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Nutritional Quality, Functional Properties, and Sensory Acceptability of Complementary Food Porridge Blends Formulated From Fermented Millet, Pigeon Pea, and Carrot Flour

[1]Igbokwe Amarachi C. and *[2]Igbokwe Kosisochukwu C

[1]Department of Food Science and Technology, Faculty of Agriculture and Natural Resources, Enugu State University of Science and Technology, Enugu State, Nigeria.
[2]Department of Nutrition and Dietetics, Faculty of Agriculture, Federal University of Mubi, Adamawa State, Nigeria.

*Corresponding authors' email: kosidinma05@gmail.com
ORCID: 0009-0005-8078-4101

ABSTRACT

Protein-energy malnutrition and micronutrient deficiencies remain persistent public health challenges among infants aged 6-24 months in Nigeria and sub-Saharan Africa, driven largely by the nutritional inadequacy of cereal-based complementary foods. This study formulated and evaluated five complementary food porridge blends from fermented millet, pigeon pea, and carrot flour at ratios of 100:0:0 (A, control), 90:5:5 (B), 80:15:5 (C), 70:25:5 (D), and 60:35:5 (E). Proximate composition, mineral and vitamin content, amino acid profile, functional properties, and sensory acceptability were determined using AOAC standard methods and a nine-point hedonic scale. Protein content increased significantly ($p < 0.05$) from 19.11% in Sample A to 21.80% in Sample E, exceeding the WHO-recommended minimum of 10% for infant complementary foods across all blends. Calcium (0.21–0.52 mg/100 g), magnesium (0.13–0.33 mg/100 g), and iron (0.28–0.56 mg/100 g) improved with pigeon pea inclusion, while vitamins A, C, D, and B6 declined due to processing-related thermal losses. Essential amino acids, particularly lysine, leucine, threonine, and valine, increased progressively, confirming the nutritional complementarity of the cereal-legume combination. The functional properties were appropriate for infant porridge reconstitution across all blends. Sensory evaluation favored Sample B (90:5:5), which recorded the highest overall acceptability score (8.33/9.0). These findings demonstrate that fermented millet-pigeon pea-carrot blends represent a sustainable, locally available, and low-cost strategy to address infant malnutrition in Nigeria.

Keywords: Complementary food; Infant nutrition; Protein-energy malnutrition; Sensory evaluation

INTRODUCTION

Malnutrition continues to represent a major public health burden globally, with the greatest consequences borne by infants and young children in low- and middle-income countries (LMICs). According to the UNICEF/WHO/World Bank Joint Child Malnutrition Estimates, an estimated 148 million children under five were stunted, 45 million were wasted, and nearly 40 million were overweight in 2023 (UNICEF *et al.*, 2023). In Nigeria, stunting, wasting, and underweight remain prevalent particularly across the northern geopolitical zones contributing substantially to infant morbidity and mortality (Obasohan *et al*., 2020).

The period between 6 and 24 months of age represents a critical nutritional window; as breast milk alone becomes insufficient to meet the growing infant's energy and micronutrient demands, the quality of complementary foods assumes paramount importance (WHO, 2021). However, conventional complementary foods in most LMIC settings including Nigeria are predominantly thin cereal-based gruels derived from maize, millet, or sorghum, which are characteristically deficient in protein, essential amino acids, iron, zinc, calcium, and provitamin A (Oke *et al*., 2022). This nutritional gap predisposes infants to stunting, wasting, anaemia, and impaired cognitive development.

Millet (Pennisetum glaucum and related species) is a drought-tolerant, climate-resilient cereal extensively cultivated across the Sahel and northern Nigeria. Compared with wheat and rice, millet offers a higher concentration of protein, iron, zinc, calcium, and B-vitamins, as well as a low glycemic index (Anitha *et al*., 2024). Pigeon pea (Cajanus cajan L. Millsp.) is a grain legume ranking among the six most widely cultivated legumes globally, prized for its high lysine content, dietary fiber, and essential mineral profile (Abebe *et al*., 2022). Because millet and most cereals are limiting in lysine while pigeon pea is rich in it, combining the two ingredients creates a nutritionally complementary protein source. Carrot (Daucus carota L.) provides provitamin A (β-carotene), vitamin C, and dietary fiber, directly addressing the micronutrient deficiencies most commonly observed in LMIC infant diets (Ignaczak *et al*., 2023).

