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Evaluating the Effects of Fermentation, Sprouting and Roasting on the Chemical Composition of Local Raw Materials for Complementary Food Formulation

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Authors' contributions

This work was carried out in collaboration among all authors. Author PACO designed the study. Author UEE wrote the protocol. Author PNI wrote the first draft of the manuscript, managed the analyses and did literature searches. Author KCN performed the statistical analysis. All authors read and approved the final manuscript.

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ABSTRACT

This study evaluates the effects of processing techniques (fermentation, sprouting, and toasting) on the chemical composition of local raw materials (yellow maize, sorghum, millet, and soybeans) for complementary food formulation. The raw materials underwent fermentation, sprouting, and toasting processes before analysis. Both processed and unprocessed samples were assessed for their proximate, mineral, and vitamin composition using standardized analytical methods. Fermentation, sprouting, and toasting significantly ($p<0.05$) enhanced protein and mineral content while reducing carbohydrates. For instance, crude protein in millet increased from 7.90% to 8.23%, and iron in yellow maize rose from 15.76 mg/100g to 19.43 mg/100g post-processing. The samples showed nearly double their vitamin C content post-processing. Yellow maize increased from 7.50 mg/100g to 13.41 mg/100g. These results demonstrate that processing methods can significantly ($p<0.05$) enhance the nutritional profile of local raw materials, making them suitable for cost-effective, nutrient-dense complementary food formulations.

Keywords: Local raw materials; fermentation; sprouting; bioavailability; nutritional composition.

1. INTRODUCTION

Adequate nutrition during infancy and early childhood is fundamental for a child's cognitive, emotional, and overall development. Adequate nourishment forms the basis for intellectual, social, and emotional skills, as these develop rapidly in the first few years of life. The World Health Organization (2023) recommends exclusive breastfeeding for the first six months, followed by complementary foods alongside breastfeeding up to two years or more. Complementary feeding, introduced during the critical window of 6–24 months of age, bridges the nutritional gap between breast milk and the dietary needs of a growing child (World Health Organization, 2023). The nutritional status of infants plays a fundamental role in their overall health, growth, and development, making the quality of complementary foods essential for the cognitive and physical development of children aged 1-3 years. Complementary foods should be nutrient-dense, particularly rich in micronutrients such as zinc, iodine, and vitamins, necessary for a child's development (Dutta and Das, 2020). In developing countries like Nigeria, infants face high risks of illness and mortality during their early years, especially after six months. Commercial complementary foods are often expensive or inaccessible, particularly in rural areas. Formulating nutrient-dense complementary foods from locally available and culturally accepted raw materials is essential for addressing malnutrition, boosting sustainable agriculture, promoting food security, and strengthening the local economy. Thus, there is a need to explore affordable, locally sourced, and nutritious alternatives to imported foods. Yellow maize, sorghum, millet, and soybeans are available, cheap, and accepted staples in Nigeria. Maize and millet are rich sources of carbohydrates and energy, while sorghum contributes essential micronutrients, particularly iron and zinc (Adebiyi et al., 2017). Legumes like soybeans provide high-quality protein and essential fatty acids for brain health. Processing techniques like fermentation, sprouting, and toasting are effective ways to improve nutritional value and nutrient bioavailability of these materials while reducing anti-nutritional components. Research showed that fermenting cereal grains for complementary foods, which involves washing, sieving, and decanting, changes their chemical composition and nutritional value (Oyegoke et al., 2020, Tripathi et al., 2021). Fermentation is a traditional food processing technique that enhances nutrient content and bioavailability through microbial activity. It increases vitamin levels, particularly B-complex vitamins and vitamin C, while degrading anti-nutritional factors such as phytates and tannins (Chaves et al., 2014). Likewise, sprouting triggers the activation of natural enzymes in grains and legumes, breaking down complex compounds, enhancing the availability of nutrients, improving protein digestibility, vitamin levels, and mineral absorption. Toasting enhances the taste and aroma of foods while reducing enzyme inhibitors and microbial contamination. Combining these processes could create complementary foods that are nutritionally dense, appealing, and safe for infants and young children. However, the impact of such methods on nutrients, particularly vitamins and minerals in these raw materials that will be sourced from the market needs further evaluation. The aim of this research is to evaluate the chemical composition of yellow maize, sorghum, millet, and soybeans for complementary food formulation, focusing on the effects of fermentation, sprouting, and

toasting. These insights will help create affordable, nutritious, and culturally suitable complementary foods to fight childhood malnutrition in places like Nigeria.

