Original Research Article

EVALUATINGTHE EFFECTS OF PROCESSING TECHNIQUES ON THE CHEMICAL COMPOSITION OF LOCAL RAW MATERIALS FOR COMPLEMENTARY FOODFORMULATION

ABSTRACT

This research aims at evaluating the chemical composition of local raw materials (yellow corn, sorghum, millet, soybeans) to be utilized in formulating complementary foods focusing on the effects of their processing methods. Yellow maize, sorghum, millet, and soybean were subjected to a sprouting process for three days after a 24-hour fermentation period. Soybeans was toasted after oven drying before grinding. Both processed and unprocessed samples were analysed.The proximate, mineral, and vitamin compositions were determined using standardized analytical methods. Fermentation, sprouting and toasting processes significantly *($p<0.05$)* alter the chemical composition of the evaluated samples. The proximate composition result showed that the crude protein content increased from 7.90% in untreated (UT)millet to 8.23% in fermented and sprouted (FS) millet while carbohydrate content reduced from 36.56% in UT soybeans to 29.49% in fermented, sprouted and toasted (FST) soybeans.The results obtained from atomic absorption spectrophotometry concerning mineral concentrations revealed an increase in iron level from 15.76 mg/100g in UT yellow maize to 19.43 mg/100g in FS yellow maize. The processed samplesshowed nearly double the vitamin C content compared to their UT counterparts.Yellow maize increased from (7.50 to 13.41) mg/100g in (UT and FS) samples.Therefore, processed variants of these local raw materials can be used in their optimized ratios to formulate cost-effective and nutrient-dense complementary foods.

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/Food and AgricultureOrganisation (WHO/FAO,2004) 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 (WHO, 2020). 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&Das, 2022). 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 improvenutritional 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. Itincreases vitamin levels, particularly B-complex vitamins and vitamin C, while degrading anti-nutritional factors such as phytates and tannins (Chaves-López 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 andmicrobial 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. Theaim 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. MATERIAL 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.

2.2.2Preparation 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 was 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 (1999) standard methods**.**

2.3.2 Vitamin Analysis

2.3.2.1 Determination of Vitamin A

The method described by Bayfield and Cole (1980), was adopted [11]. 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

The Emmerie-Engel reaction described by Rosenberg and Miller (1992), was used for vitamin E estimation. 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 as described by Roe and Keuther(1943), was used to analyse Vitamin C.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.

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.

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 Brockmann et al. (1974). 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 0.1g 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 MineralAnalysis

The mineral analysis was conducted using Varian AA240 Atomic Absorption Spectrophotometer according to the American Public Health Association (1995). Thesamples 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.

2.5Statistical 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 proximatecomposition 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 UTto FS samples. There is an increase in the crude protein content of soybeans from 36.61% inUT 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 is alligns with 35.53 % obtained by Ikese et al. (2017), for soybean flour. Also, protein level increased from 7.90% in UTmillet to 8.23% in FS millet. Osman(2011), observed similar trends in pearl millet, with protein content rising from 15.25% in unfermented millet to 15.35% in fermented 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% ofUTsorghum, 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 UTsoybeans to 29.49% in FSTsoybeans. 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 (Makinde & Ladipo, 2012).

Table 1Proximate 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] ± 4.95	374.46[bcd] ± 0.40	377.66[bc] ± 1.16	374.98[cd] ± 0.34	370.16[cd] ± 2.06	369.31[d] ± 1.07	426.42[a] ± 0.54	423.08[a] ± 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.

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 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, 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 some soybeans may contain iron as phytoferrin, which may be highly bioavailable (Gibson et al., 2006). 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 (Dewettinck et al. 2008).

