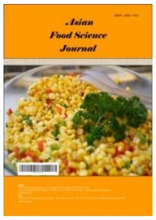

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Effect of Fermentation and Mango Mesocarp or Fluted Pumpkin Powders on the Chemical Composition and Potential Mineral Bioavailability of Sorghum-Based Complementary Foods

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The effect of fermentation, mango mesocarp or fluted pumpkin leaf powders on the chemical properties and potential mineral bioavailability of sorghum-based complementary foods was investigated. Samples were formulated based on 16% protein to satisfy the nutrient requirement of preschool children to obtain non-fermented sorghum/mango mesocarp/crayfish (NFSMC), non-fermented sorghum/fluted pumpkin leaf/crayfish (NFSPC), fermented sorghum/ mango mesocarp/crayfish (FSMC) and fermented sorghum/ fluted pumpkin leaf /crayfish (FSPC). Some physico-chemical properties of the blends were analysed using standard procedures. Moisture (10.22–10.99%) and carbohydrate (78.73-79.89%). The protein (15.84-16.91%), fibre (0.07-0.08%) and ash (2.07-2.15%) were within the recommended limits. Fat contents ranged from 2.00-2.16% and energy values ranged from 401.40 to 402.10 kCal. Fermentation did not significantly ($p \geq 0.05$) affect the proximate composition of the products. The mineral values for magnesium (53.25-

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61.60%), sodium (32.06-46.30%), potassium (20.80-44.66%), calcium (198.60-230.30%) and phosphorus (98.99-101.50%) with no significant ($p \geq 0.05$) difference in most of the products. The iron and copper values ranged from 10.03-17.09% and 0.42-1.43% respectively. Mineral ratios for the products ranged from 0.74 – 2.19 for Na/K, 1.96 – 2.71 for Ca/P and 3.69 – 5.07 for Ca/Mg. The tannins content ranged from 20.23 to 51.51 mg/100 g, phytate (7.25-22.16 mg/100 g), oxalate (5.50 to 14.37 mg.100 g), pH (6.20 to 7.80) and beta-carotene ranged from 724.50 - 1215.40 µg/100 g with significant ($p<0.05$) difference between the blends. The molar ratios of the blends, except NFSMC, indicated good potential for mineral bioavailability.

Keywords: Crayfish; mango; mineral ratios; anti-nutrients.

1. INTRODUCTION

Sorghum contains 60-80% starch and thus needs to be enriched with affordable source of other essential nutrients needed by children and complementary foods are made from starchy staple foods which, due to their heavy viscosity, have to be diluted with water before being given to children [1]. This practice results in reduced nutrients and energy in the already deficient complementary food.

Fasuan et al. [2] reported that crayfish is classified as an animal polypeptide, it accounts for 36-45% of crude protein and is reported to have high nutritive value with a superior biological value, true digestibility, net protein utilization, high content of amino acid, and protein efficiency is favourable compared to casein. Kittiyut et al. [3] reported that vegetables are widely designated as “protective foods” in human diet due to their varied health benefits attributable to the richness in vitamins, essential fatty acids, minerals, amino acids and dietary fiber and various essential bioactive compounds. Combination of common cereals, which are deficient in lysine and tryptophan but have sufficient amount of sulphur-containing amino acids, with inexpensive protein sources like legumes and crayfish that are rich in lysine can be used to improve the nutritive value of a food product. Obiakor-Okeke et al. [4] and Tufa et al. [5] found that formulation and development of nutritious complementary foods from local and readily available raw materials has received considerable attention in many developing countries.

The cost of baby formula is currently high, beyond the reach of low or average income household mothers and the traditional complementary foods based on cereals alone usually have inadequate nutrients required by the infants [6]. Such families often depend on inadequately processed traditional foods consisting mainly of un-supplemented cereal porridges made from maize, sorghum and millet.

Fermentation of cereal-based foods is a common practice of food preservation in Africa [7]. Several researchers [8,9,10] have reported that fermentation modifies some physical characteristics of cereals and legumes such as reduction in bulk density, increases the level of some nutrients such as vitamins and minerals, and decreases the levels of anti-nutrients while improving digestibility as well as bioavailability of essential micronutrients. Other advantages of fermentation as reported by the authors include the introduction of antimicrobial properties in the food. Fermentation therefore holds promise as a processing method that can be used to diversify the food uses of some under exploited plant foods.