2. MATERIALS AND METHODS

2.1 Sources of Material

The yellow maize, sorghum, millet, and soybeans were acquired from the grain seed market located in Onitsha, Anambra State. The chemicals and reagents utilized in the study were of analytical grade and procured from reputable scientific chemical suppliers at Bridgehead Market in Onitsha, Anambra State.

2.2 Preparation of Samples

2.2.1 Preparation of untreated (UT) yellow maize, millet, sorghum, and soybeans

Yellow maize, millet, sorghum and soybeans were separately sorted, and any bad seeds were removed. They were separately washed twice, sprayed on metal trays and oven dried at 65°C for 6 hours. They were ground into flour using an electric milling machine and stored in airtight containers before analysis.

2.2.2 Preparation of fermented and sprouted (FS) yellow maize, millet, sorghum, and fermented, sprouted and toasted (FST)soybeans

Yellow maize, millet, sorghum grains, and soybean seeds were separately cleaned. The grains and seeds were separately soaked for 24 hours at room temperature. The fermented grains were drained, washed, poured into a colander, and covered with a muslin cloth. The colander was kept at room temperature. The grains and seeds were rinsed under running water every 12 hours for 3 days for the grains and seeds to sprout. On the fourth day, they were rinsed, sprayed on a metal tray, and dried in an oven at 65°C for 12 hours. They were ground into flour using an electric milling machine and stored in airtight containers before analysis. The soybeans after oven drying were toasted at 175°C for 10 minutes, cracked and the seed coat removed before grinding. It was stored in an airtight container before analysis.

2.3 Analysis

2.3.1 Proximate Analysis

The crude fiber, crude fat, crude protein, moisture, ash, carbohydrate, and energy contents were determined by AOAC standard methods as described by Tittikpina et al. (2021).

2.3.2 Vitamin Analysis

2.3.2.1 Determination of Vitamin A

The method described by Kesuma et al. (2020), was modified. One gram of each sample was mixed with 1.0 cm^3 of saponification mixture (12 g potassium hydroxide dissolved in 88 cm^3 ethanol) and refluxed for 20 minutes at 60°C in the dark to avoid light interference. The saponified mixtures were poured into boiling tubes. The tubes were cooled, 20 cm^3 of water was added and mixed well. Vitamin A was extracted twice with 10 cm^3 of 40°C petroleum ether. The samples were cooled and washed thoroughly with water. Anhydrous sodium sulphate was added to remove excess moisture. An aliquot of the sample (1.0 cm^3) was taken and evaporated to dryness at 60°C. The residue was dissolved in 1.0 cm^3 chloroform. Standards (vitamin A palmitate) of concentrations ranging from 0 - 7.5 mg were pipetted into a series of test tubes. The volume in all the tubes was made up to 1.0 cm^3 with chloroform. Tricarboxylic acid (TCA) reagent (2.0 cm^3) was added rapidly, mixed and the absorbance was read immediately at 620 nm in a spectrophotometer (Genesys 10UV). The same procedure was repeated for the sample tubes. Vitamin A content was obtained in mg/kg and converted to µg/100g.