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

Parameter(mg/100g)	UT Yellow maize	FS Yellow maize	UT Sorghum	FS Sorghum	UT Millet	FS Millet	UT Soybean	FST Soybean
Sodium	176.38[a] ± 0.07	177.74[a] ± 0.49	180.35[a] ± 7.07	186.93[a] ± 2.49	155.69[b] ± 6.64	178.74[bc] ± 0.42	154.23[b] ± 0.77	178.05[c] ± 0.59
Calcium	50.64[ab] ± 0.25	56.88[ab] ± 5.9	62.39[ab] ± 5.65	68.61[a] ± 1.56	46.96[b] ± 2.79	48.76[b] ± 1.20	61.44[ab] ± 1.09	61.70[ab] ± 0.03
Potassium	51.30[a] ± ± 3.64	65.31[a] ± 14.95	60.75[a] ± 9.72	70.25[a] ± 4.81	60.25[a] ± 0.69	63.73[a] ± 2.11	58.23[a] ± 2.14	63.73[a] ± 2.11
Magnesium	161.86[ab] ± 3.58	174.16[a] ± 0.27	153.94[ab] ± 0.06	169.16[a] ± 0.45	140.13[b] ± 5.78	161.48[ab] ± 1.32	155.55[ab] ± 6.46	172.84[a] ± 14.03
Phosphorus	408.87[a] ± 0.64	403.77[a] ± 0.83	350.12[c] ± 1.03	344.08[c] ± 2.72	368.85[b] ± 2.02	365.64[b] ± 3.34	370.2[b] ± 0.31	369.06[d] ± 0.83
Iron	15.76[a] ± 1.30	19.43[a] ± 0.45	3.51[b] ± 1.17	5.51[b] ± 2.53	2.77[b] ± 0.26	5.25[b] ± 0.35	3.07[b] ± 0.04	7.17[b] ± 1.70
Zinc	2.61[b] ± 0.67	5.60[ab] ± 0.93	3.66[b] ± 1.27	5.76[ab] ± 0.62	3.72[b] ± 0.04	7.69[a] ± 0.30	2.81[b] ± 0.93	7.91[a] ± 1.13

Manganese	2.22[a] ± 0.01	2.92[a] ± 0.06	2.57[a] ± 0.57	2.88[a] ± 0.18	2.36[a] ± 0.25	2.44[a] ± 0.35	2.84[a] ± 0.07	2.93[a] ± 0.85
Iodine	87.54[a] ± 4.13	87.61[a] ± 3.87	85.35[a] ± 4.73	85.41[a] ± 4.72	87.95[a] ± 0.91	88.08[a] ± 0.80	75.76[a] ± 0.60	75.82[a] ± 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

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. (2014) 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 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 (Makinde & Ladipo, 2012).

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

Parameter	UT Yellow maize	FS Yellow maize	UT Sorghum	FS Sorghum	UT Millet	FS Millet	UT Soybean	FST Soybean
VitaminA (µg/100g)	502.83[b]± 3.56	506.38[b] ± 1.16	499.73[b] ±7.47	495.09[b] ± 1.29	503.28[b] ± 2.57	505.21[b] ± 1.12	520.63[a] ± 0.46	520.39[a] ± 0.86
Vitamin D (µg/100g)	4.55[a] ± 0.08	4.57[a] ± 0.07	4.76[a] ± 0.16	4.77[a] ± 0.16	4.63[a] ± 0.06	4.64[a] ± 0.04	3.86[b] ± 0.13	3.87[b] ± 0.13
Vitamin E (mg/100g)	10.11[ab] ± 0.01	10.22[a] ± 0.07	9.39[c] ± 0.10	9.69[bc] ± 0.23	8.23[ef] ± 0.06	8.78[d] ± 0.23	7.85[f] ± 0.12	8.60[de]± 0.06
Vitamin C (mg/100g)	7.50[b] ± 0.25	13.41[a] ± 0.14	6.39[c] ± 0.15	13.60[a] ± 0.07	6.62[c] ± 0.30	13.65[a] ± 0.04	6.46[c] ± 0.31	13.38[a] ± 0.03
Vitamin B1 (mg/100g)	0.01[a] ± 0.06	0.12[a] ± 0.01	0.01[a] ± 0.06	0.12[a] ± 0.01	0.11[a] ± 0.01	0.13[a] ± 0.01	0.01[a] ± 0.06	0.20[a] ± 0.01

