

Nutritional assessment of composite postnatal diets formulated from traditionally fermented cereal blends

Grace Mosunmola Adegbola^{1,2}, Ruth Adefolakemi O. Gabriel-Ajobiewe^{2*}, Blessing Mosope Gabriel-Ogunniyi^{2,3}, Olawale Peter Odeleye², Bartholomew Saanu Adeleke^{4,5,6*}

¹Department of Food Science, Faculty of Food and Consumer Sciences, Ladoko Akintola University of Technology, Ogbomosho, Oyo State, Nigeria; gmadegbola@lautech.edu.ng (G.M.A.).

²Food and Applied Microbiology Unit, Department of Microbiology, Faculty of Life Sciences, Federal University, Oye-Ekiti, Ekiti State, Nigeria; adefolakemi.gabriel-ajobiewe@fuoye.edu.ng (R.A.O.G.A.) blessingbrl10@gmail.com (B.M.G.O.) olawale.odeleye@fuoye.edu.ng (O. P.O.).

³Department of Microbiology and Public Health, Federal University of Agriculture, Abeokuta, Ogun State, Nigeria.

⁴Microbiology Programme, Department of Biological Sciences, Olusegun Agagu University of Science and Technology, Okitipupa, Ondo State, Nigeria; bs.adeleke@oaustech.edu.ng (B.S.A.).

⁵Food Security and Safety Focus Area, Faculty of Natural and Agricultural Sciences, North-West University, Mmabatho 2735, South Africa.

⁶Department of Microbiology, Federal University of Technology and Environmental Sciences, Iyin-Ekiti, Ekiti State, Nigeria.

Abstract: This study was designed to evaluate the nutritional quality and acceptability of composite postnatal diets formulated from traditionally fermented cereals. The physicochemical properties, proximate, mineral, vitamins, and sensory attributes of the fermented products were assessed. In the fermented samples, the total dissolved solids (TDS) were lower compared to the control, with minimum values of 158, 190, and 181 ppm recorded at 24 hours of fermentation. However, at 120 hours, an increase in TDS values of 317, 336, and 565 ppm was observed. Optimal fermentation temperatures of 27-28°C were recorded at 48 hours. The pH of fermented sample A increased from 3.5 to 4.0. Proximate analysis showed an increase in protein content, with a maximum value of 28.87%. Improvements were also observed in fiber, fat, carbohydrate, and moisture contents. Ash content showed no significant difference between fermented and unfermented samples. Mineral analysis revealed an increase in phosphorus and calcium contents in the fermented samples, whereas potassium and magnesium contents were higher in the unfermented samples. The fermented products also exhibited varied vitamin contents. Sensory evaluation showed that the fermented recipe composed of yellow maize, red sorghum, millet, African-yam beans, turmeric, and alligator pepper scored highest for color and texture. Overall, traditional cereal fermentation improved the nutritional profile, mineral bioavailability, and sensory quality of the composite postnatal diets, supporting their affordable use as nutrient-dense foods for postnatal nutrition.

Keywords: Consumer acceptability, Fermentation technology, Food composites, Postnatal diets, Sensory evaluation, Sustainable healthy living.

1. Introduction

The nutritional balancing in human diets plays a vital role in ensuring sustainable, healthy living and optimal functioning of the vital organs in the body systems [1]. Adequate intake of essential nutrients from fermented foods and their products is known to boost human immunity and contribute to overall well-being [2, 3]. However, achieving balanced nutrition remains a major challenge in many parts of Sub-Saharan Africa, especially Nigeria. Limited access to quality food products, ineffective food processing systems, inadequate technological capacity, and socio-economic constraints contribute to

widespread nutritional deficiencies [4]. These challenges continue to undermine health outcomes, especially among vulnerable and pregnant populations.

Furthermore, proper dietary recommendations for pregnant women underscore nutritional support for both mother and developing fetus [5]. Ensuring access to nutrient-dense foods during pregnancy and maintaining appropriate dietary practices after childbirth are essential for long-term maternal and child health. Post-pregnancy nutrition supports recovery, enhances breastfeeding quality, and contributes to infants' healthy growth [6]. Therefore, there is a pressing need to explore and implement sustainable interventions, improved food production systems, and evidence-based nutritional programs to address these nutritional gaps across Sub-Saharan Africa.

Human postnatal nutrition-based fermented foods from cereals play a crucial role in modern maternal recovery and infant health during feeding and weaning stages [7, 8]. In South-Western Nigeria, where a wide variety of fermented foods are traditionally consumed, these diets are intentionally formulated to enhance maternal health, strengthen immunity, and support milk production [9]. Many of these plant-based foods contain nutrient-dense ingredients with potential probiotic properties that promote gut health [10]. For example, fermented African yam bean blends provide high-quality protein that aids tissue repair and supports lactation [11]. Likewise, cereals such as sorghum offer strong antioxidant activity and dietary fiber, millet provides essential minerals and vitamins that promote lactation, and maize supplies carbohydrates and key micronutrients needed for energy [12]. Ingredients like turmeric, known for its anti-inflammatory and immunity-boosting effects, and alligator pepper, valued for its antimicrobial action and role as a traditional uterine tonic, further contribute to maternal well-being [13].