2.3.2.2 Determination of Vitamin E

Vitamin E was estimated according to the method described by Kesuma et al. (2020) with little modification. Two and a half grams of each sample was homogenized in 50 cm^3 of 0.1M sulphuric acid and allowed to stand overnight. The flask contents were shaken vigorously and filtered through the Whatman No.1 filter paper. Aliquots of the filtrate were used for the estimation. The sample filtrate (1.5 cm^3), 1.5 cm^3 of the standard, and 1.5 cm^3 of water were pipetted separately into 3 stoppered centrifuge tubes. Ethanol (1.5 cm^3) and 1.5 cm^3 of xylene were added to all the test tubes, mixed well, and centrifuged. Xylene layer (1.0 cm^3) was transferred into another stoppered tube. Dipyridyl reagent (1.0 cm^3) was added to each tube. The mixture (1.5 cm^3) was pipetted into a cuvette and the extinction was read at 460 nm. Vitamin D content was obtained in µg/kg and converted to µg/100g.

2.3.2.3 Determination of Vitamin C

The spectrophotometric method described by Shara et al. (2019), was used to analyse vitamin C with little modification. Ascorbate was extracted from 1.0 g of the sample using 4% TCA and the volume was made up to 10 cm^3 with the same TCA. The supernatant obtained after centrifuging at 2000 rpm for 10 minutes was treated with a pinch of activated charcoal, shaken vigorously using a cyclomixer, and kept for 5 minutes. The charcoal particles were removed by centrifugation and aliquots were used for the estimation. Standard ascorbate ranging between 0.2 – 1.0 cm^3 and 0.5 cm^3 and 1.0 cm^3 of the supernatant were taken in a test tube. The volume was made up to 2.0 cm^3 with 4 % TCA. Dinitrophenyl hydrazine (DNPH) reagent (0.5 cm^3) was added to all the tubes, followed by 2 drops of 10% thiourea solution. The contents in the tubes were mixed and incubated at 37°C for 3 hours. The result was the formation of osazane crystals. The crystals were dissolved in 2.5 cm^3 of 85% sulphuric acid. To the blank alone, DNPH reagent and thiourea were added after the addition of sulphuric acid. The tubes were cooled in ice and the absorbance was read at 540 nm in a spectrophotometer. A standard graph was constructed using an electronic calculator set to the linear regression mode. The concentration of ascorbate in the samples was calculated using the formula ($\boldsymbol{Y = mx + c}$) where Y= absorbance, x = concentration, m = 0.0135 and c = 0.0062. It was obtained in mg/kg and converted to mg/100g

2.3.2.4 Determination of Vitamins B1 and B2 (Thiamine and Riboflavin)

One gram of each sample was weighed into a conical flask and dissolved with 100 cm^3 of deionized water. This was shaken thoroughly heated for 5 minutes and allowed to cool and filtered. The filtrate was poured into a cuvette and the respective wavelength for the vitamins (vitamin B_1 = 261nm and vitamin B_2 = 242nm) was set to read the absorbance using a spectrophotometer.

$$\text{Concentration (mg \%)} = \frac{A \times D.F \times volume\ of\ cuvette}{E}$$

where A = absorbance, E = extinction coefficient = 25 for B_1 and B_2, D.F = dilution factor.

2.3.2.5 Determination of vitamin B3 (Niacin)

Five grams of each sample was dissolved in 20 cm^3 of anhydrous glacial acetic acid and warmed slightly. Acetic anhydride (5 cm^3) was added and mixed. Two drops of crystal violet solution were added as an indicator. The mixture was titrated with 0.1M perchloric acid to a greenish blue colour.

$$\text{Vitamin } B_3 = \frac{titre\ value \times 0.0122}{0.1}$$

2.3.2.6 Determination of Vitamin B6 (Pyridoxine)

Five grams of each sample was dissolved in a mixture of 5 cm^3 of anhydrous glacial acetic acid and 6 cm^3 of 0.1M mercury II acetate solution. Two drops of crystal violet solution were added as an indicator. The mixture was titrated with 0.1M perchloric acid to a green colour endpoint. Calculation: each cm^3 of 0.1M perchloric acid is equivalent to 0.02056g of $C_8H_{11}NO_3HCL$