Fermentation is a low-cost, traditional food processing technique that significantly improves the nutritional quality of cereal-legume blends by reducing antinutritional factors principally phytate, tannins, and polyphenols while enhancing protein digestibility and mineral bioavailability (Adebo, 2022; Anaemene and Fadupin, 2022). Several studies have investigated complementary food formulations from cereal-legume blends; however, the specific combination of fermented millet, fermented pigeon pea, and carrot remains understudied, and data on its amino acid balance, functional properties, and consumer acceptability are limited.

This study therefore aimed to produce and evaluate the nutritional quality, functional properties, and sensory acceptability of complementary food porridge blends formulated from fermented millet, pigeon pea, and carrot flour, with the objective of providing evidence-based support for the development of sustainable, locally sourced infant foods capable of addressing protein-energy malnutrition and micronutrient deficiencies in Nigeria.

MATERIALS AND METHODS

Procurement of Raw Materials

Whole millet grains, dried pigeon pea seeds, and fresh carrots were purchased from Ogbete Main Market, Enugu State, Nigeria. All chemicals and reagents used for laboratory analyses were of analytical grade.

Production of Flour Components

Millet flour: Whole millet seeds were sorted, cleaned, washed, and soaked in tap water (seed-to-water ratio 1:3 w/v) for 48 hours at 28°C to facilitate natural fermentation. Fermented grains were oven-dried at 60°C for 12 hours, milled using an attrition mill, and sieved through a 250 µm aperture sieve. The flour was stored in sealed airtight containers until use.

Pigeon pea flour: Seeds were sorted, cleaned, washed, and soaked in distilled water (1:3 w/v) for 72 hours to facilitate fermentation. Fermented seeds were washed, drained, oven-dried at 60°C for 12 hours, dehulled manually, milled, and sieved as above.

Carrot flour: Fresh carrots were sorted, washed, peeled, sliced, blanched in hot water for 3 minutes, drained, and oven-dried at 50°C for 12 hours. Dried slices were milled to fine powder, sieved, packaged, and stored.

Formulation of Composite Blends

Five flour blends were formulated by combining fermented millet, fermented pigeon pea, and carrot flour in the proportions shown in Table 1. Sample a (100% millet flour) served as the control.

Table 1: Composition of the Complementary Food Flour Blends

Sample	Millet (%)	Pigeon pea (%)	Carrot (%)
A	100	0	0
B	90	5	5
C	80	15	5
D	70	25	5
E	60	35	5

Proximate Composition

Moisture, crude protein, crude fat, ash, and crude fiber contents were determined in duplicate according to AOAC (2015) methods. Protein content was calculated using a nitrogen-to-protein conversion factor of 6.25. Carbohydrate content was determined by difference: 100 – (moisture + protein + fat + ash + fiber).

Mineral Composition

Calcium and magnesium were determined by complexometric titration using 0.02N EDTA solution as described by Onwuka (2018). Iron and zinc were determined by atomic absorption spectrophotometry (AAS) after acid digestion of samples.

Vitamin Composition

Provitamin A (β-carotene equivalents) was determined spectrophotometrically at 325 nm following saponification and solvent extraction (Onwuka, 2018). Vitamin C was quantified by titration against 0.01 mol/L CuSO4 solution using starch as indicator. Vitamins D and B^6 were determined according to AOAC (2016) spectrophotometric procedures involving saponification and solvent extraction for vitamin D, and DMAB colorimetric reaction at 430 nm for vitamin B6.

Amino Acid Profile

The amino acid profile was determined using HPLC with a cation exchange column and post-column ninhydrin derivatization following acid hydrolysis in 6N HCl at 110°C for 24 hours under nitrogen atmosphere (AOAC, 2018; Onwuka, 2018). Sulfur amino acids (methionine, cysteine) were oxidized with performic acid prior to hydrolysis. Results are expressed as g per 100 g crude protein.

Functional Properties

Bulk density (BD), water absorption capacity (WAC), oil absorption capacity (OAC), and swelling capacity (SC) were determined in duplicate as described by Onwuka (2018). WAC and OAC are expressed as g water or oil absorbed per g dry sample; SC as percentage volume increase after one-hour hydration.