Therefore, application of natural fermentation as an adaptable technology and incorporation of materials such as crayfish, mango mesocarp or fluted pumpkin leaves could improve the nutrients availability and quality of the sorghum-based diets. Information on the effect of natural fermentation of sorghum and complementation with crayfish, mango mesocarp or fluted pumpkin leaves are scarce. Therefore, the aim of this study was to develop sorghum-based complementary foods using crayfish, mango mesocarp or fluted pumpkin leaf for improved nutrient composition.

2. MATERIALS AND METHODS

2.1 Materials

About 10 kg of red sorghum grains [*Sorghum bicolor*, (L) Moench] and 5 kg of semi ripe mango fruits (a local variety) (*Mangifera indica*) popularly known as *Wua nyian* and *Chul kpev* in Tiv respectively, 1 kg of crayfish (*Procambarus clarkii*) and fluted pumpkin leaves *(Telferia accidentalis)* each were sourced from a local market in Makurdi, Benue State. The materials were transported to the Department of Food Science and Technology, University of Agriculture, Makurdi for processing prior to product formulation and subsequent analysis.

2.2 Methods

2.2.1 Sample preparation

Sorghum flour and solid state fermentation, mango mesocarp (MM), fluted pumpkin leaf (FPL) and crayfish flours were prepared as reported by Sengev et al. [11].

2.2.1.1 Product formulation

The protein content of fermented and Non-fermented sorghum flours, crayfish, mango mesocarp and fluted pumpkin leaf powders were determined. Products were formulated using material balance as described by Chiba [12] to achieve 16% protein as shown in Table 1.

2.3 Analyses

2.3.1 Proximate analysis

This was determined using the methods of AOAC [13] while available carbohydrate was determined by difference and energy values were calculated using the Atwater factor as described by FAO [14]

2.3.2 Mineral analysis

Mineral determination was carried out by acid digestion according to AOAC [13]. Ash obtained after incineration at 500^{o}C was dissolved in aquaregia (10 mL nitric acid + 30 mL HCl) solution and boiled for 30 min. The mixture was transferred into a 250 mL volumetric flask and boiled again for 30 min. The mixture was filtered into 100 mL volumetric flask and made up to the mark with distilled water. The mineral concentration was determined using the Atomic Absorption Spectrophotometer (Model: 6405 UV/VIS, Jenway, UK).

2.3.3 Determination of anti-nutrients

The concentrations of tannins, phytate and oxalate were determined using the method of AOAC [13]. A known quantity (2.0 g) of sample was weighed and dissolved with hexane, extracted and filtered using micro chromatography syringe filter (0.25 µL) into a 1.0 mL vial. The prepared sample was then injected into a Buck scientific (USA) BLC10/11. High Performance Liquid Chromatography (HPLC) system fitted with a fluorescence detector (excitation at 295 nm and emission at 325 nm) and an analytical silica column (25 cm x 4.6 mm ID, stainless steel, 5 µm). The mobile phase used was hexane: tetrahydrofuran: Iso-propanol (1000:60:4 v/v/v) at a flow rate of 1.0 mL/min. Standards of each anti-nutrients were also prepared using similar method. Five serially diluted concentrations of each anti-nutrient were prepared. A five-point calibration curve was developed for each anti-nutrient using the peak area against the five standards concentrations and was used to obtain the concentrations of each anti-nutrient in the samples.

2.3.4 Computation of mineral ratios

The molar ratio was calculated on the basis of 100 g sample using the method described by Tamanna et al. [15]. The mole of phytate and minerals was determined by dividing the weight of phytate and minerals with its atomic weight (phytate: 660 g/mol; Oxalate: 88.02 g/mol; Fe: 56 g/mol; Zn: 65 g/mol; Ca: 40 g/mol). The molar ratio of the anti-nutrients to mineral was obtained after dividing the mole of the anti-nutrients with the respective mole of minerals.