2.3.2.7 Determination of Vitamin B12 (Cobalamin)

An equivalent of 0.1 g of each sample was weighed and taken into the separator. Water (5 cm^3) was added, mixed well, and extracted with 5 cm^3 chloroform. The water layer was discarded, and the chloroform layer was taken in a dry 50 cm^3 volumetric flask after passing through anhydrous sodium sulphate. It was made up to 50 cm^3 with chloroform. The extracted sample (2 cm^3) and blank solution were taken into a test tube. In each test tube, 2 cm^3 of 0.2 % solution of phenylhydrazine (in hydrochloric acid and alcohol in the ratio of 1:5 v/v) was added and mixed well. After that, it was heated in a water bath to almost dry and cooled at room temperature. A 2 cm^3 solution mixture (ammonia and alcohol in a ratio of 1:1) was added to each test tube followed by 1 cm^3 pyridine. Its absorbance was recorded at 635 nm against blank. Standard cobalamin was also analyzed and treated the same as the samples. The calibration curve was plotted, and the concentration of the samples was extrapolated.

2.3.2.8 Determination of Vitamin D

Vitamin D was assayed according to the method of Vinhas et al. (2017), with little modification. Vitamin D working standard (25 mg) was weighed and put into a 25 cm^3 volumetric flask. It was dissolved with a solution mixture (chloroform and methanol in a ratio of 1:9), diluted with the same solution mixture, and made up to the mark. It was thoroughly mixed. An equivalent 0.1 g sample was weighed into a 25 cm^3 volumetric flask. It was dissolved with a solution mixture (chloroform and methanol in a ratio of 1:9), diluted with the same solution

mixture, and made up to the mark. It was mixed thoroughly, 1.6 cm^3 of 0.25 M HCl, 0.5 cm^3 of 15.0 % trichloroacetic acid, and 0.5 cm^3 of 0.375% thiobarbituric acid (TBA) were added. Its absorbance was recorded at 464 nm against blank.

2.4 Mineral Analysis

The mineral analysis was conducted using Varian AA240 Atomic Absorption Spectrophotometer according to the method of Yitayal et al., (2017). The samples were weighed into porcelain crucibles and heated at 400^oC for 4 hours in a muffle furnace. After 4 hours, they were removed and cooled in a desiccator. After that, 0.5 cm^3 of 1M trioxonitrate (V) acid (HNO_3) solution was added to the left-over ash and evaporated to dryness on a hot plate. They were returned to the furnace for heating again at 400^0C for 20 minutes until perfect grayish-white ash was obtained. The samples were allowed to cool in a desiccator for 20 minutes. The ash was dissolved with 15 cm^3 of hydrochloric acid in a 100 cm^3 volumetric flask. The volume was made up to the mark with distilled water. The solution was filtered into a 100 cm^3 volumetric flask and the volume was made to 100 cm^3 with distilled water. A series of standard metal solutions in the optimum concentration range were prepared. The reference solutions were prepared daily by diluting the single stock element solutions with water containing 1.5 cm^3 concentrated nitric acid. A calibration blank was prepared using all the reagents except the mineral stock solutions. A calibration curve for each mineral was prepared by plotting the absorbance of standards versus their concentrations.

2.5 Statistical Analysis

The results were expressed as mean ± standard deviation of duplicate result and the test for statistical significance was carried out using one-way analysis of variance (ANOVA). The OriginPro 2024 statistical software was used to determine significant differences. Significant means was separated using Tukey test and differences was considered significant at (*$p<0.05$).*