Sensory Evaluation

Reconstituted porridge samples were evaluated by 20 trained mothers (panelists) attending immunization clinic at a Primary Health Center in Agbani, Enugu State. Panelists assessed appearance, mouthfeel, taste, aroma, consistency, and overall acceptability using a nine-point hedonic scale (1 = dislike extremely; 9 = like extremely). Mouth rinse was provided between samples. Samples were coded and presented in randomized order.

Statistical Analysis

Data are expressed as mean ± standard deviation of duplicate determinations. One-way analysis of variance (ANOVA) was performed using IBM SPSS Statistics v25. Mean separation was by Duncan's Multiple Range Test (DMRT) at $p < 0.05$.

RESULTS AND DISCUSSION

Proximate Composition

The proximate composition of the five complementary food blends is presented in Table 2. Moisture content ranged from 8.82% in Sample C to 10.25% in Sample A, declining progressively with increasing pigeon pea substitution. The lower moisture values in legume-enriched blends suggest improved stability and reduced susceptibility to microbial spoilage, consistent with findings in fermented maize-soybean-carrot formulations (Barber *et al*., 2017) and pearl millet-pigeon pea composites (Ahmed and Pandey, 2024). Foods with moisture content below 10% generally exhibit acceptable shelf life and reduced water activity (Forsido *et al.*, 2021).

Protein content increased significantly ($p < 0.05$) from 19.11% (Sample A) to 21.80% (Sample E), driven by the higher protein concentration of pigeon pea (16.7–26.8%) relative to millet (Abebe *et al*., 2022). All five blends exceeded the WHO/FAO minimum recommended protein level of 10% for infant complementary foods (Arsenault and Brown, 2017). Comparable improvements have been reported by Agomuo *et al*. (2025), who observed increased protein and improved nutritional quality following pigeon pea supplementation of maize-based weaning foods, as well as by Sodipo *et al.* (2018) in extruded pearl millet-pigeon pea products, and by Adeoye *et al*. (2024) in co-fermented maize-millet-pigeon pea blends. The fermentation applied to both cereal and legume components likely contributed further protein enhancement through microbial protease activity (Adebo, 2022).

Fat content decreased from 3.35% (Sample A) to 1.45% (Sample D), reflecting the inherently lower lipid content of pigeon pea relative to millet. Although reduced fat slightly lowers the energy density of the blend, this is readily compensated during infant feeding by the addition of small quantities of vegetable oil or milk. Ash content, an indicator of total mineral load, ranged from 2.00% (Sample C) to 3.35% (Sample D), increasing with greater pigeon pea and carrot inclusion and reflecting the enhanced mineral contribution from both ingredients (Adeoye *et al*., 2024). Crude fiber increased from 1.80% (Sample A) to 3.50% (Sample E); these values are within the range considered acceptable for infant complementary foods by Forsido *et al*. (2021) and align with data from millet-sweet potato-pigeon pea formulations (Oyarekua *et al*., 2023). Carbohydrate content ranged from 60.83% to 63.81%, declining marginally with increasing legume substitution as protein and fiber displaced the millet-derived carbohydrate fraction (Ukeyima *et al*., 2019; Bello *et al*., 2020).

Table 2: Proximate Composition (%) of the Complementary Food Flour Blends

Sample	Moisture	Protein	Fat	Ash	Fibre	Carbohydrate
A	10.25 ± 0.21^{a}	19.11 ± 0.98^{c}	3.35 ± 0.21^{a}	2.90 ± 0.14^{ab}	1.80 ± 0.28^{b}	62.99 ± 0.98^{ab}
B	9.45 ± 0.21^{bc}	19.83 ± 0.24^{bc}	2.50 ± 0.28^{b}	2.75 ± 0.35^{b}	1.96 ± 0.18^{b}	63.51 ± 0.18^{ab}
C	8.82 ± 0.26^{d}	21.12 ± 0.45^{ab}	2.08 ± 0.01^{b}	2.00 ± 0.00^{c}	2.17 ± 0.04^{b}	63.81 ± 0.22^{a}
D	9.80 ± 0.28^{ab}	21.47 ± 0.18^{a}	1.45 ± 0.35^{c}	3.35 ± 0.21^{a}	3.10 ± 0.14^{a}	60.83 ± 0.10^{c}
E	8.90 ± 0.01^{cd}	21.80 ± 0.09^{a}	1.50 ± 0.00^{c}	2.60 ± 0.14^{b}	3.50 ± 0.14^{a}	61.69 ± 0.10^{bc}

Values are mean ± SD of duplicate determinations. Means with different superscript letters in the same column differ significantly ($p < 0.05$). Sample A = 100% millet (control); B = 90:5:5; C = 80:15:5; D = 70:25:5; E = 60:35:5 (millet: pigeon pea: carrot).