Despite their cultural importance and nutritional richness, traditional postnatal composite diets, such as *kunu* and *ogi*, remain understudied regarding their specific benefits for breastfeeding mothers and infants. Existing research largely focuses on general dietary practices rather than formulations tailored to pregnant or nursing women [14], creating a gap in evidence-based understanding. Key aspects, such as physicochemical properties, nutritional profiling, and sensory attributes of these diets, have not been adequately explored. As a result, the scientific basis for many perceived health benefits remains limited, even though these foods continue to play a central role in maternal nutrition across the region.

To the best of our knowledge, no detailed investigations have specifically examined the effects of maternal nutritional supplementation using locally fermented diets from cereals in South-Western Nigeria. Therefore, it is essential to evaluate the nutritional composition and potential health impacts of postnatal diets formulated from traditionally fermented cereal blends. This study aims to provide scientific evidence supporting the role of these culturally relevant foods in improving maternal and infant health, thereby strengthening nutrition interventions and promoting sustainable maternal-child well-being.

2. Materials and methods

2.1. Sample Collection, Preparation, and Formulation

The fresh and healthy cereals, African yam beans, and African spices were procured from local markets in and around Ogbomoso, Oyo State, Nigeria. The samples were carefully sorted and selected. Then, the fermented samples were blended with spices to formulate diets accordingly (Table 1). The fermentation process was achieved under aseptic conditions devoid of any contamination, as presented in Figure 1.

2.2. Physicochemical And Nutritional Analysis of the Blended-Fermented Samples

The physicochemical analysis, such as total titratable acidity (TTA), pH, temperature, and total dissolved solids (TDS) on the blended-fermented samples were achieved following the methods of AOAC [15]. Similarly, the proximate analysis (protein, fiber, fat, moisture, ash, and carbohydrates), mineral analysis (potassium, calcium, sodium, magnesium, and phosphorus), and vitamin analysis

(vitamin A, B2, B3, B9, C, and E of the fermented and unfermented samples were performed accordingly [15]).

2.3. Sensory evaluation

The sensory evaluation was conducted in a controlled sensory laboratory following guidelines to ensure objectivity, reproducibility, and reliability [16]. The hedonic scale measurement of consumer acceptability testing was employed to comprehensively evaluate the sensory attributes and overall acceptability of the formulated probiotic food products. The panelists were informed about the study objectives and provided consent before participation.

2.3.1. Hedonic (Consumer Acceptance) Test

A total of 50 untrained panelists, including pregnant women and breastfeeding mothers, were randomly selected for acceptability assessment using a 9-point hedonic scale. The panelists identified and defined key sensory attributes during preliminary sessions. Each attribute, color, flavor, texture, appearance, taste, and overall acceptability, was evaluated. Consumer evaluation using a 9-point hedonic scale included 1 = Dislike extremely, 2 = Dislike very much, 3 = Dislike moderately, 4 = Dislike slightly, 5 = Neither like nor dislike, 6 = Like slightly, 7 = Like moderately, 8 = Like very much, and 9 = Like extremely [17].

2.3.2. Sample Preparation and Presentation

Samples were prepared under hygienic conditions and coded with random three-digit numbers to avoid bias. Each participant received the samples in randomized order to minimize order effects. Samples were served at ambient temperature ($25\pm 2^\circ\text{C}$) in 30 mL portions using identical white disposable cups and water for palate cleansing between evaluations.

2.4. Statistical analysis

Data were collected in triplicate, the mean scores were calculated, and subjected to Analysis of Variance (ANOVA) and Duncan's Multiple Range Test ($p < 0.05$) using SPSS version 25.

3. Results

3.1. Physicochemical Composition of the Tribal Post-Natal Formulated Fermented Blends

3.1.1. Total Dissolved Solids of the Fermented Substrates

The TDS of the fermented substrates at different fermentation times are presented in Figure 2. The values obtained for the fermenting substrates were generally lower than those of the control. However, higher TDS values of 317, 336, and 565 ppm were recorded at 120 hours of fermentation for all samples compared with the control. Conversely, lower values of 158, 190, and 181 ppm were observed in all fermenting substrates at 24 hours of fermentation.

3.1.2. Temperature of the Formulated from Traditionally Fermented Blends

The temperature values of the fermenting substrates are shown in Table 2. Optimum temperature values of 28°C and 27°C were recorded in samples A, B, and C at 48 hours of fermentation compared with the control. Similarly, higher pH values of 4.0 and 4.2 were recorded in fermented substrates A, B, and C at 96 and 120 hours, respectively, compared with the control (Table 3).

3.1.3. Total Titratable Acidity (ppm) of the Formulated from Traditionally Fermented Blends

The TTA of the fermented substrates is presented in Table 4. Higher TTA values of 11.9 and 30.4 ppm were recorded at 120 hours in fermented substrates A and C, respectively. In contrast, fermented substrate B recorded a higher value of 46.1 ppm at 48 hours compared with the control, which showed lower values.

Table 1.
The formulation of Different Blends of the Tribal Pre-natal Diets.