Vitamin B2 (mg/100g)	0.12^{bc} ± 0.01	0.15^{abc} ± 0.01	0.11^{bc} ± 0.01	0.16^{ab} ± 0.01	0.11^{bc} ± 0.01	0.15^{abc} ± 0.01	0.11^{c} ± 0.02	0.18^{a} ± 0.01
Vitamin B3 (mg/100g)	1.35^{e} ± 0.04	1.45^{de} ± 0.05	1.59^{bcd} ± 0.02	1.64^{abc} ± 0.04	1.50^{cde} ± 0.01	1.52^{bcd} ± 0.01	1.66^{ab} ± 0.06	1.75^{a} ± 0.05
Vitamin B6 (mg/100g)	0.15^{c} ± 0.02	0.24^{a} ± 0.01	0.15^{c} ± 0.01	0.23^{ab} ± 0	0.19^{bc} ± 0.01	0.27^{a} ± 0.01	0.16^{c} ± 0.01	0.26^{a} ± 0.01
Vitamin B12 (µg/100g)	3.29^{a} ± 0.03	3.39^{a} ± 0.02	1.48^{c} ± 0.12	2.11^{d} ± 0.01	2.00^{c} ± 0.15	2.70^{b} ± 0.06	1.93^{c} ± 0.08	2.74^{b} ± 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.

4. CONCLUSION

The findings from this study showed the chemical composition of yellow maize, sorghum, millet, and soybeans for complementary food formulation, focusing on the effects of fermentation, sprouting, and toasting.These processing techniques enriched protein, iron, zinc, and vitamin contents particularly vitamins C, B1, B6, and B12 while slightly reducing carbohydrate and fiber content. Therefore, theprocessed variants of these local raw materials can be used in their optimized ratios to formulatecost-effective and nutrient-richcomplementary foods. 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.

COMPETING INTERESTS

No competing interests exist.

REFERENCES

A.O.A.C. (1999). Official methods of analysis (16th ed.). Association of Official Analytical Chemists.

American Public Health Association. (1995). Standard methods for the examination of water and wastewater (19th ed.). American Public Health Association Inc.

Adebiyi, J.A., Obadina, A.O., Adebo, O.A. &Kayitesi, E. (2017). Comparison of nutritional quality and sensory acceptability of biscuits obtained from native, fermented, and malted pearl millet (*Pennisetum glaucum*) Flour. Food Chemistry, 232, 210-217. https://doi.org/10.1016/j.foodchem.2017.04.020

Akinola, R., Pereira, L., Mabhaudhi, T., De Bruin, F-M. & Rusch, L. (2020). A Review of Indigenous food crops In Africa and the implications for more sustainable and healthy food systems. Sustainability, 12(8), 3493. Doi: 10.3390/Su12083493

Bayfield, R. F., & Cole, E. R. (1980). Colorimetric estimation of vitamin A with trichloroacetic acid. Methods in enzymology, 67,189-195. Https://Doi.Org/10.1016/S0076-6879(80)67026-8. PMID: 7366425

Brockmann, R. E., Deluca, H. F., & Potts, J. T., Jr. (1974). A rapid assay for 25-OH-Vitamin D3 without preparative chromatography. Journal of clinical endocrinology & metabolism, 38(6), 1046-1051.

Chaves-López, C., Serio, A., Grande-Tovar, C. D., Cuervo-Mulet, R., Delgado-Ospina, J., & Paparella, A. (2014). Traditional fermented foods and beverages from a microbiological and nutritional perspective: The Colombian heritage. Comprehensive Reviews in Food Science and Food Safety, 13(2), 1031-1042.

Dewettinck, K., Van Bockstaele, F., Kuhne, B., Van de Walle, D., &Courtens, T. et al. (2008). Nutritional value of bread: influence of processing, food interaction and consumer perception. Journal of Cereal Science, 48(2), 243-257. https://doi.org/10.1016/j.jcs.2008.01.003

Dutta, M., & Das, P. (2020). Sensory Evaluation and nutrient analysis of pumpkin incorporated complementary food. Annals Food Science and Technology, 21(3), 473-477.

