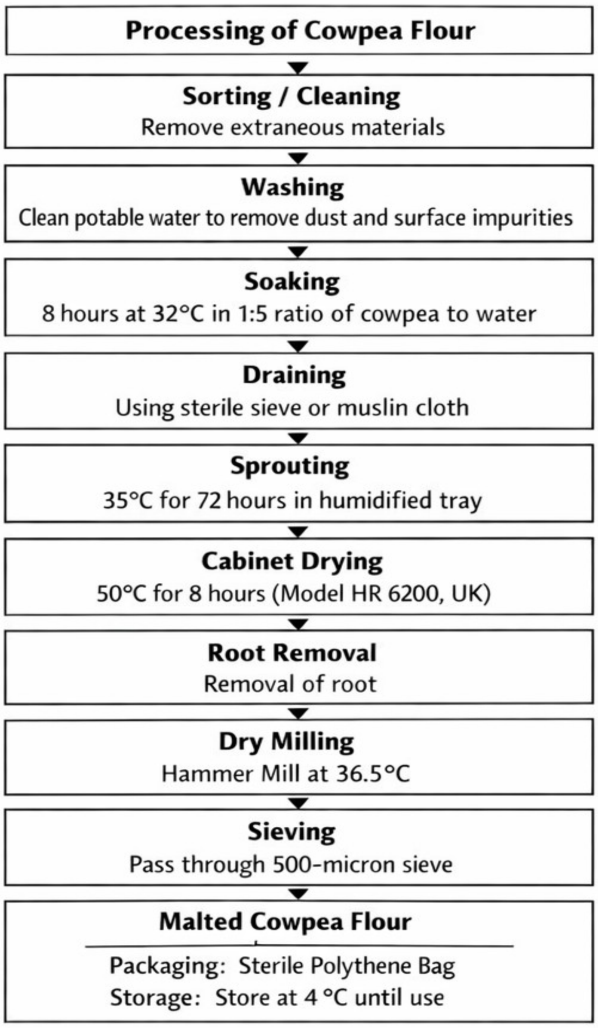




Figure 1: Processing of Cowpea Flour (22)

Figure 2: Processing of Maize Flour

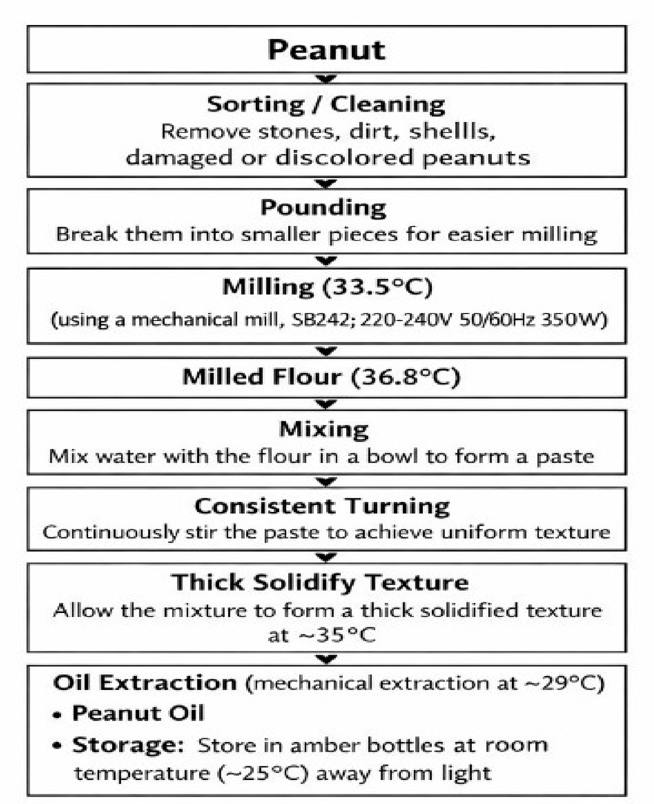



Figure 3: Processing of Peanut Oil

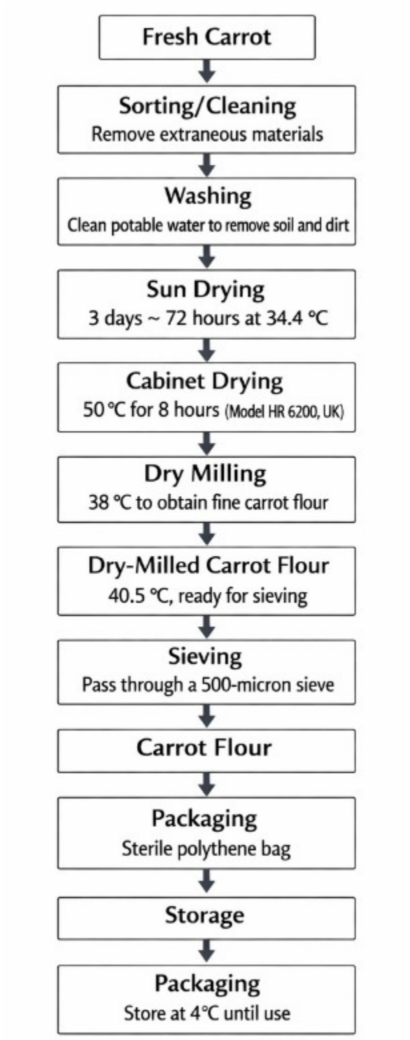



Figure 4: Processing of carrot flour (22)