Sample code	Recipes
A	Yellow maize (400g), red sorghum(200g), millet (300g), African-yam beans (500g), Turmeric (20g), and alligator pepper (21.5g)
B	Red sorghum (500g), millet (300g), African yam beans (500g), Turmeric (20g), and alligator pepper (15g)
C	White sorghum (400g), millet (400g), African yam beans (500g), ginger (50g), and negro pepper (50g)

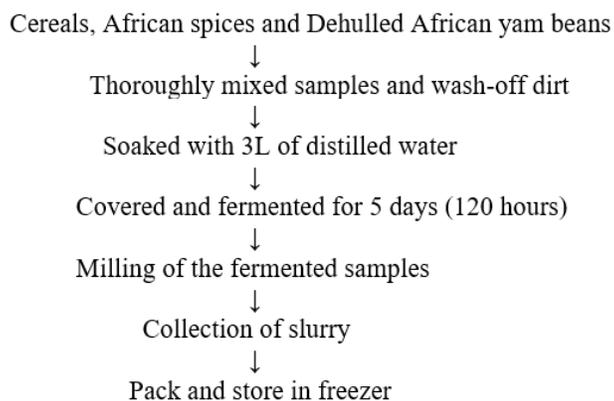


Figure 1.
The fermented formulation flow chart.

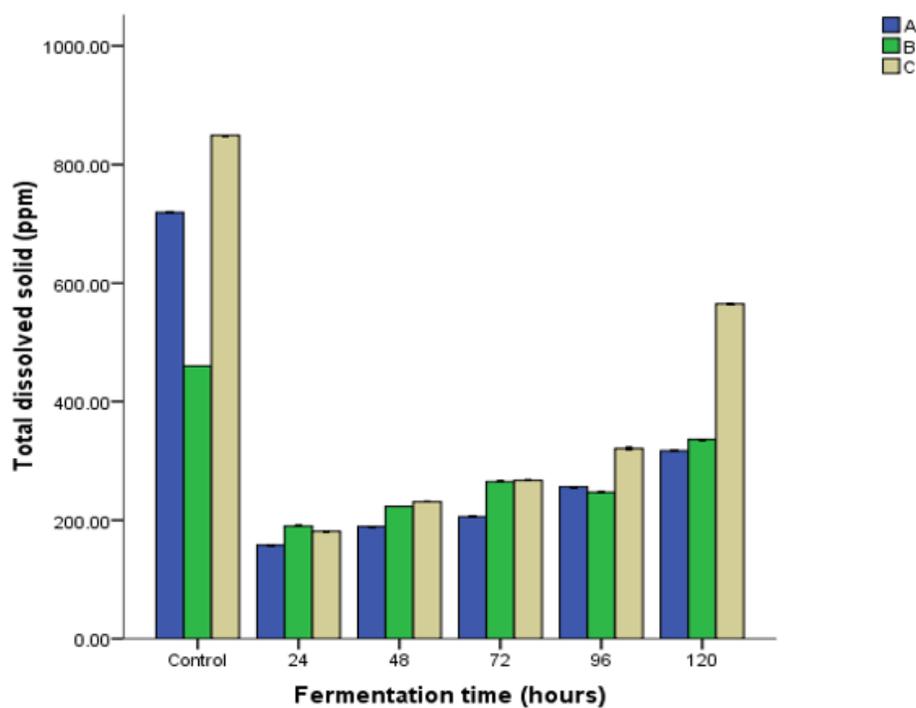


Figure 2.
Total dissolved solids (ppm) of the Formulated from Traditionally Fermented Blends.
Note: A-Fermented sample A, B - Fermented sample B, and C - Fermented sample C.

Table 2.
Temperature of the Formulated from Traditionally Fermented Blends.

Sample code	0 hour/control	24 hours	48 hours	72 hours	96 hours	120 hours
Fermented A	29.2±0.01 ^a	27.7±0.02 ^a	28.0±0.00 ^a	26.0±0.00 ^a	24.7±0.02 ^a	26.3±0.01 ^a
Fermented B	28.6±0.02 ^a	27.7±0.02 ^a	27.6±0.00 ^a	26.0±0.00 ^a	27.9±0.01 ^c	26.0±0.00 ^a
Fermented C	27.5±0.00 ^a	26.9±0.01 ^a	26.9±0.02 ^a	25.9±0.01 ^a	25.6±0.00 ^b	25.5±0.01 ^a

Note: Means within the same column with different superscripts are significantly different ($p < 0.05$). Values of triplicate readings were presented as mean±standard deviation. The represented alphabet down the column revealed the significant difference.

Table 3.
pH of the Formulated from Traditionally Fermented Blends.

Sample ID	0 hour/control	24 hours	48 hours	72 hours	96 hours	120 hours
Fermented A	3.7±0.01 ^a	3.5±0.01 ^a	3.6±0.01 ^a	3.9±0.01 ^a	4.0±0.00 ^a	4.0±0.00 ^a
Fermented B	3.7±0.01 ^a	3.6±0.00 ^a	3.5±0.00 ^a	3.8±0.01 ^a	3.5±0.01 ^a	4.2±0.01 ^a
Fermented C	3.8±0.00 ^a	3.6±0.00 ^a	3.5±0.00 ^a	3.3±0.01 ^a	4.0±0.00 ^a	4.2±0.01 ^a

Note: Means within the same column with different superscripts are significantly different ($p < 0.05$). Values of triplicate readings were presented as mean±standard deviation. The represented alphabet down the column revealed the significant difference.

Table 4.
Total titratable acidity (ppm) of the Formulated from Traditionally Fermented Blends.