2.3.5 Determination of beta-carotene

Beta-carotene was determined using the method described by Sengev et al. [16] with modification. Five grams (5.0 g) of the sample was poured into a 125 mL separating funnel and a solution containing 50 mL of 3:2 ethanol:hexane was added. About 2 mL of 2% sodium chloride (NaCl) solution was also added to avoid formation of emulsion. The mixture was manually shaken vigorously for about 60 sec., allowed to settle for 30 min. and the lower layer was run off. The absorbance of the top layer (hexane) was collected. The absorbance reading was read at the wavelength of 452 nm using a spectrophotometer (Spectro Sc 20, Labomed, Inc. USA) and the concentration of β-carotene was calculated using Lambert-Beer law as follows:

$$\text{Beta} - \text{carotene}\ (\mu g/100\ g) = \frac{A\ x\ V\ x\ 10^6}{A_{1cm}^{1\%}\ x\ W}$$

Where, A = Absorbance, V = Total volume of extract (20 mL), W = Weight of sample (g), $A_{1cm}^{1\%}$ = 2590 (Absorption coefficient of β-carotene in hexane)

2.3.6 Determination of pH

The pH of the samples was determined using the method described by Akpapunam and Sefa-Dedeh [17] using a pH meter (Labtech digital pH meter Model 152R).

2.4 Statistical Analysis

The data generated were analyzed using analysis of variance (ANOVA), and means were separated using Duncan's Multiple Range Test (DMRT) at 5% level of probability [18].

3. RESULTS AND DISCUSSION

3.1 Proximate Composition (%) of Sorghum-Based Complementary Foods

The results of NFSMC, NFSPC, FSMC and FSPC are presented in Table 2. The moisture, protein, fat, fibre, ash and carbohydrate ranged from 10.22 to 10.99, 15.84 to 16.91, 2.00 to 2.15, 0.07 to 0.08, 2.07 to 2.14 and 78.64 to 79.86 respectively. The energy values of the products ranged from 401.40 to 402.10 Kcal/100 g. The results of the proximate composition in Table 2 indicate that there was no significant difference ($p \geq 0.05$) between the products in terms of moisture content. The moisture content reported in this study compared favourably with Badifu et al. [19] who reported that the moisture content of maize/soybean/mango mesocarp complementary foods ranged from 8.7 to 9.5%. The moisture content though higher than the 5% recommended by FAO/WHO [20] for complementary foods for infants and younger children, is an advantage in nutrient composition and shelf life. Studies [21,22] have indicated that low moisture content in complementary foods increased the nutrient composition, shelf life of the product and inhibits biochemical activities of invading microorganisms, and thereby prevents food spoilage during storage.

The protein content of the products also agreed with the findings of Iombor et al. [23] who reported 15.9–16.9% protein for millet/soybean/crayfish complementary foods. The protein content of the products met the minimum requirement of 15% as recommended by FAO/WHO [20]. The increase in protein content could be attributed to the addition of crayfish to the products. Findings by Fasuan et al. [2] revealed that the protein content of crayfish ranged between 36 and 45%. Hence, the inclusion of crayfish in the products is expected to increase their protein contents. The low values of fat, ash and fibre observed were partly ascribed to their respective low values in the ingredient used in the product composition. This is in agreement with the observation of Bally [24] and Ajanaku et al. [25] who reported 0.27% fat, 0.50% ash, 1.87% fibre for mango and 0.92% fat, 0.96% ash and 0.22% fibre for crayfish respectively. The low values could also be attributed to dehulling of sorghum grains which removed the germ, aleurone layer and the pericarp resulting to the reduction in fat, ash and fibre contents respectively [26].

The high carbohydrate values observed were as a result of using cereal as the base material in the formulations. This is also in close agreement with the observation of Ibironke et al. [27] who reported carbohydrate content in the range of 75.19–89.49% when cereal (maize) was used as the base material in complementary foods formulation. The energy values of the products were higher compared to the reports of Ibironke et al. [26] and Sengev et al. [28]. The variation in carbohydrate and consequent increase in energy values could be due to alterations in other components such as protein, ash, fibre, moisture and fat. The blends provided the energy requirement as recommended by FAO/WHO [20]. The high energy and protein contents of these complementary foods revealed that they are suitable to support growth and development in infants and young children.