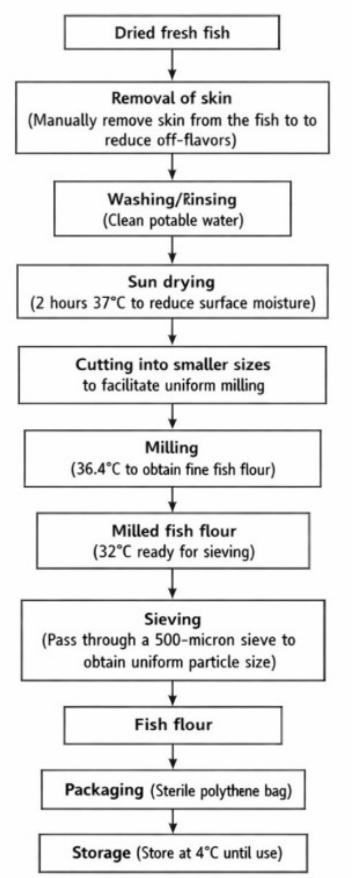



Figure 5: Processing of Fish flour (23)

## Nutri-Survey software (Linear Programming)

The optimization of the complementary food formulation was carried out using Nutri-survey software 2007 with the GLPK Integer Optimizer version 4.57 to determine the optimal combination of maize, cowpea, carrot, fish, and peanut oil for infants aged 6–8, 9–11, and 12–23 months. Nutrient constraints were set for energy, protein, fat, calcium, iron, zinc, vitamin A, vitamin C, and other key micronutrients based on WHO/FAO recommendations, with both minimum and maximum limits. Ingredient quantities were bounded according to practical and acceptability considerations. The linear programming model minimized deviation from recommended nutrient intakes while keeping total weight and energy within acceptable limits. The resulting ingredient amounts, recorded in grammes, were verified for nutrient adequacy and used for subsequent processing into flour blends, ensuring the complementary foods were nutritionally balanced and safe for infants.

The composition of the different flour formulation of the complementary foods are shown in Table 1.

The price index of the purchased ingredient used in the formulation of the complementary foods are shown in Figure 6.

**Table 1: Composition of the different flour formulation (Linear programming: Nutri-Survey software)**

| Age Group (months) | Maize (g) | Cowpea (g) | Peanut (g) | Fish (g) | Carrot (g) |
|---|---|---|---|---|---|
| **6–8** | 40.0 | 6.7 | 20.0 | 16.7 | 16.7 |
| **9–11** | 29.1 | 8.7 | 20.3 | 21.5 | 20.3 |
| **12–23** | 30.8 | 13.2 | 17.6 | 21.6 | 16.8 |
| **Range** | 29–40 | 7–13 | 17–20 | 16–22 | 16–20 |