Sample ID	0 hour/control	24 hours	48 hours	72 hours	96 hours	120 hours
Fermented A	2.4±0.01 ^a	6.1±0.00 ^a	8.7±0.00 ^a	7.8±0.02 ^b	9.7±0.02 ^b	11.9±0.00 ^a
Fermented B	20.8±0.03 ^b	18.2±0.01 ^b	46.1±0.02 ^c	4.9±0.01 ^a	5.8±0.03 ^a	16.3±0.01 ^b
Fermented C	22.5±0.00 ^c	20.7±0.02 ^c	14.9±0.0 ^b	16.0±0.00 ^c	5.1±0.00 ^a	30.4±0.02 ^c

Note: Means within the same column with different superscripts are significantly different ($p < 0.05$). Values of triplicate readings were presented as mean±standard deviation. The represented alphabet down the column revealed the significant difference.

3.2. Proximate Composition of Formulated from Traditionally Fermented Blends

The proximate composition of fermented and unfermented samples is presented in Table 5. Higher protein contents of 28.87%, 24.52%, and 28.87% were observed in the fermented samples compared with the unfermented samples. A fiber content of 6.00% was recorded in fermented sample C, while fat and carbohydrate contents of 3.20% and 17.05% were recorded in fermented sample A. A moisture content of 55.00% was observed in fermented sample B. There were no significant differences in the ash contents of both fermented and unfermented samples.

3.3. Mineral Composition of Formulated from Traditionally Fermented Blends

The mineral composition of fermented and unfermented samples is shown in Table 6. Increased phosphorus contents of 1.47, 1.43, and 1.42 were observed in the fermented samples compared with the unfermented samples, which recorded values of 0.81, 0.83, and 0.94, respectively. Conversely, the unfermented samples showed higher potassium and magnesium contents than the fermented samples. No significant differences were observed in the sodium contents of both fermented and unfermented samples. A slight increase in calcium content, 1.45, 0.40, and 1.69, was recorded in the fermented samples, compared with the unfermented samples with values of 1.16, 0.06, and 1.34, respectively.

3.4. Vitamin Composition of the Formulated from Traditionally Fermented Blends

The vitamin composition of fermented and unfermented samples is presented in Table 7. Varying concentrations of vitamins A, C, and E were observed in both fermented and unfermented samples. Vitamins B2 and B3 were not detected in fermented sample A, while vitamins B9 and vitamin C recorded values of 48.76 and 46.38, respectively. For vitamin B3, fermented samples B and C recorded values of 48.23 and 78.94. Vitamin B9 was detected only in fermented sample A, with a value of 48.76, and was not detected in the other fermented or unfermented samples.

Table 5.
Proximate Composition of the Formulated from Traditionally Fermented Blends.

Sample ID	Protein	Fiber	Fat	Moisture	Ash	CHO
FA	28.87±0.03 ^a	5.49±0.01 ^a	3.20±0.01 ^a	43.01±0.01 ^f	2.38±0.03 ^a	17.05±0.01 ^d
FB	24.52±0.01 ^c	4.60±0.01 ^e	2.00±0.01 ^e	55.00±0.01 ^b	2.52±0.01 ^c	11.36±0.03 ^e
FC	28.87±0.01 ^a	6.00±0.01 ^d	3.01±0.02 ^b	49.02±0.03 ^d	2.87±0.01 ^a	10.23±0.01 ^e
UA	24.50±0.01 ^c	6.69±0.01 ^c	2.10±0.01 ^d	52.00±0.01 ^c	2.50±0.01 ^c	12.21±0.02 ^b
UB	23.64±0.01 ^d	7.20±0.01 ^b	3.01±0.01 ^b	46.01±0.02 ^e	2.64±0.01 ^d	17.50±0.04 ^a
UC	25.38±0.01 ^b	3.40±0.01 ^a	2.19±0.01 ^c	58.02±0.03 ^a	2.88±0.01 ^b	8.13±0.03 ^e

Note: Legend: UA - Unfermented sample A, UB - Unfermented sample B, UC - Unfermented sample C, FA-Fermented sample A, FB - Fermented sample B, and FC - Fermented sample C. Values of triplicate readings were presented as mean±standard deviation. The represented alphabet down the column revealed the significant difference.

Table 6.
Mineral Composition of the Formulated from Traditionally Fermented Blends.

Sample ID	Potassium	Calcium	Sodium	Magnesium	Phosphorus
FA	4.74±0.05 ^b	1.45±0.06 ^b	2.51±0.01 ^a	5.93±0.01 ^c	1.47±0.00 ^a
FB	3.97±0.01 ^c	0.40±0.01 ^e	2.46±0.02 ^{ab}	5.54±0.02 ^e	1.43±0.01 ^b
FC	4.54±0.07 ^b	1.69±0.02 ^a	2.49±0.02 ^a	5.84±0.00 ^d	1.42±0.01 ^b
UA	5.98±0.14 ^a	1.16±0.02 ^d	2.36±0.02 ^c	6.12±0.01 ^a	0.81±0.00 ^e
UB	5.73±0.11 ^a	0.06±0.01 ^f	2.41±0.04 ^{bc}	6.05±0.01 ^b	0.83±0.01 ^d
UC	5.78±0.15 ^a	1.34±0.01 ^c	2.49±0.02 ^a	6.10±0.14 ^a	0.94±0.01 ^c

Note: Legend: UA - Unfermented sample A, UB - Unfermented sample B, UC - Unfermented sample C, FA - Fermented sample A, FB - Fermented sample B, and FC - Fermented sample C. Values of triplicate readings were presented as mean±standard deviation. The represented alphabet down the column revealed the significant difference.