Mineral Composition

Mineral composition results are presented in Table 3. Calcium content increased progressively from 0.21 mg/100 g (Sample A) to 0.52 mg/100 g (Sample E), attributable to the higher calcium content of pigeon pea compared with most cereals (Haji *et al*., 2024). Magnesium also increased significantly from 0.13 to 0.33 mg/100 g; magnesium is essential for bone development, energy metabolism via ATP synthesis, and enzyme function (Maphosa and Jideani, 2017). These findings are consistent with reports by Anitha *et al*. (2019) and Adeoye *et al*. (2024), who documented enhanced calcium and magnesium in millet-legume blend formulations.

Iron content ranged from 0.28 to 0.56 mg/100 g, peaking in Sample B, indicating that a 5% pigeon pea inclusion optimally increased iron retention in the blend. Iron is essential for haemoglobin synthesis and neurological development in infants (Georgieff *et al*., 2019). Zinc was highest in Sample B (41.50 mg/100 g) and lower at higher legume inclusion levels. This pattern is consistent with studies phytate-zinc binding observed in legume-rich blends, where elevated phytate concentrations reduce zinc bioavailability (Nsabimana *et al*., 2024). Processing interventions such as germination or extrusion in future work could mitigate this effect.

Table 3: Mineral Composition (Mg/100 G) of the Complementary Food Flour Blends

Sample	Calcium (Ca)	Magnesium (Mg)	Zinc (Zn)	Iron (Fe)
A	0.21 ± 0.01^{d}	0.13 ± 0.01^{c}	29.00 ± 1.41^{b}	0.28 ± 0.00^{c}
B	0.39 ± 0.01^{c}	0.25 ± 0.02^{b}	41.50 ± 0.71^{a}	0.56 ± 0.00^{a}
C	0.45 ± 0.04^{bc}	0.25 ± 0.01^{b}	27.50 ± 2.12^{b}	0.28 ± 0.01^{c}
D	0.51 ± 0.01^{ab}	0.30 ± 0.01^{a}	26.00 ± 2.83^{b}	0.45 ± 0.01^{b}
E	0.52 ± 0.03^{a}	0.33 ± 0.01^{a}	30.50 ± 2.12^{b}	0.43 ± 0.01^{b}

Values are mean ± SD of duplicate determinations. Different superscript letters within the same column indicate significant differences ($p < 0.05$).

Vitamin Composition

Vitamin composition data are presented in Table 4. Provitamin A (β-carotene equivalents) decreased significantly from 453.67 µg/100 g in Sample A to 200.72 µg/100 g in Sample E. This progressive decline reflects the dilution of millet-associated carotenoids by increasing pigeon pea substitution, compounded by thermal degradation of β-carotene during drying (Garg, 2021). The fixed 5% carrot inclusion was insufficient to compensate for this reduction; Ignaczak *et al*. (2023) reported losses of up to 70% of carotenoids from carrot-based powders during drying at temperatures above 60°C, while Šeregelj *et al*. (2022) documented similar degradation trends during storage of encapsulated carrot extracts.

Vitamin C ranged from 4.50 mg/100 g (Sample A) to 1.66 mg/100 g (Sample E), declining significantly with pigeon pea substitution. Vitamin C is among the most heat-labile of all nutrients, and its loss during oven drying and milling is well established (Ignaczak *et al*., 2023). Vitamin D decreased from 216.25 to 160.51 µg/100 g, an outcome likely related to the reduced lipid matrix in legume-rich blends, since fat-soluble vitamins depend on lipid presence for stability and absorption (Janoušek *et al*., 2022). Vitamin B6 (pyridoxine) declined from 0.18 to 0.07 mg/100 g, consistent with the well-documented susceptibility of water-soluble B-vitamins to thermal and oxidative losses during processing (Gowda *et al*., 2022). These findings collectively underscore the need for optimized, lower-temperature drying conditions or post-processing fortification to preserve the vitamin content of future formulations.