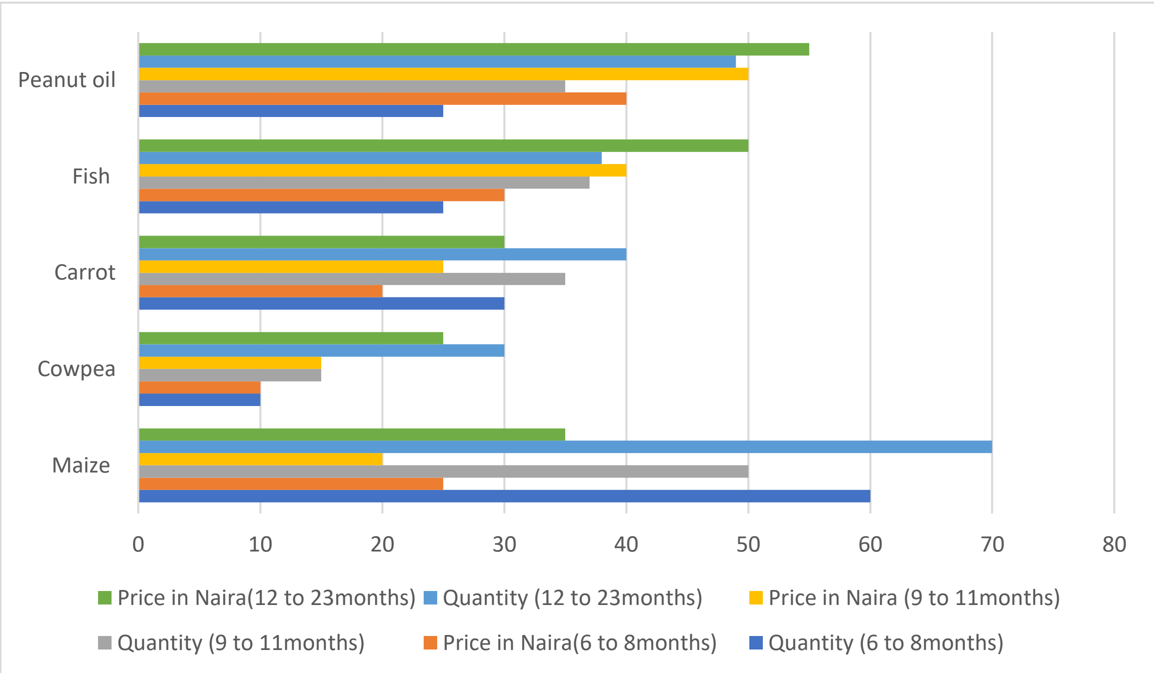



**Figure 6: Price index of the purchased ingredient used in the formulation of the complementary foods**

## Chemical analysis

Moisture, ash, protein, lipid, and crude fibre in the samples were determined using the recommended methods of the Association of Official Analytical Chemists (24). Moisture content was determined by drying the sample in an oven at 105°C until constant weight is achieved. Ash was obtained through incineration of the dried material in a muffle furnace at 550°C for 48 h, Organic nitrogen content was quantified using the micro-Kjeldahl method, crude protein content was estimated by multiplying the organic nitrogen content by a factor of 6.25, lipid content was determined using a Soxhlet apparatus, and crude fibre content was determined by successive digestion. Total carbohydrate content was calculated by difference.

### Determination of minerals

One gramme of the sample (dry, milled complementary food flour) was weighed into a conical flask. Sulfuric acid (10 mL) and nitric acid (30 mL) were added, and the mixture was digested on a hot plate in a fume cupboard until the digest became clear. The digest was then diluted to 100 mL with deionized water and analyzed using an atomic absorption spectrophotometer (AAS) for mineral and heavy metal contents. Calcium, iron, zinc, magnesium, and copper were determined, with the specific wavelengths used as follows: Calcium – 422.7 nm, Iron – 248.3 nm, Zinc – 213.9 nm, Magnesium – 285.2 nm, and Copper – 324.7 nm (24). Among these, copper and iron are often considered heavy metals, while calcium, magnesium, and zinc are essential minerals.

### Determination of the mineral ratio

The ratios of sodium to potassium (Na:K), calcium to phosphorus (Ca:P), calcium to magnesium (Ca:Mg), zinc to copper (Zn:Cu), sodium to magnesium (Na:Mg), iron to copper (Fe:Cu), and iron to zinc (Fe:Zn) were calculated to evaluate the interrelationships among minerals and their implications for nutrient bioavailability, metabolic balance, and long-term health outcomes when the complementary foods are consumed regularly by infants and young children. These ratios are widely used in infant and child nutrition to assess whether mineral interactions may enhance or inhibit absorption, utilization, and physiological functions during periods of rapid growth and development. This was done by dividing one mineral by the other for instance, dividing the value of calcium by the value of phosphorus (25).

### Determination of phytate and mineral molar ratio

Mineral bioavailability was predicted by estimating the molar ratio of phytate to mineral. The mole of phytate to minerals in the samples were calculated by dividing the weight of phytate and minerals with its atomic weight (phytate: 660 g/mol; Fe: 56 g/mol; Zn: 65 g/mol; Ca: 40 g/mol, K: is 39g/mol, Mg: 24g/mol, Cu: 64g/mol, P: 31g/mol).. The molar ratio of phytate and minerals was obtained after dividing the moles of phytate by the moles of minerals (26). Vitamin A was determined spectrophotometrically after appropriate extraction (27). The inclusion of carrot and fish in the formulations was intended to enhance provitamin A and fat-soluble vitamin content

The phytate content was determined using a colorimetric method involving acid extraction and reaction with ferric chloride, followed by spectrophotometric measurement of the ferric–phytate complex (27). Oxalate was analyzed by acid extraction and titration after precipitation as calcium oxalate using standard AOAC procedures (27). α-Amylase activity was measured using the starch–iodine method, in which the degree of starch hydrolysis was quantified spectrophotometrically (28).