3. RESULTS AND DISCUSSION

Table 1 shows the proximate composition of the local raw materials. Fermentation, sprouting and toasting processes significantly *($p<0.05$)* alter the proximate composition of yellow corn, sorghum, millet, and soybeans. Crude fiber decreased from (0.42, 4.21, and 2.57) % in untreated (UT) yellow maize, sorghum and millet respectively to (0.40, 4.06, and 2.42) % in fermented and sprouted (FS) yellow corn, sorghum, and millet. This reduction aligns with observed trends in earlier studies, where fiber reduction improves digestibility (Akinola et al., 2020). Similarly, crude fat content decreased across all samples from the UT to FS samples. There is an increase in the crude protein content of soybeans from 36.61% in UT soybeans to 38.23% in FST soybeans. This is consistent with findings by Igbabul et al. (2014) and Ogodo et al. (2018), who documented enhanced protein levels in various legumes post-fermentation and sprouting, suggesting increased nutrient density and digestibility. The 36.61% obtained for UT soybeans alligns with 35.53% obtained by Ikese et al. (2017), for soybean flour. Also, protein level increased from 7.90% in UT millet to 8.23% in FS millet. Aande et al. (2020), observed similar trends in pearl millet, with protein content rising from 12.58% in unprocessed millet to 18.35% in roasted millet. No significant *($p<0.05$)* difference exists between the moisture level of each untreated sample and the FS sample. Ash content, represents mineral density, enhancing mineral bioavailability. Ash level, 2.50% of UT sorghum, significantly *($p<0.05$)* increased to 3.88% in FS sorghum. Carbohydrate and energy content showed minimal decrease form UT samples to FS samples, except in soybeans where carbohydrate reduced from 36.56% in UT soybeans to 29.49% in FST soybeans. This reduction may indicate carbohydrate utilization by fermentative microbes. Also, toasting might have caused some nutrient losses due to thermal degradation. Similar declines in carbohydrates and energy have been observed in post-fermentation, attributed to the partial breakdown of complex sugars (Mohapatra et al., 2019).

The mineral composition of the local raw materials for complementary food formulation was recorded in Table 2. The effects of fermentation, sprouting and toasting on mineral composition across all samples reveal significant ($p<0.05$) differences, indicating that these processes enhance specific mineral bioavailability. There was an increase in sodium and calcium contents across all samples from UT samples to FST samples confirming the role of these processes in enhancing nutrient profiles. Sodium is required for acid-base balance and

Table 1. Proximate composition of local raw materials for complementary food formulation

Parameters (%)	UT Yellow maize	FS Yellow maize	UT Sorghum	FS Sorghum	UT Millet	FS Millet	UT Soybeans	FST Soybeans
Crude fibre	$0.42^{c} \pm 0.06$	$0.40^{e} \pm 0.07$	$4.21^{a} \pm 0.27$	$4.06^{a} \pm 0.24$	$2.57^{b} \pm 0.25$	$2.42^{b} \pm 0.22$	$2.43^{b} \pm 0.15$	$2.73^{b} \pm 0.23$
Crude fat	$6.29^{c} \pm 0.43$	$5.22^{d} \pm 0.07$	$8.28^{b} \pm 0.34$	$7.97^{b} \pm 0.03$	$6.29^{c} \pm 0.09$	$6.31^{c} \pm 0.07$	$17.08^{a} \pm 0.06$	$16.92^{a} \pm 0.07$
Crude protein	$9.39^{c} \pm 0.53$	$9.98^{c} \pm 0.25$	$8.9^{e} \pm 0.63$	$9.28^{c} \pm 0.25$	$7.90^{e} \pm 0.08$	$8.23^{de} \pm 0.25$	$36.61^{b} \pm 2.64$	$38.23^{a} \pm 0.25$
Moisture	$10.18^{ab} \pm 0.11$	$10.18a^{b} \pm 0.11$	$8.23^{c} \pm 0.14$	$8.29^{c} \pm 0.10$	$9.56^{b} \pm 0.34$	$9.64^{b} \pm 0.26$	$10.32^{ab} \pm 0.19$	$10.44^{a} \pm 0.18$
Ash	$2.02^{c} \pm 0.16$	$2.33b^{c} \pm 0.17$	$2.50^{bc} \pm 0.04$	$3.88^{a} \pm 0.09$	$2.71^{b} \pm 0.21$	$3.50^{a} \pm 1.40$	$2.00^{c} \pm 0.02$	$2.21b^{c} \pm 0.08$
Carbohydrate	$73.22^{a} \pm 0.26$	$71.90a^{b} \pm 0.19$	$69.19^{c} \pm 0.10$	$66.54^{d} \pm 0.23$	$71.48^{abc} \pm 0.23$	$69.91^{bc} \pm 0.14$	$31.56^{e} \pm 1.63$	$29.49^{f} \pm 0.20$
Energy (kcal)	$379.00^{b} \pm 4.95$	$374.46^{bcd} \pm 0.40$	$377.66^{bc} \pm 1.16$	$374.98^{bcd} \pm 0.34$	$370.16^{cd} \pm 2.06$	$369.31^{d} \pm 1.07$	$426.42^{a} \pm 0.54$	$423.08^{a} \pm 0.46$

