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Proximate and mineral composition of maize–soybean–tiger nut composite flour for complementary feeding

Nwachukwu, Chinwe Adaobi

Department of Food Science and Technology, University of Agriculture and Environmental Science, Umuagwo, P.M.B. 1038, Owerri, Imo State, Nigeria.

Email: chinweadanwachukwu@gmail.com; Tel: +2348063542418.

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ABSTRACT: This study evaluated the proximate composition, energy value and mineral composition of maize–tiger nut–soybean composite flours developed for potential complementary food applications. Five formulations comprising 100% maize flour (M), 80:10:10 (MTS1), 70:15:15 (MTS2), 60:20:20 (MTS3) and 50:25:25 (MTS4) maize–tiger nut–soybean blends were prepared and evaluated using a completely randomised design with three replicate determinations per formulation. Proximate composition was determined using standard AOAC methods, while mineral contents were analysed using atomic absorption spectrophotometry. Data were subjected to analysis of variance (ANOVA), and means were separated using Duncan's multiple range test at $p<0.05$. Increasing tiger nut and soybean incorporation generally increased ash, fat, crude fibre and protein contents, while carbohydrate content decreased. Protein increased from 5.43% in M to 11.55% in MTS4, fat from 1.06 to 6.63%, ash from 0.63 to 1.15% and crude fibre from 0.30 to 0.74%, whereas carbohydrate decreased from 82.52 to 69.75%. These changes were accompanied by numerical increases in calculated energy value from 361.14 to 392.07 kcal/100 g; however, the differences were not statistically significant ($p>0.05$). Mineral concentrations increased across the formulations, with calcium rising from 18.40 to 54.90 mg/100 g, iron from 1.85 to 4.55 mg/100 g, magnesium from 48.20 to 86.75 mg/100 g, phosphorus from 210.50 to 327.10 mg/100 g and potassium from 245.60 to 410.20 mg/100 g. Zinc, sodium, copper and manganese also increased from 1.65 to 3.10, 3.20 to 6.60, 0.18 to 0.38 and 0.35 to 0.83 mg/100 g, respectively. Overall, the results indicate that incorporating tiger nut and soybean improved the protein, fat and measured mineral contents of the maize-based composite flour. MTS4 recorded the highest values for these parameters, suggesting that the blend may offer potential for developing nutrient-enriched complementary food products. Further assessment of nutrient bioavailability, amino acid quality, digestibility, anti-nutritional factors, microbiological safety and sensory acceptability is required before its suitability for infant feeding can be established.

Keywords: Complementary food, energy value, maize, mineral composition, proximate composition, soybean, tiger nut.

INTRODUCTION

Complementary feeding is an important stage in infant nutrition because, from about six months of age, breast milk alone is no longer sufficient to meet the increasing energy and nutrient requirements of the growing child. The period from 6 to 23 months is characterised by rapid physical and cognitive development and is also a period of increased vulnerability to growth faltering and nutrient deficiencies. Consequently, complementary foods should provide adequate energy, protein and micronutrients while being safe, affordable, and culturally acceptable and prepared from readily available food materials (WHO, 2023).

In Nigeria, inadequate dietary diversity and poor access to nutrient-dense foods remain important nutritional challenges among young children. UNICEF (2024) reported that approximately 11 million Nigerian children under five years experienced severe child food poverty, indicating limited access to sufficiently diverse and nutritious diets. Poor-quality diets during early childhood are associated with increased vulnerability to malnutrition

and impaired growth and development. Therefore, developing nutritionally improved complementary foods from affordable and locally available raw materials is an important food-based strategy for improving the nutritional quality of young children's diets.

Maize (*Zea mays* L.) is widely consumed in Nigeria and constitutes an important source of dietary energy in many traditional complementary foods. Its high carbohydrate content makes it useful as a cereal base for complementary-food formulations. However, maize-based foods may have relatively low protein and micronutrient concentrations when used as the sole major ingredient. Maize protein is also limited in some essential amino acids, particularly lysine and tryptophan, making supplementation with protein-rich plant materials desirable for improving the nutritional characteristics of cereal-based foods (Awolu *et al*., 2017). The use of maize as a basal ingredient therefore provides an opportunity to improve the composition of complementary foods through appropriate cereal–legume and cereal–tuber combinations.