### Functional properties

Functional properties, including water absorption capacity, bulk density, swelling capacity, solubility index, and pasting characteristics, were evaluated using standard laboratory methods commonly applied to cereal–legume flour blends to assess their suitability for complementary food formulations (29).

### Sensory evaluation

Sensory evaluation was conducted in the Food Processing and Sensory Evaluation Laboratory of the Department of Nutrition and Dietetics under hygienic conditions. A total of 100 panelists, comprising 20 semi-trained panelists with backgrounds in nutrition and food-related disciplines and 80 untrained panelists, who were nursing mothers recruited from local health centres and surrounding communities, participated in the study. The nursing mothers were familiar with both commercially produced and locally prepared complementary foods and represented the target consumer group.

The complementary food samples were prepared by cooking measured quantities of each flour blend with potable water at a standardized flour-to-water ratio to obtain smooth porridges, following common household preparation methods. Cooking was carried out on a laboratory hot plate, and samples were cooled to a safe serving temperature (~40 °C). All samples were coded with random three-digit numbers and presented in random order. Sensory evaluation was carried out in a well-lit and ventilated sensory room, with panelists seated individually to prevent interaction. To minimize carry-over effects, panelists rinsed their mouths with potable water between samples and were given short rest intervals. Taste, texture, aroma, appearance, colour, and overall acceptability were evaluated using a 9-point hedonic scale, ranging from 9 (like extremely) to 1 (dislike extremely) (30). The results obtained were recorded for subsequent statistical analysis.

### Data analysis

The statistical analysis of all experimental data was performed using IBM SPSS Statistics Version 23. Results are presented as mean ± standard deviation (SD). One-way Analysis of Variance (ANOVA) was used to determine significant differences among means, and Duncan's multiple range test was applied for post hoc comparison at a 5% significance level ($p < 0.05$). Linear programming using Nutri-survey software 2007 was applied separately for ingredient optimization in the formulation of complementary foods and is not part of the statistical analysis.

## RESULT

### Proximate and β-carotene content of the raw materials, composite flour and complementary food

Table 2 reveals the proximate composition of the raw ingredient, composite flour and cooked products. The composite flour for 6-8 months children ranked the highest in moisture, protein and total ash content (10.11 ± 0.01, 14.61 ± 0.03 and 3.28 ± 0.04) respectively, while 9 to 11 months ranked the lowest in same nutrients (8.47 ± 0.04, 11.73 ± 0.04 and 2.07 ± 0.02). 9 to 11 months ranked highest in fat (22.11 ± 0.03), while 6 to 8 months ranked lowest (16.93 ± 0.04), crude fiber ranked the same for all samples.

### Minerals content of the raw materials, composite flour and complementary food

Table 3 reveals the minerals composition of the raw ingredient, composite flour and cooked product. The composite flour for 9-11 months children ranked highest in calcium (72.30 ± 0.45), magnesium (40.99 ± 0.12), potassium (94.89 ± 0.33), iron (9.59 ± 0.03), copper (1.11 ± 0.00), zinc (0.54 ± 0.00) and phosphorus (54.84 ± 0.01) content respectively, The composite flour for 6 to 8 months children ranked the lowest in same nutrients.