Values are mean of duplicate determinations ± standard deviation. Means with different superscripts in the same row are significantly ($p<0.05$) different. UT means untreated, FS means fermented and sprouted and FST means fermented, sprouted and toasted

Table 2. Mineral composition of local raw materials for complementary food formulation

Parameters (mg/100g)	UT Yellow maize	FS Yellow maize	UT Sorghum	FS Sorghum	UT Millet	FS Millet	UT Soybean	FST Soybean
Sodium	$176.38^{a} \pm 0.07$	$177.74^{a} \pm 0.49$	$180.35^{a} \pm 7.07$	$186.93^{a} \pm 2.49$	$155.69^{b} \pm 6.64$	$178.74^{bc} \pm 0.42$	$154.23^{b} \pm 0.77$	$178.05^{c} \pm 0.59$
Calcium	$50.64^{ab} \pm 0.25$	$56.88^{ab} \pm 5.9$	$62.39^{ab} \pm 5.65$	$68.61^{a} \pm 1.56$	$46.96^{b} \pm 2.79$	$48.76^{b} \pm 1.20$	$61.44^{ab} \pm 1.09$	$61.70^{ab} \pm 0.03$
Potassium	$51.30^{a} \pm \pm 3.64$	$65.31^{a} \pm 14.95$	$60.75^{a} \pm 9.72$	$70.25^{a} \pm 4.81$	$60.25^{a} \pm 0.69$	$63.73^{a} \pm 2.11$	$58.23^{a} \pm 2.14$	$63.73^{a} \pm 2.11$
Magnesium	$161.86^{ab} \pm 3.58$	$174.16^{a} \pm 0.27$	$153.94^{ab} \pm 0.06$	$169.16^{a} \pm 0.45$	$140.13^{b} \pm 5.78$	$161.48^{ab} \pm 1.32$	$155.55^{ab} \pm 6.46$	$172.84^{a} \pm 14.03$
Phosphorus	$408.87^{a} \pm 0.64$	$403.77^{a} \pm 0.83$	$350.12^{c} \pm 1.03$	$344.08^{c} \pm 2.72$	$368.85^{b} \pm 2.02$	$365.64^{b} \pm 3.34$	$370.2^{b} \pm 0.31$	$369.06^{d} \pm 0.83$
Iron	$15.76^{a} \pm 1.30$	$19.43^{a} \pm 0.45$	$3.51^{b} \pm 1.17$	$5.51^{b} \pm 2.53$	$2.77^{b} \pm 0.26$	$5.25^{b} \pm 0.35$	$3.07^{b} \pm 0.04$	$7.17^{b} \pm 1.70$
Zinc	$2.61^{b} \pm 0.67$	$5.60^{ab} \pm 0.93$	$3.66^{b} \pm 1.27$	$5.76^{ab} \pm 0.62$	$3.72^{b} \pm 0.04$	$7.69^{a} \pm 0.30$	$2.81^{b} \pm 0.93$	$7.91^{a} \pm 1.13$
Manganese	$2.22^{a} \pm 0.01$	$2.92^{a} \pm 0.06$	$2.57^{a} \pm 0.57$	$2.88^{a} \pm 0.18$	$2.36^{a} \pm 0.25$	$2.44^{a} \pm 0.35$	$2.84^{a} \pm 0.07$	$2.93^{a} \pm 0.85$
Iodine	$87.54^{a} \pm 4.13$	$87.61^{a} \pm 3.87$	$85.35^{a} \pm 4.73$	$85.41^{a} \pm 4.72$	$87.95^{a} \pm 0.91$	$88.08^{a} \pm 0.80$	$75.76^{a} \pm 0.60$	$75.82^{a} \pm 0.92$