Gibson, R. S., Perlas, L., & Hotz, C. (2006). Improving the bioavailability of nutrients in plant foods at the household level. Proceedings of the Nutrition Society, 65, 160-168 DOI: 10.1079/PNS2006489

Igbabul, B., Hiikyaa, O., &Amove, J. (2014) Effect of fermentation on the proximate composition and functional properties of mahogany bean (*Afzelia Africana*) flour. Current Research in Nutrition and Food Science, 2(1), Doi: Http://Dx.Doi.Org/10.12944/Crnfsj.2.1.01

Ikese, C. O, Okoye, P. A. C, Ubwa, S. T., Akende, S. (2017). Proximate analysis and formulation of infant food from soybean and cereals obtained in Benue state, Nigeria. International Journal of Food Science and Biotechnology, 2(5), 106-113.

Izuakor, P. N, Ejidike, L. C and Muobike, C. M. (2024). Extraction, physicochemical, fatty acid analysis of *Chrysophyllumalbidum* (African starapple) seed oil and nutrient composition of the fruit parts. International Journal of Research and Innovation in Applied Science, 9(5), 157-171 DOI: https://doi.org/10.51584/IJRIAS.2024.905014

Khattak, K. F. (2013). Proximate composition, phytochemical profile and free radical scavenging activity of radiation processed*Emblica officinalis.* International Food Research Journal, 20(3), 1125-1131

Liomba, C. M., Kunyanga, C. N., & Adhiambo, A. (2018). Formulation of a Complementary Flour with High Nutrient Density and Micronutrient Content, International Journal of Food and Nutrition Research, 2(11) http://escipub.com

Makinde, F. M. & Ladipo, A. T. (2012) Physico-Chemical and Microbial Quality of Sorghum-Based Complementary Food Enriched with Soybean (Glycine max) and Sesame (Sesamum indicum), Journal of Food Technology,10(2) 46-49. DOI:10.3923/jftech.2012.46.49

Nkhata, G. S., Kamau, H., Ayua, E., & Bosco, S., J. (2018). Fermentation and germination improve nutritional value of cereals and legumes through activation of endogenous enzyme. Food science and nutrition, 6(7), 1-13 Doi: 10.1002/fsn3.846

Ogodo AC, Ugbogu OC, Onyeagba RA (2018) Variations in The Functional Properties Of Soybean Flour Fermented With Lactic Acid Bacteria (Lab)-Consortium. Applied Microbiology Open Access 4: 141. Doi:10.4172/2471-9315.1000141

Osman, M. A. (2011) Effect of traditional fermentation process on the nutrient and antinutrient contents of pearl millet during preparation of lohoh. Journal of the Saudi Society of Agricultural Sciences, 10, 1-6. Https://doi.org/10.1016/j.jssas.2010.06.001

Oyegoke, T. G., Adedayo, E. O., Fasuyi, F. O. &Oyegoke, D. A. (2020). Vitamin and mineral composition of complementary food formulated from yellow maize, soybean, millet, and carrot composite fours. International Journal of Science and Research, 9(2), 450-456.

Roe, J. H., & Kuether, C. A. The determination of ascorbic acid in whole blood and urine through the 2,4-dinitrophenylhydrazine derivative of dehydroascorbic acid. Journal of Biological Chemistry, 147, 399 – 407. https://doi.org/10.1016/S0021-9258(18)72395-8

Rosenberg, I. H., Miller, J. W. (1992). Nutritional factors in physical and cognitive functions of elderly people. The American Journal of Clinical Nutrition, 55(6 Suppl) 1237S - 1243S https://doi.org/10.1093/ajcn/55.6.1237S

Tripathi, M. K., Mohapatra, D., Jadam, R. S, Pandey, S., Singh, V., Kumar. V., *et al*. (Eds.). (2021). Nutritional Composition of Millets. Millets and Millet Technology. Springer, Singapore. DOI:10.1007/978-981-16-0676-2_5

WHO (World Health Organization). (2004) Vitamin and mineral requirements in human nutrition, 2nd edition. World Health Organization https://iris.who.int/handle/10665/42716

WHO (World Health Organization). (2020). Complementary feeding: Report of a global consultation. Geneva: WHO.