Table 7.
Vitamin Composition of the Formulated from Traditionally Fermented Blends.

Sample ID	Vit A/ Conc	Vit B2	Vit B3	Vit B9 /Conc	Vit C/Conc	Vit E/Conc
FA	88.74±0.03 ^d	ND	ND	48.76±0.03 ^a	46.38±0.03 ^a	11.33±0.03 ^a
FB	75.46±0.03 ^b	ND	48.23±0.03 ^a	ND	92.76±0.03 ^d	50.75±0.03 ^d
FC	66.59±0.03 ^a	ND	78.94±0.03 ^b	ND	93.90±0.03 ^d	45.70±0.03 ^b
UA	98.68±0.03 ^e	96.66±0.03 ^a	ND	ND	78.76±0.03 ^c	47.98±0.03 ^c
UB	77.81±0.03 ^c	ND	91.42±0.03 ^c	ND	77.47±0.03 ^b	62.14±0.03 ^e
UC	88.08±0.03 ^d	97.16±0.03 ^a	ND	ND	79.09±0.03 ^c	95.84±0.03 ^f

Note: Legend: UA - Unfermented sample A, UB - Unfermented sample B, UC - Unfermented sample C, FA - Fermented sample A, FB - Fermented sample B, and FC - Fermented sample C, ND - not detected. Values of triplicate readings were presented as mean±standard deviation. The represented alphabet down the column revealed the significant difference.

3.5. Sensory Evaluation of the Formulated from Traditionally Fermented Blends

The sensory evaluation of the fermented diet is presented in Table 8. Fermented sample A was rated higher in terms of color and texture, with mean values of 7.61 and 9.92, respectively. There were no significant differences observed in flavor, appearance, taste, or overall acceptability among the fermented diet samples.

Table 8.
Sensory evaluation of the Formulated from Traditionally Fermented Blends.

Samples	Color	Flavor	Texture	Appearance	Taste	Overall Acceptability
FA	7.61±0.484 ^c	6.78±0.403 ^a	9.92±0.311 ^c	7.16±0.900 ^c	6.83±0.279 ^b	7.28±0.215 ^b
FB	6.28±0.965 ^a	6.78±0.403 ^a	6.92±0.311 ^c	7.17±0.900 ^c	6.66±0.073 ^a	7.28±0.984 ^a
FC	6.03±0.208 ^a	6.86±0.056 ^a	7.22±0.303 ^b	6.81±0.992 ^a	7.03±0.729 ^b	7.54±0.279 ^a

Note: Legend: FA - Fermented sample A, FB - Fermented sample B, and FC - Fermented sample C. Values of triplicate readings were presented as mean±standard deviation. The represented alphabet down the column revealed the significant difference.

4. Discussion

Some microorganisms involved in the fermentation of substrates have the tendency to produce certain metabolites mediating the solubility of organic and inorganic constituents of substrates under

experimental conditions [18]. The actions of fermentative microbes depend on factors influencing their reaction rate in breaking down composites of the fermenting medium [9]. In this study, the observed reduction in TDS values of the fermented substrates compared to the control could be attributed to the presence of fermenting microorganisms in the growth medium. More importantly, the reduction observed at the beginning of fermentation suggests the ability of microorganisms to utilize carbon and nitrogen sources (sugars and amino acids), and other metabolites required for their metabolism [19]. Previous studies reported a decrease in TDS values of some fermented cereals and legumes due to microbial actions in nutrient utilization and assimilation, supporting their growth and survival [20-22]. However, the increase in TDS values towards the end of the fermentation suggests the ability of fermenting microorganisms to hydrolyze complex starch and proteins, the macromolecules present in the medium. Similarly, the action of enzymes produced by microorganisms, aiding the hydrolysis and breaking down of non-starch compounds into soluble dextrans, peptides, amino acids, and organic acids as fermentation progresses, can cause an increase in TDS levels Olguin-Maciel [23]. Mohammed [24] and Villa [25] reported fermentation effects in the solubility of macromolecules, carbohydrate and proteins, leading to increased TDS. In addition, the increase in TDS with fermentation time may be an indication of microbial autolysis and the accumulation of organic acids and ethanol production in the fermenting medium with desirable substrates. Our results align with the findings of Pratiwi et al. [26], who reported that the action of microorganisms in the breaking down of food components due to their enzyme production, with significant differences in the solubility of solids. Furthermore, mineral leaching into the fermenting medium may also contribute to increase TDS of samples under study [27]. Furthermore, the variation observed in the TDS content of the samples with fermentation time reflects the biochemical actions of microorganisms in the bioconversion of the substrates during the fermentation process.