Values are mean of duplicate determinations ± standard deviation. Means with different superscripts in the same row are significantly ($p<0.05$) different. UT means untreated. FS means fermented and sprouted. FST means fermented, sprouted and toasted

Table 3. Vitamin composition of local raw materials for complementary food formulation

Parameters	UT Yellow maize	FS Yellow maize	UT Sorghum	FS Sorghum	UT Millet	FS Millet	UT Soybean	FST Soybean
Vitamin A (µg/100g)	$502.83^{b} \pm 3.56$	$506.38^{b} \pm 1.16$	$499.73^{b} \pm 7.47$	$495.09^{b} \pm 1.29$	$503.28^{b} \pm 2.57$	$505.21^{b} \pm 1.12$	$520.63^{a} \pm 0.46$	$520.39^{a} \pm 0.86$
Vitamin D (µg/100g)	$4.55^{a} \pm 0.08$	$4.57^{a} \pm 0.07$	$4.76^{a} \pm 0.16$	$4.77^{a} \pm 0.16$	$4.63^{a} \pm 0.06$	$4.64^{a} \pm 0.04$	$3.86^{b} \pm 0.13$	$3.87^{b} \pm 0.13$
Vitamin E (mg/100g)	$10.11^{ab} \pm 0.01$	$10.22^{a} \pm 0.07$	$9.39^{c} \pm 0.10$	$9.69^{bc} \pm 0.23$	$8.23^{ef} \pm 0.06$	$8.78^{d} \pm 0.23$	$7.85^{f} \pm 0.12$	$8.60^{de} \pm 0.06$
Vitamin C (mg/100g)	$7.50^{b} \pm 0.25$	$13.41^{a} \pm 0.14$	$6.39^{c} \pm 0.15$	$13.60^{a} \pm 0.07$	$6.62^{c} \pm 0.30$	$13.65^{a} \pm 0.04$	$6.46^{c} \pm 0.31$	$13.38^{a} \pm 0.03$
Vitamin B1 (mg/100g)	$0.01^{a} \pm 0.06$	$0.12^{a} \pm 0.01$	$0.01^{a} \pm 0.06$	$0.12^{a} \pm 0.01$	$0.11^{a} \pm 0.01$	$0.13^{a} \pm 0.01$	$0.01^{a} \pm 0.06$	$0.20^{a} \pm 0.01$
Vitamin B2 (mg/100g)	$0.12^{bc} \pm 0.01$	$0.15^{abc} \pm 0.01$	$0.11^{bc} \pm 0.01$	$0.16^{ab} \pm 0.01$	$0.11^{bc} \pm 0.01$	$0.15^{abc} \pm 0.01$	$0.11^{c} \pm 0.02$	$0.18^{a} \pm 0.01$
Vitamin B3 (mg/100g)	$1.35^{e} \pm 0.04$	$1.45^{de} \pm 0.05$	$1.59^{bcd} \pm 0.02$	$1.64^{abc} \pm 0.04$	$1.50^{cde} \pm 0.01$	$1.52^{bcd} \pm 0.01$	$1.66^{ab} \pm 0.06$	$1.75^{a} \pm 0.05$
Vitamin B6 (mg/100g)	$0.15^{c} \pm 0.02$	$0.24^{a} \pm 0.01$	$0.15^{c} \pm 0.01$	$0.23^{ab} \pm 0$	$0.19^{bc} \pm 0.01$	$0.27^{a} \pm 0.01$	$0.16^{c} \pm 0.01$	$0.26^{a} \pm 0.01$
Vitamin B12 (µg/100g)	$3.29^{a} \pm 0.03$	$3.39^{a} \pm 0.02$	$1.48^{c} \pm 0.12$	$2.11^{d} \pm 0.01$	$2.00^{c} \pm 0.15$	$2.70^{b} \pm 0.06$	$1.93^{c} \pm 0.08$	$2.74^{b} \pm 0.06$