**Table 2: Proximate and β-carotene content of the raw materials, composite flour and complementary food**

| Raw Ingredients | | | | | | | |
|---|---|---|---|---|---|---|---|
| Ingredients | Moisture (g) | Protein (g) | Fat (g) | Crude Fibre (g) | Ash (g) | CHO (g) | B-carotene (mcg) |
| Malted Maize | $10.42^{b}\pm0.02$ | $9.59^{c}\pm0.03$ | $2.34^{d}\pm0.02$ | $5.02^{a}\pm0.13$ | $1.16^{d}\pm0.01$ | $71.48^{a}\pm0.08$ | $0.43^{c}\pm0.00$ |
| Malted Cowpea | $9.91^{c}\pm0.13$ | $10.02^{b}\pm0.07$ | $2.17^{e}\pm0.06$ | $4.79^{b}\pm0.00$ | $1.51^{c}\pm0.05$ | $71.62^{a}\pm0.07$ | $0.48^{b}\pm0.00$ |
| Fish Flour | $8.57^{d}\pm0.05$ | $60.05^{a}\pm0.07$ | $7.12^{b}\pm0.01$ | $0.00^{c}\pm0.04$ | $17.37^{a}\pm0.04$ | $6.88^{c}\pm0.01$ | $0.44^{c}\pm0.00$ |
| Carrot Flour | $17.67^{a}\pm0.09$ | $7.04^{d}\pm0.04$ | $4.46^{c}\pm0.03$ | $4.99^{a}\pm0.03$ | $5.51^{b}\pm0.04$ | $60.32^{b}\pm0.09$ | $2.10^{a}\pm0.00$ |
| Peanut Oil | $0.45^{e}\pm0.02$ | $0.17^{e}\pm0.02$ | $94.15^{a}\pm0.04$ | $0.00^{c}\pm0.00$ | $0.19^{e}\pm0.02$ | $5.04^{d}\pm0.07$ | $0.05^{d}\pm0.00$ |
| Composite Flour | | | | | | | |
| Flour Formulation | Moisture (g) | Protein (g) | Fat (g) | Crude fiber (g) | Total ash (g) | Carbohydrate (g) | B-carotene (mcg) |
| 6 to 8 months children | $10.11^{b}\pm0.01$ | $14.61^{a}\pm0.03$ | $16.93^{c}\pm0.04$ | $4.34^{a}\pm0.02$ | $3.28^{a}\pm0.04$ | $50.72^{a}\pm0.02$ | $1.12^{a}\pm0.00$ |
| 9 to 11 months children | $8.47^{b}\pm0.04$ | $11.73^{b}\pm0.04$ | $22.11^{ab}\pm0.03$ | $4.01^{a}\pm0.03$ | $2.07^{b}\pm0.02$ | $51.61^{a}\pm0.02$ | $0.83^{b}\pm0.01$ |
| 12 to 23 months children | $8.59^{b}\pm0.03$ | $13.35^{ab}\pm0.06$ | $17.85b^{c}\pm0.17$ | $4.26^{a}\pm0.01$ | $2.13^{b}\pm0.01$ | $53.82^{a}\pm0.20$ | $0.73^{c}\pm0.00$ |
| Cooked Samples | | | | | | | |
| Samples | Moisture | Protein | Fat | Crude fiber | Total ash | Carbohydrate | B-carotene |
| 6 to 8 months children | $30.00^{a} \pm 10.00$ | $9.02^{c} \pm 1.27$ | $17.99^{bc} \pm 2.52$ | $2.41^{b} \pm 0.33$ | $2.11^{b} \pm 0.32$ | $38.46^{b} \pm 5.57$ | $0.52^{d} \pm 0.07$ |
| 9 to 11 months children | $30.00^{a} \pm 10.00$ | $6.96^{d} \pm 0.95$ | $23.14^{a} \pm 3.37$ | $1.93^{bc} \pm 0.29$ | $1.12^{c} \pm 0.14$ | $36.83^{b} \pm 5.26$ | $0.26^{e} \pm 0.04$ |
| 12 to 23 months children | $45.00^{a} \pm 5.00$ | $6.27^{d} \pm 0.55$ | $14.73^{c} \pm 1.39$ | $1.65^{c} \pm 0.16$ | $0.96^{c} \pm 0.10$ | $31.38^{b} \pm 2.80$ | $0.19^{e} \pm 0.02$ |

Values are reported as mean ± standard deviation, and mean values bearing different superscript letters within the same column differ significantly ($p < 0.05$)

**Table 3: Minerals content of the raw materials, composite flour and complementary food**

| Raw Ingredients | | | | | | | |
|---|---|---|---|---|---|---|---|
| Ingredients | Ca | Mg | K | Fe | Cu | Zn | P |
| Malted Maize | $62.73^{b}\pm0.01$ | $32.10^{c}\pm0.08$ | $105.05^{b}\pm0.14$ | $5.68^{c}\pm0.09$ | $1.06^{c}\pm0.08$ | $0.18^{c}\pm0.02$ | $50.77^{c}\pm0.22$ |
| Malted Cowpea | $55.55^{c}\pm0.11$ | $37.37^{b}\pm0.05$ | $113.93^{a}\pm1.26$ | $6.04^{b}\pm0.01$ | $1.19^{b}\pm0.00$ | $0.20^{c}\pm0.01$ | $61.25^{b}\pm0.29$ |
| Fish Flour | $26.41^{d}\pm0.44$ | $19.48^{d}\pm0.11$ | $21.72^{d}\pm0.04$ | 5.81bc±0.28 | $0.45^{d}\pm0.04$ | $7.32^{b}\pm0.00$ | $12.16^{d}\pm0.06$ |
| Carrot Flour | $215.96^{a}\pm0.24$ | $114.57^{a}\pm0.00$ | $97.01^{c}\pm0.16$ | $14.05^{a}\pm0.03$ | $1.44^{a}\pm0.00$ | $12.09^{a}\pm0.00$ | $101.29^{a}\pm0.08$ |
| Peanut Oil | $0.10^{e}\pm0.00$ | $0.02^{e}\pm0.00$ | $0.04^{e}\pm0.00$ | $0.04^{d}\pm0.00$ | $0.00^{e}\pm0.00$ | $0.00^{d}\pm0.00$ | $0.00^{e}\pm0.00$ |