3.2 Mineral Composition (Mg / 100 g) and Mineral Ratios of Sorghum–Based Complementary Foods

The results of mineral contents of NFSMC, NFSPC, FSMC and FSPC and mineral ratios are presented in Table 3 and 4 respectively. The results showed that Magnesium, Sodium, Potassium, Calcium and Phosphorus ranged from 53.25 to 61.60, 32.86 to 46.30, 21.11 to 44.66, 198.60 to 230.30 and 98.99 to 101.50 respectively with significant difference ($p<0.05$) between the products. The results of Iron, Copper and Zinc ranged from 10.03 to 17.09, 1.33 to 1.42 and 2.67 to 3.95 respectively with significant difference ($p<0.05$) between the products. The mineral ratios for Na/K, Ca/P and Ca/Mg ranged from 0.74 to 2.19, 1.96 to 2.31 and 3.35 to 4.27 respectively. Fermentation of sorghum flour and addition of mango mesocarp or fluted pumkin leaf (FPL) powders significantly (p<0.05) affected the mineral contents of the products. The Mg content of the fermented products increased significantly (p<0.05). This could be attributed to fermentation and or addition of FPL. Ijarotimi [29] and Azhari et al. [30] also reported that fermentation significantly increased mineral content (mg/100 g) of wheat and sorghum flours. High mineral contents of mango pulp and fluted pumpkin leaf have been reported by Bally [24] and Asaolu et al. [31] respectively. Therefore, as expected, addition of fluted pumpkin leaf powder significantly (p<0.05) increased Mg, Na, P, Ca and Fe contents of the products while mango mesocarp significantly increased the K content of the products.

NFSPC provided 47.38% of magnesium as contribution to RDA. Sodium and potassium of the products had the least percentages of 3.86 and 1.18% respectively as contribution to RDA. Therefore, Sodium and potassium which form electrolytes responsible for the homeostatic balance of body fluids were limiting in the products. Calcium and phosphorus contents in the products were below the recommended 1000 and 500 mg/day respectively, as required by WHO [32] and IOM [33].

The formulated products provided at least 100.3% of iron and 95.45% of copper to the target group (6-59 months) as contribution to RDA. Malamurugan et al. [34] reported that in human metabolism, copper allows many critical enzymes to function properly and also production of hemoglobin, myelin and melanin. The adequate supply of iron by the products implies that anaemic conditions in prospective consumers could be controlled. Zinc contributed at least 51.40% to RDA and is limiting in all the products.

The Na/K ratio in the products with mango mesocarp was observed to be <1.0, while the products with fluted pumpkin leaf had ratios > 1.0. Findings by Watts [35] indicated that the ideal ratio of Na/K is 2.4:1 and a preferred range of 1.4 to 3.4. Previous reports by Cappuccio and McGregor [36] showed that Na/K ratio less than 1.0 is recommended in the diets of people who are proned to high blood pressure. This implies that NFSMC and FSMC are more suitable for consumption by hypertensive patients.

The Ca/P ratios for the products are within the range suggested by Watts (2010). It was reported by Nieman et al. [37] that foods containing Ca/P ratio of >1.0 are rated good while < 0.5 are rated poor. Adeyeye et al. [38] also reported that these levels would enhance strong bone development since absorption under this condition would be high. The Ca/Mg ratios of the products as reported fell within the acceptable range. Watts [35] reported that the ideal ratio of Ca/Mg is 7:1 and the preferred ranged from 3 to 11. The elevated Ca/Mg ratios were reported to be associated with increased insulin levels.

3.3 Anti-Nutrient, pH and Beta-carotene of Sorghum-Based Complementary Foods

The results of the anti-nutrients and pH of NFSMC, NFSPC, FSMC and FSPC are presented in Table 5. The results revealed that the anti-nutrient contents (mg / 100 g) and pH in the non-fermented products was significantly (p < 0.05) higher than its fermented counterpart.