Temperature is one of the major factors that influence microbial growth and mediate metabolite secretions during fermentation [28]. Different microorganisms have varied tolerance to temperatures for a desirable product yield. Also, temperatures can mediate microbial abilities in the production of extracellular enzymes and other metabolites when required under optimized growth conditions. The optimum temperature values of 27-28°C recorded in some samples are known to favor the growth of mesophilic microorganisms involved in the fermentation of plant-based foods [29]. Optimally, temperatures influence microbial metabolism with an increase in the amount of heat released during biochemical reactions in the conversion of substrates to useful end products [30]. Fermentation, resulting in the exothermic reactions, primarily occurs due to carbohydrate metabolism and microbial respiration [31]. The temperature recorded in this study aligns with the findings of Ishiwu and Tope [32], who reported similar temperatures during the traditional fermentation of castor oil seed.

pH control remains an important approach for improved yield and recovery of fermenting products [28]. An increase in the pH may affect the fermentation processes due to the proteolytic action of microorganisms and ammonia synthesis from amino acid deamination. Sometimes, the fermentation medium can be buffered for medium stability and maximum organic compounds synthesis [33]. The results obtained from this study fall within the safe limit of most commonly fermented foods. The medium with low pH may exert lethal effects on the spoilage and pathogenic microorganisms while providing an enabling environment for the growth of lactic acid bacteria. The pH values of fermented food recorded between 3.8 and 4.5 have been reported to be safe, with stability under shelf, and sensory acceptability of Quinoa fermented milk via fermentation with specific lactic acid bacteria [34]. Hence, the temperature-pH controls during fermentation are crucial for a desirable and acceptable yield of end products. The production of organic acids (lactic, acetic, and citric acids) has been reported to increase the acidity of fermented foods, thus enhancing the flavor development and shelf life extension [35]. The higher TTA observed in fermented sample B at 48 hours can be due to the high organic acid production rate based on sample composition and the type of microorganisms involved in the fermentation.

During fermentation, organic acids are produced in the growth medium. The amount of acid produced in the growth medium can be influenced by the nature of the substrates and the types of

associated microorganisms [30]. Through microbial actions, organic acids can be recovered through the metabolism of organic substrates. An increase in the TTA of fermented foods due to fermentation has been reported to contribute to the sensory quality of fermented foods [28, 36]. In fermented sample B, the high TTA values of 46.10 ppm obtained at 48 hours indicate the presence of lactic acid-producing bacteria as key factors contributing to the bacterial activities in improving food preservation and sensory quality.

Fermentation influences the proximate composition of fermented foods. The increase in protein content of fermented samples due to microbial actions in the production of single-cell proteins can result in the degradation of carbohydrate contents [28]. Protein enhancement in fermented foods has been reported recently to improve the nutritional quality of foods as recommended in the fortification of food limited in protein content [37, 38]. Improvement in the dietary fiber content of fermented food has also been reported to contribute to human health by aiding digestibility [39]. The ash content obtained in this study corroborates the findings of Ozoh et al. [40], who reported mineral stability during fermentation of fermented foods.

It is evident from this study that the fermented samples showed an increase in the phytate content, which could be linked to the ability of the fermenting microorganisms to produce phytases, making phosphorus available in foods [41]. Although the higher potassium and magnesium contents in unfermented samples could be a result of partial microbial metabolic activities in the uptake of the nutrients during fermentation [42]. Furthermore, the enhancement of calcium content in fermented samples pin pointed the microbial actions with the possibility of producing organic acids for mineral solubilization and absorption during fermentation [43]. The observed vitamins biosynthesis underscores the role of certain strains of microorganisms in enhancing vitamin content in fermented foods through natural means or biofortification strategy.

Fermentation contributes to the sensory properties of fermented foods, with underlying factors in the determination of consumers' overall acceptability [44]. The improvement in the textural architecture of the fermented foods can be due to the conversion of polysaccharide compounds produced by fermenting microbes and their metabolites in softening the fermenting substrates and stabilization of the sample pigment [45]. The observed no significant difference in flavor, appearance, taste, and overall acceptability among samples informed the quality of the formulated products. Therefore, the maintenance of the consistency of fermented products to improve the sensory qualities can be more easily achieved under controlled fermentation [44].

5. Conclusion

In this study, the fermented cereal-based postnatal diet showed marked improvements in nutritional composition, including protein, fiber, calcium, and phosphorus contents. These findings indicate that fermentation technology can be effectively employed to improve food quality while also extending shelf life.

The overall acceptability of the blended yellow maize, red sorghum, millet, African yam bean, turmeric, and alligator pepper, in terms of color and texture, demonstrates the potential of traditional fermentation to enhance postnatal nutrition through food fortification, thereby supporting sustainable and healthy living.

Transparency:

The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

Acknowledgments:

The authors acknowledge their affiliated institutions.

Copyright:

© 2026 by the authors. This article is an open-access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