Values are mean of duplicate determinations ± standard deviation. Means with different superscripts in the same row are significantly ($p<0.05$) different. UT means untreated, FS means fermented and sprouted and FST means fermented, sprouted and toasted

osmoregulation (Izuakor et al., 2024) There is no significant ($p<0.05$) difference in the potassium content across all samples. The magnesium content of all samples significantly ($p<0.05$) increased from UT samples to FST samples. The phosphorous content decreased from 408.87 mg/100g in UT yellow maize to 403.77mg/100g in FS yellow maize. Similar trend was observed across all samples. This may be attributed to metabolic consumption during sprouting (Khattak et al., 2013). There is a notable increase in iron level from 15.76 mg/100g in UT yellow maize to 19.43 mg/100g in FS yellow maize and from 3.07 mg/100g in UT soybeans to 7.17 mg/100g in FST soybeans. This alligns with the finding that fermentation was proved to improve the nutritional value of soybeans by increasing nutrient bioavailability and reducing antinutritional factors (Sukhikh et al., 2022). The 2.61 mg/100g zinc content of UT yellow maize obtained in this study is close to 2.01 mg/100g reported by Liomba et al. (2018), for unprocessed maize flour. No significant ($p<0.05$) difference exists between the manganese level across all samples. Iodine content remained stable across all samples, supporting previous reports that iodine retention is largely unaffected by these processes (Ademulegun et al., 2021).

Fermentation, sprouting and toasting processes significantly ($p<0.05$) impact the vitamin concentration of the samples as shown in Table 3. The vitamin A content increased from 502.83 µg/100g in UT yellow maize to 506.38 µg/100g in FS yellow maize while it increased from 503.28 µg/100g in UT millet to 505.21 µg/100g in FS millet. The vitamin D content remained relatively stable across all samples, with minor increases. This stability is consistent with findings from Nkhata et al. (2018), which indicated that fermentation and sprouting processes do not significantly affect vitamin D levels due to its fat-soluble nature. There is a remarkable increase in vitamin C contents of all FS samples. The FS variants showed nearly double the vitamin C content compared to their UT counterparts (e.g., yellow maize increased from 7.50 mg/100g to 13.41 mg/100g). This finding aligns with that of Chaves-López et al. (2024) where fermentation was shown to increase vitamin C levels through microbial metabolism, which generates ascorbic acid. The water-soluble B vitamins showed significant ($p<0.05$) increases probably due to fermentation and sprouting treatments, particularly in vitamin B6 and B12 content in soybeans, where levels increased by over 50%. These results are consistent with studies which observed that enzymatic action during sprouting enhances bioavailability and concentration of B vitamins in legumes and cereals (Mohapatra et al., 2019, World Health Organization, 2020).

4. CONCLUSION

The findings from this study showed the effects of processing techniques (fermentation, sprouting, and toasting) on the chemical composition of local raw materials (yellow maize, sorghum, millet, and soybeans) for complementary food formulation. These processing techniques enriched protein, iron, zinc, and vitamin contents particularly vitamins C, B1, B6, and B12 while slightly reducing carbohydrate and fiber content. These results revealed that the processing methods significantly ($p<0.05$) enhanced the nutritional profile of local raw materials, making them suitable for cost-effective, nutrient-dense complementary food formulations. However, incorporating ingredients like walnuts, pumpkin seeds, and date palm fruits can further improve nutrient bioavailability. It is recommended that further research to formulate complementary foods using the optimized ratios of these raw materials and adding the suggested diverse materials needs to be embarked on. Further analysis to determine proximate, mineral, vitamin, and anti-nutritional factors of the formulated foods would confirm the findings from this study.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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