Tannins ranged from 51.51 to 20.13, phytate (20.16 to 7.25), oxalate (14.37 to 5.50) and pH ranged from 7.80 to 6.20 for NFSMC, NFSPC, FSMC and FSPC. The beta-carotene of the blends ranged from 724.50 to 1215.40 µg /100 g with significant difference (p<0.05) between the blends. The anti-nutrient content and pH of the

Table 1. Blend formulation (%)

Blend	Ingredient mix (g / 100 g sample)			
	Sorghum	Mango Mesocarp (MM)	Fluted Pumpkin Leaf (FPL)	Crayfish
NFSMC	91.06	0.17	-	8.77
FSMC	91.06	0.17	-	8.77
NFSPC	91.04	-	0.19	8.77
FSPC	91.04	-	0.19	8.77

Key: NFSMC= Non-Fermented Sorghum + Mango Mesocarp + Crayfish, NFSPC= Non-Fermented Sorghum + Fluted Pumpkin Leaf + Crayfish, FSMC = Fermented Sorghum + Mango Mesocarp + Crayfish, FSPC =Fermented Sorghum + Fluted Pumpkin Leaf + Crayfish

Table 2. Effect of fermentation, MM or FPL on the proximate composition (% dry basis) of sorghum-based complementary foods

Product	Moisture	Crude protein	Crude fat	Crude fibre	ash	Carbohydrate(Fibre free)	Energy (kCal/100 g)
NFSMC	10.35[a] ±0.04	15.84[b] ±0.52	2.15[a] ±0.02	0.07[a] ±0.01	2.08[a] ±0.03	79.86[a] ±0.53	402.10[a] ±0.25
FSMC	10.99[a] ±0.08	16.05[b] ±0.10	2.13[a] ±0.01	0.08[a] ±0.01	2.15[a] ±0.00	79.59[ab] ±0.08	401.70[ab] ±0.04
NFSPC	10.22[a] ±0.04	16.83[a] ±0.06	2.00[a] ±0.12	0.08[a] ±0.02	2.07[a] ±0.03	79.03[ab] ±0.12	401.40[b] ±2.40
FSPC	10.32[a] ±0.69	16.91[a] ±0.07	2.14[a] ±0.07	0.08[a] ±0.01	2.14[a] ±0.01	78.73[b] ±0.01	401.80[ab] ±0.39
FAO/WHO (1991)	<5	>15	10-25	<5	<3	64	400-425

Values are means ± Standard deviation of three determinations. Means in the same column not followed by the same superscript are significantly different ($p < 0.05$)
Key: NFSMC= Non-Fermented Sorghum + Mango Mesocarp + Crayfish, NFSPC= Non-Fermented Sorghum + Fluted Pumpkin Leaf + Crayfish, FSMC = Fermented Sorghum + Mango Mesocarp + Crayfish, FSPC =Fermented Sorghum + Fluted Pumpkin Leaf + Crayfish, MM = Mango Mesocarp, FPL = Fluted pumpkin leaves

Table 3. Effect of fermentation, MM or FPL on the mineral content of sorghum-based complementary foods

Mineral (mg/100g)	RDA/AI(mg/day)	Blend			
		NFSMC	FSMC	NFSPC	FSPC
Magnesium	130	55.68±0.45[b]	59.89±1.28[a]	61.60±2.26[a]	53.25±1.20[b]
Sodium	1200	34.35±1.06[b]	32.86±0.49[b]	46.30±1.56[a]	44.46±1.05[a]
Potassium	3800	42.42±0.81[a]	44.66±0.49[a]	21.11±1.57[b]	20.80±1.14[b]
Phosphorus	500	101.50±2.12[a]	98.99±1.43[a]	99.78±0.30[a]	99.90±1.89[a]
Calcium	1000	227.60±0.03[b]	230.30±0.72[b]	198.60±0.02[c]	200.50±0.72[a]
Iron	10	11.96±0.51[b]	10.03±0.54[c]	16.30±0.77[a]	17.09±0.03[a]
Copper	0.44	1.33±0.06[a]	1.36±0.01[a]	1.39±0.04[a]	1.42±0.05[a]
Zinc	5	2.67±0.35[a]	2.57±0.81[a]	3.95±0.26[a]	3.95±0.46[a]

Values are mean ± Standard deviation of three determinations. Means in the same row not followed by the same superscript are significantly different ($p < 0.05$)
Key:NFSMC= Non-Fermented Sorghum + Mango Mesocarp + Crayfish, NFSPC= Non-Fermented Sorghum + Fluted Pumpkin Leaf + Crayfish, FSMC = Fermented Sorghum + Mango Mesocarp + Crayfish, FSPC =Fermented Sorghum + Fluted Pumpkin Leaf + Crayfish, RDA = Recommended Dietary Allowance/Adequate Intakes (mg/day) from IOM (2005), MM = Mango Mesocarp, FPL = Fluted pumpkin leaves