References

- [1] J. Bassaganya-Riera *et al.*, "Goals in nutrition science 2020–2025," *Frontiers in Nutrition*, vol. 7, p. 606378, 2021. <https://doi.org/10.3389/fnut.2020.606378>
- [2] V. Valentino *et al.*, "Fermented foods, their microbiome and its potential in boosting human health," *Microbial Biotechnology*, vol. 17, no. 2, p. e14428, 2024. <https://doi.org/10.1111/1751-7915.14428>
- [3] M. S. Hossain *et al.*, "Flavor and well-being: A comprehensive review of food choices, nutrition, and health interactions," *Food Science & Nutrition*, vol. 13, no. 5, p. e70276, 2025. <https://doi.org/10.1002/fsn3.70276>
- [4] S. Maulu *et al.*, "Contribution of fish to food and nutrition security in Southern Africa: Challenges and opportunities in fish production," *Frontiers in Nutrition*, vol. 11, p. 1424740, 2024. <https://doi.org/10.3389/fnut.2024.1424740>
- [5] B. Koletzko *et al.*, "Nutrition during pregnancy, lactation and early childhood and its implications for maternal and long-term child health: The early nutrition project recommendations," *Annals of Nutrition and Metabolism*, vol. 74, no. 2, pp. 93–106, 2019. <https://doi.org/10.1159/000496471>
- [6] R. Ajmal, "Promoting breastfeeding and complementary feeding practices for optimal maternal and child nutrition," *Pakistan Journal of Public Health*, vol. 14, no. Special. NI, pp. 168–180, 2024. <https://doi.org/10.32413/pjph.v14iSpecial.ni.1301>
- [7] M. A. Tufa, K. Urga, G. Weledesemayat, and B. Mitiku, "Development and nutritional assessment of complementary foods from fermented cereals and soybean," *Journal of Food Science and Nutrition*, vol. 2, no. 2, pp. 1–8, 2016.
- [8] D. A. Kitessa, K. Bacha, Y. B. Tola, and M. Murimi, "Effect of fermentation time and blending ratio on microbial dynamics, nutritional quality and sensory acceptability of Shameta: A traditional cereal-based fermented porridge for lactating mothers in Ethiopia," *Fermentation*, vol. 10, no. 3, p. 118, 2024. <https://doi.org/10.3390/fermentation10030118>
- [9] E. T. Adesemoye, A. I. Sanni, G. Spano, V. Capozzi, and M. Fragasso, "Lactic acid bacteria diversity in fermented foods as potential bio-resources contributing to alleviate malnutrition in developing countries: Nigeria as a case study," *Fermentation*, vol. 11, no. 2, p. 103, 2025. <https://doi.org/10.3390/fermentation11020103>
- [10] K. Sridhar, S. Bouhallab, T. Croguennec, D. Renard, and V. Lechevalier, "Recent trends in design of healthier plant-based alternatives: Nutritional profile, gastrointestinal digestion, and consumer perception," *Critical Reviews in Food Science and Nutrition*, vol. 63, no. 30, pp. 10483–10498, 2023. <https://doi.org/10.1080/10408398.2022.2081666>
- [11] G. M. Adegbola and R. A. O. Gabriel-Ajobiwe, *Optimizing fortified fermented local weaning foods*. In B. J. Akinyele, R. Kayode, & A. A. Akinsemolu (Eds.), *Microbes, mentorship, and beyond*. Ibadan, Nigeria: SustainE, 2025.
- [12] D. J. Arotupin, S. Adewole, B. S. Adeleke, S. Adewole, and A. O. Arogunjo, "Effect of different processing techniques on the chemical composition of fermented maize product (Ipekere)," *Annals: Food Science & Technology*, vol. 20, no. 3, pp. 502–512, 2019.
- [13] E. Gupta and P. Mishra, "Functional food with health benefits (superfoods): A review," *Current Nutrition & Food Science*, vol. 17, no. 2, pp. 144–166, 2021.
- [14] K. A. Afolabi, A. O. Afolabi, and M. Y. J. Omishakin, "Complementary feeding and associated factors: Assessing compliance with recommended guidelines among postpartum mothers in Nigeria," *Population Medicine*, vol. 3, no. June, pp. 1–11, 2021. <https://doi.org/10.18332/popmed/138939>
- [15] AOAC, *Official methods of analysis*, 22nd ed. Washington, DC, USA: Association of Official Analytical Chemists, 2023.
- [16] H. T. Lawless and H. Heymann, *Sensory evaluation of Food: Principles and practices*, 2nd ed. New York, USA: Springer, 2010.
- [17] H. Stone, R. N. Bleibaum, and H. A. Thomas, *Sensory evaluation practices*, 5th ed. London, U.K: Academic Press, 2020.
- [18] Q. Yin, K. He, G. Collins, J. De Vrieze, and G. Wu, "Microbial strategies driving low concentration substrate degradation for sustainable remediation solutions," *npj Clean Water*, vol. 7, p. 52, 2024. <https://doi.org/10.1038/s41545-024-00348-z>
- [19] R. O. Alves *et al.*, "Evaluation of the impact of fermentation conditions, scale up and stirring on physicochemical parameters, antioxidant capacity and volatile compounds of green tea Kombucha," *Fermentation*, vol. 11, no. 4, p. 201, 2025. <https://doi.org/10.3390/fermentation11040201>
- [20] R. N. Salek *et al.*, "Sauerkraut juice fermented with different symbiotic starter cultures: Comprehensive assessment of physicochemical, rheological, antioxidant, and microbiological characteristics," *Frontiers in Sustainable Food Systems*, vol. 9, p. 1570465, 2025.
- [21] J. Espinosa-Ramírez, "Substitution of wheat flour with ayocote bean flour in bread," *Journal of Food Science*, vol. 87, no. 9, pp. 3766–3780, 2022.
- [22] F. Sparvoli, "Sensory and nutritional quality of biofortified common bean products," *Nutrients*, vol. 13, no. 12, p. 4517, 2021.