**Table 3 contd**

| Composite Flour |
|---|

| Nutrient | Ca | Mg | K | Fe | Cu | Zn | P |
|---|---|---|---|---|---|---|---|
| 6 to 8 months children | 60.64$^{a}$b±0.04 | 36.85$^{a}$±0.05 | 80.43$^{a}$±0.44 | 6.98$^{a}$±0.05 | 1.08$^{a}$±0.01 | 0.50$^{a}$±0.00 | 43.87$^{a}$±0.08 |
| 9 to 11 months children | 72.30$^{a}$±0.45 | 40.99$^{a}$±0.12 | 94.89$^{a}$±0.33 | 9.59$^{a}$±0.03 | 1.11$^{a}$±0.00 | 0.54$^{a}$±0.00 | 54.84$^{a}$±0.01 |
| 12 to 23 months children | 68.56$^{a}$±0.13 | 38.48$^{a}$±0.14 | 88.50$^{a}$±0.14 | 8.43$^{a}$±0.08 | 1.10$^{a}$±0.00 | 0.52$^{a}$±0.00 | 50.03$^{a}$±0.05 |
| Cooked Samples | | | | | | | |
| Nutrient | Ca | Mg | K | Fe | Cu | Zn | P |
| 6 to 8 months children | 31.98$^{cd}$±10.65 | 18.85$^{a}$±6.27 | 44.71$^{a}$±14.89 | 3.59$^{a}$±1.24 | 0.52$^{a}$±0.16 | 1.86$^{a}$±0.61 | 30.13$^{a}$±10.20 |
| 9 to 11 months children | 46.63$^{bc}$±6.68 | 25.49$^{a}$±3.67 | 63.31$^{a}$±9.07 | 6.39$^{a}$±0.91 | 0.60$^{a}$±0.08 | 2.51$^{a}$±0.35 | 36.11$^{a}$±5.15 |
| 12 to 23 months children | 24.99$^{d}$±4.94 | 15.14$^{a}$±3.04 | 34.94$^{a}$±7.00 | 3.99$^{a}$±0.75 | 0.41$^{a}$±0.08 | 1.71$^{a}$±0.34 | 24.83$^{a}$±4.94 |

Values are reported as mean ± standard deviation, and mean values bearing different superscript letters within the same column differ significantly ($p < 0.05$).

### Antinutrient contents and mineral ratio of the raw materials, composite flour and complementary food

Table 4 presents the anti-nutritional content and mineral ratio of the raw ingredient, composite flour, and cooked product. The composite flour for 6-8 months children ranked highest in phytate (6.14 ± 0.00), oxalate (61.17 ± 0.20), α amylase (12.81a±0.06), Ca:P (1.386), Zn:Cu (0.472), Fe:Zn (13.789), K:Mg (2.192), Mg:K (0.456) and Ca:Mg (1.644) content ranked highest in composite flour respectively. Additionally, the composite flour for 12-23-month-old children ranked the lowest in same nutrients.

**Table 4: Antinutrient contents and mineral ratio of the raw materials, composite flour and complementary food**

| Ingredients | Phytate | Oxalate | α Amylase | Ca:P | Zn:Cu | Fe:Zn | K:Mg | Mg:K | Ca:Mg |
|---|---|---|---|---|---|---|---|---|---|
| Malted Maize | 6.11$^{b}$±0.01 | 44.06$^{b}$±0.00 | 7.04$^{c}$±0.08 | 1.239 | 0.174 | 30.562 | 3.312 | 0.302 | 1.962 |
| Malted Cowpea | 5.50$^{c}$±0.01 | 39.92$^{c}$±0.95 | 8.50$^{b}$±0.03 | 0.902 | 0.166 | 30.675 | 3.056 | 0.327 | 1.488 |
| Fish Flour | 8.83$^{a}$±0.02 | 0.00$^{d}$±0.00 | 1.25$^{d}$±0.02 | 2.146 | 15.14 | 0.779 | 1.111 | 0.9 | 1.326 |
| Carrot Flour | 4.94$^{d}$±0.03 | 171.92$^{a}$±0.20 | 12.56$^{a}$±0.14 | 2.138 | 8.872 | 1.184 | 0.845 | 1.184 | 1.885 |
| Peanut Oil | 4.38$^{e}$±0.01 | 0.00$^{d}$±0.00 | 0.00$^{e}$±0.00 | 19.6 | 0.00 | 0.00 | 1.714 | 0.583 | 4.667 |
| 6 to 8 months children | 6.14$^{a}$±0.00 | 61.17$^{a}$±0.20 | 12.81$^{a}$±0.06 | 1.386 | 0.472 | 13.789 | 2.192 | 0.456 | 1.644 |
| 9 to 11 months children | 6.11$^{a}$±0.01 | 51.58$^{b}$±0.15 | 10.17$^{b}$±0.04 | 1.326 | 0.482 | 17.91 | 2.314 | 0.432 | 1.78 |
| 12 to 23 months children | 5.59$^{a}$±0.02 | 44.49$^{c}$±0.02 | 11.12$^{ab}$±0.03 | 1.369 | 0.474 | 16 | 2.312 | 0.433 | 1.785 |
| 6 to 8 months children | 3.47$^{a}$±1.18 | 6.07$^{e}$±2.06 | 5.62$^{c}$±1.86 | 1.071 | 3.488 | 1.875 | 2.371 | 0.422 | 1.696 |
| 9 to 11 months children | 3.59$^{a}$±0.40 | 8.78$^{e}$±1.35 | 5.90$^{c}$±0.86 | 1.292 | 4.17 | 2.553 | 2.482 | 0.403 | 1.828 |
| 12 to 23 months children | 2.69$^{a}$±0.53 | 19.67$^{d}$±4.12 | 4.52$^{c}$±0.91 | 1.005 | 4.123 | 2.317 | 2.307 | 0.434 | 1.646 |
| Standard value | | | | ≥0.5 | 10.0 | 2 | 2 | 1 | 2 |