Table 4: Vitamin Composition (Per 100 G) of the Complementary Food Flour Blends

Sample	Vitamin A (µg)	Vitamin C (mg)	Vitamin D (µg)	Vitamin B6 (mg)
A	453.67±0.47^{a}	4.50±0.00^{a}	216.25±5.30^{a}	0.18±0.01^{a}
B	253.71±0.43^{b}	2.90±0.14^{b}	203.80±1.14^{b}	0.17±0.02^{ab}
C	217.36±0.98^{c}	1.77±0.09^{c}	198.60±2.84^{c}	0.12±0.01^{bc}
D	201.75±0.36^{d}	1.74±0.05^{c}	186.15±2.62^{d}	0.09±0.01^{c}
E	200.72±0.40^{d}	1.66±0.01^{c}	160.51±0.44^{e}	0.07±0.03^{c}

Values are mean ± SD of duplicate determinations. Different superscript letters within the same column indicate significant differences ($p < 0.05$).

Amino Acid Profile

The amino acid profile of the five blends is presented in Table 5. Leucine was the most abundant essential amino acid across all blends, rising from 8.34 to 9.65 g/100 g crude protein as pigeon pea substitution increased. Leucine plays a central role in protein synthesis and muscle tissue repair and is consistently high in cereal-legume combinations (Dimina *et al*., 2022). Lysine content increased from 4.45 g/100 g (Sample A) to 5.03 g/100 g (Sample E), a nutritionally significant improvement given that millet like most cereals is limiting in lysine. The increase confirms the protein complementarity between millet and pigeon pea, as the legume corrects the amino acid deficiency of the cereal (Abebe *et al*., 2022; Anitha *et al*., 2019). Similar patterns have been reported by Sodipo *et al*. (2018) and Ogunniran (2024) in analogous cereal-legume blends.

Threonine, valine, and isoleucine also increased progressively with pigeon pea inclusion, further strengthening the overall essential amino acid balance of the blends. Methionine and cysteine, the sulfur-containing amino acids, remained the lowest of all essential amino acids across the blend series (methionine: 1.48–2.24 g/100 g; cysteine: 1.16–2.07 g/100 g), indicating that sulfur amino acids are the primary limiting amino acids in these formulations. This outcome is characteristic of cereal-legume blends, where legume inclusion corrects lysine deficiency without fully restoring sulfur amino acid levels (Han *et al*., 2021). Future formulations should consider incorporating a sulfur-rich ingredient such as sesame or groundnut flour to further optimize the amino acid profile. Among non-essential amino acids, glutamic acid was the most abundant (14.80–16.70 g/100 g), followed by aspartic acid and arginine; their high concentrations are expected since they serve as primary backbone residues in plant storage proteins.

Table 5: Amino Acid Profile (G/100 G Crude Protein) Of the Complementary Food Flour Blends