- [23] E. Olguin-Maciél, "Ultrasound pretreatment of non-conventional starch," *Biomass Conversion and Biorefinery*, vol. 14, no. 10, pp. 11469-11477, 2024.
- [24] B. M. Mohammed, "Effect of germination and fermentation on Samh seeds," *Foods*, vol. 12, no. 22, p. 4133, 2023.
- [25] R. D. Villa, "Impact of solid-state fermentation on grains," *Critical Reviews in Food Science and Nutrition*, vol. 63, no. 21, pp. 5388-5413, 2023.
- [26] V. N. r. Pratiwi, E. Zubaidah, T. D. Widyaningsih, and J. Kusnadi, "Enhancement of phenolic content and antioxidant activity in snakefruit (*Salacca zalacca* (Gaerth.) Voss) vinegar by malolactic fermentation with *Lactobacillus plantarum*," *Journal of Food Science and Technology*, pp. 1-9, 2025. <https://doi.org/10.1007/s13197-025-06220-3>
- [27] J. A. Adebo *et al.*, "Fermentation of cereals and legumes: Impact on nutritional constituents and nutrient bioavailability," *Fermentation*, vol. 8, no. 2, p. 63, 2022. <https://doi.org/10.3390/fermentation8020063>
- [28] K. Adegbehingbe, "Effect of fermentation on African breadfruit seeds," *Microbiology Research Journal International*, vol. 20, no. 5, pp. 1-11, 2017.
- [29] K. Gustaw, "Bacterial interaction with plant-based fermented food matrices," *Foods*, vol. 10, no. 7, p. 1603, 2021.
- [30] R. A. O. Gabriel-Ajobiwe, "Biochemical evaluation of solid-state fermentation," *Research Journal of Microbiology*, vol. 6, no. 2, pp. 105-110, 2011.
- [31] M. Raimbault, "General and microbiological aspects of solid substrate fermentation," *Electronic Journal of Biotechnology*, vol. 1, no. 3, pp. 26-27, 1998. <http://dx.doi.org/10.4067/S0717-34581998000300007>
- [32] C. N. Ishiwu and V. A. Tope, "Effect of fermentation period on castor oil seed nutrients," *Direct Research Journal of Agriculture and Food Science*, vol. 3, no. 10, pp. 178-183, 2015.
- [33] X. Yang, Q. Li, X. Bai, C. Li, X. Li, and T. Yao, "Optimal fermentation of *Pseudomonas synxantha* M1 and metabolomics analysis," *Preparative Biochemistry & Biotechnology*, vol. 55, no. 4, pp. 502-512, 2025. <https://doi.org/10.1080/10826068.2024.2428322>
- [34] L. Zhao, J. Liao, T. Wang, and H. Zhao, "Enhancement of nutritional value and sensory characteristics of quinoa fermented Milk via fermentation with specific lactic acid Bacteria," *Foods*, vol. 14, no. 8, p. 1406, 2025. <https://doi.org/10.3390/foods14081406>
- [35] Z. Xing *et al.*, "Recent advances in *Lactobacillus plantarum* fermentation in modifying fruit-based products: Flavor property, bioactivity, and practical production applications," *Comprehensive Reviews in Food Science and Food Safety*, vol. 24, no. 2, p. e70160, 2025. <https://doi.org/10.1111/1541-4337.70160>
- [36] O. A. Adebo, P. B. Njobeh, and E. Kayitesi, "Fermentation by *Lactobacillus fermentum* strains (singly and in combination) enhances the properties of ting from two whole grain sorghum types," *Journal of Cereal Science*, vol. 82, pp. 49-56, 2018. <https://doi.org/10.1016/j.jcs.2018.05.008>
- [37] C. G. Rizzello *et al.*, "Influence of fermented faba bean flour on the nutritional, technological and sensory quality of fortified pasta," *Food & Function*, vol. 8, no. 2, pp. 860-871, 2017.
- [38] K. Banwo, "Improving functional qualities of Ogi," *NFS Journal*, vol. 27, pp. 1-12, 2022.
- [39] E. Nordlund, "Bioprocessing modifies bran digestibility," *Journal of Cereal Science*, vol. 58, no. 1, pp. 200-208, 2013.
- [40] C. Ozoh, C. Imoisi, and J. Iyasele, "Effect of pH and duration of fermentation on the sensory, physicochemical and proximate characteristics of garri," *Trends in Applied Sciences Research*, vol. 19, no. 1, pp. 156-169, 2024.
- [41] O. Buddrick, O. A. Jones, H. J. Cornell, and D. M. Small, "The influence of fermentation processes and cereal grains in wholegrain bread on reducing phytate content," *Journal of Cereal Science*, vol. 59, no. 1, pp. 3-8, 2014. <https://doi.org/10.1016/j.jcs.2013.11.006>
- [42] K. Banwo, F. C. Asogwa, O. R. Ogunremi, A. Adesulu-Dahunsi, and A. Sanni, "Nutritional profile and antioxidant capacities of fermented millet and sorghum gruels using lactic acid bacteria and yeasts," *Food Biotechnology*, vol. 35, no. 3, pp. 199-220, 2021. <https://doi.org/10.1080/08905436.2021.1940197>
- [43] N. D. Patil *et al.*, "Effect of solid-state fermentation on kidney bean flour: Functional properties, mineral bioavailability, and product formulation," *Food Chemistry: X*, vol. 27, p. 102339, 2025. <https://doi.org/10.1016/j.fochx.2025.102339>
- [44] D. Senanayake, P. J. Torley, J. Chandrapala, and N. S. Terefe, "Microbial fermentation for improving the sensory, nutritional and functional attributes of legumes," *Fermentation*, vol. 9, no. 7, p. 635, 2023. <https://doi.org/10.3390/fermentation9070635>
- [45] A. K. Rashwan, "Plant-based proteins: Technologies and applications," *Critical Reviews in Food Science and Nutrition*, vol. 65, no. 4, pp. 667-694, 2025.