Values are reported as mean ± standard deviation, and mean values bearing different superscript letters within the same column differ significantly ($p < 0.05$).

### Functional and organoleptic properties of the developed complementary food products

Table 5 reveals the functional and sensory properties of the complementary foods. The formulation for 6-8months ranked the highest in term of water absorption and foaming capacity (120.87 ± 0.10 and 5.69 ± 0.04) while 12-23 and 9-11months ranked lowest in loose bulk density (121.81 ± 0.34and 4.22 ± 0.02) respectively. The sensory result shows that 12-23 months developed product ranked the highest (6.60 ± 1.50) in terms of general acceptability by semi-untrained panelist while 6-8 months ranked lowest (3.30 ± 1.65). Additionally, 6-8 months developed product ranked highest (5.75 ± 2.00) in terms of general acceptability by untrained panelist while 9-11 months ranked lowest.

**Table 5: Functional and organoleptic properties of the developed complementary food products**

| Nutrient | Loose bulk density (g/ml) | Packed bulk density (g/ml) | Water absorption capacity (%) | Oil absorption capacity (%) | Swelling power (%) | Solubility (%) | Dispersibility @2hrs (%) | Sedimentation volume (ml) | Foam capacity (%) |
|---|---|---|---|---|---|---|---|---|---|

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 6 to 8 months children | 0.51±0.00[a] | 0.73±0.00[a] | 120.87±0.10[c] | 54.33±0.08[c] | 243.85±1.64[c] | 42.72±0.51[b] | 67.00±0.00[a] | 33.00±0.00[b] | 5.69±0.04[a] |
| 9 to 11 months children | 0.50±0.00[b] | 0.70±0.00[c] | 125.04±0.08[a] | 57.03±0.12[a] | 262.29±0.25[b] | 47.89±0.30[a] | 66.00±0.00[b] | 34.00±0.00[a] | 4.22±0.02[b] |
| 12 to 23 months children | 0.49±0.00[c] | 0.71±0.00[b] | 121.81±0.34[b] | 55.31±0.04[b] | 281.84±0.37[a] | 47.65±0.23[a] | 66.25±0.35[b] | 33.75±0.35[b] | 4.32±0.04[b] |
| | | | | | Semi-Untrained Panelist | | | | |
| Nutrient | Attribute | Texture | Taste | Appearance | Colour | Aroma | General acceptability | | |
| 6 to 8 months children | 3.30±1.65[b] | 4.75±1.16[b] | 3.70 ± 1.68[c] | 4.00 ± 1.71[b] | 4.00 ± 1.71[c] | 5.20 ± 2.01[b] | 3.30 ± 1.65[b] | | |
| 9 to 11 months children | 6.05 ± 1.90[a] | 6.35 ± 1.63[a] | 6.60 ± 1.31[a] | 5.75 ± 1.44[a] | 6.10 ± 1.61[a] | 6.20 ± 1.54[a] | 6.05 ± 1.90[a] | | |
| 12 to 23 months children | 6.60 ± 1.50[a] | 4.80 ± 1.93[b] | 5.85 ± 1.78[b] | 5.70 ± 1.49[a] | 5.70 ± 1.68[b] | 5.25 ± 2.04[b] | 6.60 ± 1.50[a] | | |
| | | | | | Untrained Panelist | | | | |
| 6 to 8 months children | 5.75 ± 2.00[a] | 5.58 ± 2.09[a] | 5.62 ± 1.96[a] | 5.43 ± 1.86[a] | 5.76 ± 1.98[a] | 5.60 ± 1.94[a] | 5.75 ± 2.00[a] | | |
| 9 to 11 months children | 4.97 ± 2.23[b] | 4.90 ± 2.18[b] | 5.23 ± 2.00[a] | 4.93 ± 2.16[b] | 5.23 ± 2.01[a] | 5.08 ± 2.03[a] | 4.97 ± 2.23[b] | | |
| 12 to 23 months children | 5.30 ± 2.29[a] | 5.13 ± 1.97[a] | 5.23 ± 2.15[a] | 5.20 ± 2.17[a] | 5.37 ± 1.89[a] | 5.33 ± 1.92[a] | 5.30 ± 2.29[a] | | |