Table 4. Effect of fermentation, MM or FPL on the potential mineral bioavailability of sorghum-based complementary foods

Mineral ratio	Range*	Blend			
		NFSMC	FSMC	NFSPC	FSPC
Na/K	1.4-3.4	0.81	0.74	2.19	2.14
Ca/P	1.8-3.6	1.96	2.45	2.28	2.71
Ca/Mg	3-11	3.57	4.02	3.69	5.07

*Key: NFSMC= Non-Fermented Sorghum + Mango Mesocarp + Crayfish, NFSPC= Non-Fermented Sorghum + FlutedPumpkin Leaf + Crayfish, FSMC = Fermented Sorghum + Mango Mesocarp + Crayfish, FSPC =Fermented Sorghum + Fluted Pumpkin Leaf + Crayfish, RDA = Recommended Dietary Allowance/Adequate Intakes (mg/day) from IOM (2005), *Source = Watts (2010), MM = Mango Mesocarp, FPL = Fluted pumpkin leaves*

Table 5. Effect of fermentation, MM or FPL on the anti-nutrient (mg/100 g), pH and beta-carotene of sorghum-based complementary foods

Blend	Tannin	Pyhtate	Oxalate	pH	Beta-carotene (µg/ 100 g)
NFSMC	51.51 ± 0.23^a	22.16 ± 0.02^a	14.37 ± 0.21^a	7.80 ± 0.14^a	1215.40 ± 2.31^a
FSMC	32.79 ± 0.01^c	9.57 ± 0.02^c	8.36 ± 0.02^c	6.20 ± 0.14^b	1017.40 ± 1.61^b
NFSPC	40.64 ± 0.83^b	14.88 ± 0.21^b	11.50 ± 0.03^b	7.30 ± 0.28^a	745.90 ± 2.19^c
FSPC	20.13 ± 0.28^d	7.25 ± 0.02^d	5.50 ± 0.08^d	6.35 ± 0.21^b	724.50 ± 1.92^d

Values are mean ± Standard deviation of three determinations. Means in the same column not followed by the same superscript are significantly different ($p < 0.05$)
Key: NFSMC= Non-Fermented Sorghum + Mango Mesocarp + Crayfish, NFSPC= Non-Fermented Sorghum + Fluted Pumpkin Leaf + Crayfish, FSMC = Fermented Sorghum + Mango Mesocarp + Crayfish, FSPC = Fermented Sorghum + Fluted Pumpkin Leaf + Crayfish, MM = Mango Mesocarp, FPL = Fluted pumpkin leaves

products decreased significantly ($p < 0.05$) with fermentation. This is expected, Kayode et al. [39] and Azhari et al. [30] reported that fermentation reduced anti-nutrients and increase the bioavailability of nutrients. The tannin content of the products decreased significantly ($p < 0.05$).

This is consistent with the report of Abdel-Haleem et al. [40] who noted that natural lactic acid fermentation decreased tannin and phytate contents of pearl millet, sorghum and maize. Chikwendu et al. [41] observed that fermentation of millet flour for 48 h. reduced tannins and phytate contents from 0.16 to 0.02 mg/100 g and 0.26 to 0.06 mg/100 g respectively. Tannins have been reported to affect protein digestibility and carbohydrate utilisation, thereby adversely influenced the bioavailability of non-haem iron leading to poor iron, calcium absorption and reduced energy value of diets [42]. It has also been reported by Bello et al. [43] and Fekadu et al. [44] that the acceptable daily intake of tannic acid by man is 560 mg.

The decrease in phytate is expected and may be attributed to the activities of microbial phytase during fermentation. Previous studies [39,45] have respectively reported phytate reduction in sorghum and millet during fermentation. Oyarekua and Bankefa [46] also reported that co-fermentation of walnut and maize flours significantly reduced oxalate from 0.99 to 0.72%, phytate content by 90% and tannin from 77.0 to 37.5%.

The decrease in pH of the fermented products could be attributed to acid production by microorganisms during fermentation. This agreed with the findings of Singh et al. [47] who reported that pH of fermented sorghum flour was reduced from 5.20 to 3.73 due to the production of organic acids by hetero fermentors that convert glucose to equimolar mixture of lactic acid, ethanol and carbon dioxide. The observed decrease in beta-carotene of the fermented samples may be ascribed to loss of some absorbable substances during fermentation of sorghum flour.