Amino Acid	A	B	C	D	E
Essential Amino Acids					
Histidine	2.44±0.11^{b}	2.35±0.02^{b}	2.74±0.06^{b}	2.95±0.01^{ab}	3.54±0.55^{a}
Isoleucine	3.64±0.04^{d}	3.55±0.04^{e}	3.74±0.04^{c}	3.94±0.01^{b}	4.06±0.04^{a}
Leucine	8.34±0.03^{e}	8.53±0.04^{d}	8.66±0.06^{c}	9.17±0.05^{b}	9.65±0.06^{a}
Lysine	4.45±0.05^{d}	4.66±0.03^{c}	4.87±0.02^{b}	4.76±0.06^{c}	5.03±0.02^{a}
Methionine	1.48±0.01^{d}	1.36±0.02^{e}	1.63±0.04^{c}	1.81±0.01^{b}	2.24±0.02^{a}
Phenylalanine	4.42±0.03^{a}	4.56±0.07^{a}	4.81±0.02^{a}	4.52±0.63^{a}	4.75±0.69^{a}
Threonine	3.54±0.06^{e}	3.73±0.06^{d}	3.87±0.03^{c}	4.14±0.04^{b}	4.45±0.01^{a}
Tryptophan	1.18±0.04^{d}	1.26±0.00^{c}	1.31±0.01^{c}	1.36±0.01^{b}	1.46±0.01^{a}
Valine	4.03±0.04^{e}	4.23±0.02^{d}	4.43±0.57^{c}	4.56±0.04^{b}	5.03±0.04^{a}
Non-Essential Amino Acids					
Alanine	3.83±2.09^{b}	4.33±0.01^{ab}	6.24±0.03^{ab}	6.53±0.04^{a}	6.73±0.03^{a}
Aspartic acid	7.73±0.01^{e}	8.03±0.04^{d}	8.35±0.05^{b}	8.24±0.02^{c}	8.67±0.04^{a}
Glutamic acid	15.28±0.03^{d}	14.80±0.04^{e}	16.33±0.04^{b}	15.75±0.01^{c}	16.70±0.06^{a}
Serine	4.14±0.03^{c}	4.04±0.05^{c}	4.44±0.06^{b}	4.35±0.04^{b}	4.63±0.05^{a}
Glycine	4.14±0.04^{d}	4.24±0.05^{d}	4.44±0.05^{c}	4.65±0.04^{b}	4.90±0.03^{a}
Proline	5.41±0.04^{cd}	5.33±0.06^{d}	5.65±0.06^{ab}	5.52±0.05^{bc}	5.75±0.06^{a}
Tyrosine	2.94±0.01^{e}	3.10±0.00^{d}	3.61±0.01^{c}	4.04±0.11^{b}	4.32±0.02^{a}
Cysteine	1.16±0.01^{b}	1.74±0.74^{ab}	1.47±0.02^{ab}	1.66±0.04^{ab}	2.07±0.01^{a}
Arginine	5.35±0.21^{d}	5.45±0.04^{d}	5.63±0.05^{c}	5.83±0.04^{b}	6.16±0.06^{a}

Values are mean ± SD of duplicate determinations. Different superscript letters within the same row indicate significant differences ($p < 0.05$).

Functional Properties

Functional property data are presented in Table 6. Bulk density (BD) ranged from 0.81 g/mL (Sample C) to 0.89 g/mL (Sample E), with a slight increasing trend at higher legume inclusion levels. Higher BD reduces flour volume per unit mass, which is a desirable attribute in infant complementary foods as it ensures a more concentrated energy delivery per serving volume (Atuna *et al*., 2023). These values are comparable to those reported by Dendegh *et al*. (2019) and Floriam *et al*. (2020) for millet-soy-baobab and leguminous grain blends respectively.

Water absorption capacity (WAC) ranged from 1.82 to 2.04 g water/g sample. Moderate WAC supports smooth, non-lumpy porridge reconstitution, a practical requirement for infant feeding (Hasmadi *et al*., 2020). These values are consistent with the 1.8–2.1 g/g range reported by Ikegwu *et al*. (2021) for millet-soybean complementary flours. Oil absorption capacity (OAC) peaked at Sample D (4.15 g/g), reflecting the hydrophobic protein side chains of legume flour that bind lipids, enhancing palatability and energy density (Ohizua *et al*., 2017). Swelling capacity ranged from 10.64% (Sample A) to 11.53% (Sample B), indicating that pigeon pea addition did not restrict starch granule hydration; the moderate swelling values suggest the blends would produce porridges with desirable thickness and viscosity (Lawrence *et al*., 2023; Sodipo *et al*., 2018).

Table 6: Functional Properties of the Complementary Food Flour Blends

Sample	BD (g/mL)	WAC (g/g)	OAC (g/g)	SC (%)
A	0.84±0.01^{bc}	1.82±0.04^{c}	3.83±0.04^{ab}	10.64±0.03^{c}
B	0.87±0.02^{ab}	2.02±0.03^{ab}	3.53±0.04^{b}	11.53±0.04^{a}
C	0.81±0.01^{c}	1.93±0.04^{b}	4.02±0.03^{a}	11.10±0.14^{b}
D	0.85±0.01^{ab}	2.04±0.06^{a}	4.15±0.35^{a}	11.14±0.03^{b}
E	0.89±0.01^{a}	1.95±0.03^{ab}	3.55±0.07^{b}	11.46±0.04^{a}

BD = bulk density; WAC = water absorption capacity; OAC = oil absorption capacity; SC = swelling capacity. Values are mean ± SD of duplicate determinations. Different superscript letters within the same column indicate significant differences ($p < 0.05$).