Values are reported as mean ± standard deviation, and mean values bearing different superscript letters within the same column differ significantly ($p < 0.05$).

## DISCUSSION

This study determined the proximate and minerals composition, B-carotene content, sensory evaluation and functional properties of complementary foods formulations from maize, cowpea, fish, carrot and peanut oil. The linear programming optimization model designed to meet the age-specific energy and nutrient requirements of infants aged 6–23 months, using WHO/FAO recommended intakes as constraints (1). All moisture content from this study were below 11% moisture which agrees with the study previously carried out (31) to evaluate yellow maize and green pea composite flours. Low moisture content indicates lower water activity, which enhances shelf life by reducing microbial growth, unlike findings from (32) who reported higher moisture levels that could enhance microbial growth which facilitate rapid deterioration of the product.

There was significant increase in protein content with higher additions of fish and carrot flour, likely due to their rich protein profiles (33). The protein values slightly exceeded WHO/FAO standards (9.1%–10.9%). This supports earlier research (34), showing that malting processes can enhance protein content by reducing anti-nutritional factors. Protein is critical for bodily structure and function, especially for infants and young children, who require higher per-body-weight protein intake due to rapid growth (35). The fat content was slightly lower than FAO/WHO (1) recommended dietary allowance for 6-23 months children (<2.5%). Abegunde *et al.,* (36), reported decrease in fat content in their study on evaluation of maize chips fortified with cowpea flour. Despite the lower fat, it still contributed essential fatty acids like omega-3 and omega-6, which are vital for neural development, energy provision, and vitamin transport (36).

The crude fibre was within the acceptable limit (<5g/100g) set by FAO/WHO, ensuring suitability for young children's digestive systems (4). Contrarily, (37) recorded high crude fiber content which could pose digestive challenges for infants due to immature gastrointestinal systems. The ash content of the complementary foods was higher than the value of ash content reported (38). Minerals are vital to the functioning of many body processes. They are critical players in nervous system functioning, other cellular processes, water balance, and structural (e.g. skeletal) systems (11). Carbohydrate content of this study is similar to findings by (39). Since carbohydrates are the body's primary energy source, deficiencies might force the body to metabolize proteins and fats instead, risking tissue depletion. Similar to this study, (40) also reported low pro-vitamin A content attributed to processing method. β-carotene among numerous functions in the human body supplies pro-vitamin A positively affecting embryonic development, correct growth and sight (41).

The importance of mineral ratios cannot be over emphasized as they provide insight into the bioavailability of minerals and the likelihood of nutrient interactions that could affect growth, bone development, and metabolic health (42). Additionally, according to (43), when a mineral ratio is below or above the standard value, it can open up ways to metabolic disorders. The bio-availability of minerals is predicted by the molar ratios of specific anti nutrients known to form complexes with specific minerals and compared to their critical values (44). Additionally, (45) report that higher molar ratios of phytate to minerals are predicted to have poor bio availability of minerals when consumed by consumers and can lead to deficiencies which can pose a threat to the health of such individuals. The study reveals that the functional characteristics of a complementary food, including water and oil absorption, influence the body's nutrient utilization. The 12-23 months product ranked highest in general acceptability, while the 6-8 months product ranked lowest. Sensory evaluation is crucial for product optimization (46). The findings suggest that the formulations developed can be used to improve the quality of food and eliminate nutrient deficits in low-resource environments.

Our study has a limitation. The present study was restricted to the laboratory and sensory tests; hence, additional research on the shelf-life and *in vivo* feeding studies should be conducted to support the bioavailability of nutrients and the lasting nutritional advantages.

## CONCLUSION

This study suggests that the use of locally available ingredients such as maize, cowpea, carrot, fish, and peanut oil in complementary food formulation may reduce reliance on expensive commercial products while improving the nutritional status of children aged 6–23 months. Such formulations provide essential nutrients including protein, energy, vitamins, and minerals required for optimal growth and development, particularly in low-resource settings where access to commercial complementary foods may be limited.

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