3.4 Potential Bioavailability of Minerals in Sorghum-Based Complementary Foods

The molar ratios of bioavailability of selected minerals of sorghum-based complementary food are presented in Table 6. The molar ratios ranged from 0.002 to 0.007, 0.032 to 0.157, 0.180 to 0.829, 0.009 to 0.032 and 0.010 to 0.040 for phytate:Ca, phytate:Fe, phytate:Zn, oxalate:Ca and [phytate x Ca]:Zn respectively, for NFSMC, NFSPC, FSMC and FSPC. The molar ratios for oxalate, calcium, zinc, iron and phytate were calculated to evaluate the effect of elevated levels of oxalate and phytate on the bioavailability of dietary minerals.

The calculated values were compared with the reported [44] critical toxicity values for these ratios. All the molar ratios except for NFSMC (phytate: Fe) were less than the critical values reported by Fekadu et al. [44]. The phytate: Ca molar ratio of the products indicated good bioavailability of calcium. Woldegiorgis et al. [48] reported that phytate: Ca molar ratio of < 0.24 was indicative of good calcium bioavailability. The results indicated phytate:Fe molar ratio of < 0.15. Phytate:Fe molar ratios of < 0.15 have been reported to have good Fe bioavailability [49]. This suggests that the molar ratio of approximately 0.16 for NFSMC is indicative of poor Fe bioavailability.

The phytate: Zn ratios were less than 10, indicating good zinc bioavailability. Phytate may reduce the bioavailability of dietary zinc by forming insoluble mineral chelates at a physiological pH [50] and the formation of the chelates depends on relative levels of both zinc and phytic acid. Hence, the phytate: Zn molar ratio is considered a better indicator of zinc bioavailability than total dietary phytate levels alone [48].

The importance of oxalate contents of an individual plant product in limiting total dietary Ca availability is of significance only when the ratio of oxalate:Ca is > 1 [51]. From these results, it was observed that all the products had values less than the reported critical value of 1.0, indicating good calcium bioavailability. High calcium levels in foods can promote the phytate induced decrease in zinc bioavailability when the [Ca] [phytate] /[Zn] millimolar ratio exceeds 0.5 mol/kg [52]. The values reported in this study were far below the critical value, indicating better Zn bioavailability.

The ratios reported for phytate: Fe, phytate: Zn and phytate:Ca were far less than the ratios of 18.7, 25 and 1.0 respectively as reported by Gibson et al. [53] for maize-based complementary foods. The observed decrease in

Table 6. Potential bioavailability of minerals in sorghum–based complementary foods

Blend	Phytate : Ca	Phytate : Fe	Phytate : Zn	Oxalate : Ca	[Phytate x Ca] : Zn (mol/kg)
NFSMC	0.007	0.157	0.829	0.032	0.040
FSMC	0.002	0.050	0.380	0.016	0.020
NFSPC	0.004	0.127	0.377	0.023	0.020
FSPC	0.002	0.032	0.180	0.009	0.010
Critical value	0.24	0.15	10.00	1.00	0.50

Key: NFSMC= Non-Fermented Sorghum + Mango Mesocarp + Crayfish, NFSPC = Non-Fermented Sorghum + Fluted Pumpkin Leaf + Crayfish, FSMC = Fermented Sorghum + Mango Mesocarp + Crayfish, FSPC = Fermented Sorghum + Fluted Pumpkin Leaf + Crayfish

the ratios may be due to fermentation and product composition as well as dehulling of sorghum grains during processing. As reported by Ijarotimi [29], fermentation of wheat flour decreased the antinutrient to mineral ratios.

4. CONCLUSION

The results of this study revealed that addition of crayfish resulted into improved protein content of the products. Addition of mango mesocarp also impacted positively on the beta carotene content of the blends. The mineral ratios indicated suitability for consumption by hypertensive patients, good calcium absorption and good insulin secretion. Fermentation significantly ($p<0.05$) reduced the tannins, phytate and oxalate concentrations of the blends and increased the potential of mineral bioavailability, except for iron in NFSMC where the molar ratio was slightly higher than the critical value.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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