Sensory Evaluation

Sensory evaluation results are presented in Table 7. All blends were well accepted by panelists, with scores predominantly in the 'like moderately' to 'like very much' range (7.7–8.5) across all attributes. Appearance scores (7.72–8.11) did not differ significantly among samples ($p > 0.05$), though the visual appeal of blends containing carrot was noted to be improved by the orange pigment contribution of β-carotene, consistent with findings by Okudu *et al*. (2017). Mouthfeel scores (7.72–8.17) were uniformly acceptable and did not vary significantly, indicating that appropriate milling and processing produced smooth reconstituted porridges across all formulations (Ikegwu *et al*., 2021; Okoye *et al*., 2021).

Taste scores (7.89–8.44) showed no significant differences among blends, with Sample E recording the numerically highest value, suggesting that increasing pigeon pea proportion up to 35% did not reduce palatability. Aroma differed significantly ($p < 0.05$) across blends, with Sample B scoring highest (8.33) and Sample A the lowest (7.72). The moderate, pleasant nutty-roasted aroma contributed by mild legume inclusion appears to enhance perceived quality, while higher pigeon pea fractions may introduce stronger earthy volatiles that some panelists rate less favorably (Abebe *et al.*, 2022). Consistency showed the widest significant variation ($p < 0.05$), with Sample B rated highest (8.44), suggesting that 5% pigeon pea inclusion optimally balanced starch-protein interactions to achieve preferred gruel viscosity (Dendegh *et al*., 2019).

Overall acceptability scores ranged from 7.72 (Sample C) to 8.33 (Sample B). The non-linear pattern where small (5%) and high (35%) legume inclusions were preferred over intermediate levels has been reported in comparable pearl millet-pigeon pea complementary food studies (Sodipo *et al.*, 2018; Okoye *et al.*, 2019). Sample B (90:5:5) achieved the best combination of nutritional improvement and sensory acceptability and is recommended as the priority blend for scale-up and community-level evaluation.

Table 7: Sensory Evaluation Scores of the Complementary Food Porridge Blends

Sample	Appearance	Mouthfeel	Taste	Aroma	Consistency	Overall Accept.
A	7.72±0.96^{a}	7.89±0.83^{a}	7.94±1.16^{a}	7.72±1.07^{c}	7.44±1.15^{b}	7.94±0.94^{ab}
B	7.94±0.80^{a}	8.17±0.71^{a}	7.94±0.80^{a}	8.33±0.84^{a}	8.44±0.51^{a}	8.33±0.49^{a}
C	8.06±0.80^{a}	7.72±0.83^{a}	7.89±0.83^{a}	7.78±0.65^{ab}	7.44±0.98^{b}	7.72±0.96^{b}
D	7.89±0.96^{a}	7.94±0.87^{a}	8.00±0.84^{a}	7.94±0.64^{ab}	7.61±0.61^{b}	7.78±0.65^{b}
E	8.11±1.08^{a}	8.11±0.83^{a}	8.44±0.71^{a}	8.17±0.86^{ab}	7.72±1.13^{b}	8.17±0.71^{ab}

Values are mean ± SD; n = 20. Different superscript letters within the same column indicate significant differences ($p < 0.05$).

CONCLUSION

This study demonstrated that complementary food porridge blends formulated from fermented millet, pigeon pea, and carrot flour exhibit significantly improved protein content, essential amino acid balance, and mineral density compared with a millet-only control, while maintaining acceptable carbohydrate levels, functional properties, and sensory quality across all formulations. Protein content in all blends exceeded the WHO minimum threshold for infant complementary foods. Sample B (90:5:5) achieved the best overall balance of nutritional quality and consumer acceptability and is recommended as the priority blend for further development. The decline in heat-sensitive vitamins highlights the need for lower-temperature processing strategies or post-drying fortification. The study supports the use of fermented millet-pigeon pea-carrot blends as a sustainable, locally available, and cost-effective approach to addressing protein-energy malnutrition and micronutrient deficiencies among infants and young children in Nigeria. Future research should assess in vivo bioavailability, antinutritional factor content, microbiological safety, shelf-life stability, and community-based acceptability testing and longitudinal feeding trials involving children are recommended over a define period of time to assess the acceptability of the complementary food blends and its effect on children's nutritional status.

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