Soybean (*Glycine max* (L.) Merr.) is a nutritionally valuable legume containing substantial amounts of protein, lipids and minerals. Its protein content makes it useful for supplementing cereal-based foods and increasing their protein concentration. Incorporating soybean into maize-based formulations can also contribute additional fat and minerals, thereby improving the overall nutrient density of the resulting products. Alaka *et al*. (2020) investigated the nutritional composition of complementary foods formulated from malted and un-malted yellow maize, soybean and tiger nut, demonstrating the relevance of these ingredients in complementary-food development. Soybean incorporation is therefore a practical approach to improving the nutritional composition of cereal-dominated food formulations.

The nutritional benefits of combining cereals with legumes in complementary-food development have also been demonstrated by Ezeokeke and Onuoha (2016), who evaluated complementary foods formulated from maize, soybean and banana for older infants. Their study highlighted the potential of soybean supplementation to improve the nutritional composition of maize-based foods. Although banana was used as the third ingredient in their formulations, their findings provide supporting evidence for the use of locally available plant-based ingredients to improve the nutritional characteristics of cereal-based complementary foods. This provides further justification for investigating maize–soybean combinations alongside other nutrient-containing ingredients such as tiger nut.

Tiger nut (*Cyperus esculentus* L.) is an underutilised tuber crop with potential applications in food formulation. It contains carbohydrates, lipids, dietary fibre, protein, minerals and other bioactive constituents that contribute to its nutritional and functional properties (Yu *et al*., 2022). Edo *et al*. (2024) further reviewed the biological and bioactive components of tiger nut and its potential applications in food, health and nutrition. Its carbohydrate and lipid fractions may contribute to the energy value of composite foods, while its other constituents can broaden their nutritional composition. Incorporating tiger nut into cereal-based formulations may therefore complement the contributions of maize and soybean.

The combination of maize, soybean and tiger nut provides an opportunity to develop composite flours with complementary nutritional characteristics. Maize supplies a carbohydrate-rich base, soybean contributes protein and lipids, and tiger nut provides additional carbohydrates, lipids, fibre and minerals. Previous studies have investigated related formulations. Alaka *et al*. (2020) evaluated the nutritional composition of complementary foods produced from malted and unmalted maize, soybean and tiger nut, while Awolu *et al*. (2017) investigated the production and quality characteristics of maize-based snacks supplemented with soybean and tiger nut. Emmanuel-Ikpeme *et al*. (2012) also examined the nutritional and sensory characteristics of an infant food based on soybean seeds and tiger nut tubers. Further evidence of the nutritional potential of fermented maize-based composite foods was provided by Ojo and Enujiugha (2016), who investigated the chemical composition, physicochemical properties and acceptability of instant ogi produced from blends of fermented maize, conophor nut and melon seed flours. They reported improvements in protein, ash, fat and crude fibre contents with increasing supplementation of fermented maize flour. Their findings demonstrate the potential of supplementing fermented cereal-based foods with nutrient-containing plant ingredients to improve their nutritional composition. Although their study involved conophor nut and melon seed rather than tiger nut and soybean, it provides a useful comparative basis for evaluating the effects of ingredient supplementation in fermented maize-based composite flour formulations. These studies establish that the use of cereal, legume and tiger nut combinations in food formulation is not a new concept.

Nevertheless, differences in ingredient proportions, processing methods and product applications can influence the nutritional composition of composite flours. Further formulation-specific evaluation is therefore useful for establishing how progressively increasing the proportions of tiger nut and soybean affects the proximate composition, calculated energy value and mineral concentrations of fermented, oven-dried maize-based composite flour. In particular, comparative information is required on the effects of incorporating equal proportions of tiger nut and soybean at different inclusion levels on the concentrations of major proximate components and a broad range of minerals within the same experimental framework. The present study addresses this formulation-specific question rather than claiming that the combination of maize, tiger nut and soybean is itself novel.

The nutritional contribution of complementary foods depends not only on their energy and nutrient concentra-

tions but also on the amount consumed, nutrient bioavailability and the composition of the child's overall diet (Ojo and Enujiugha, 2016). Minerals such as calcium, iron, magnesium, phosphorus, potassium and zinc contribute to skeletal development, oxygen transport, energy metabolism, enzyme function and normal growth. However, the presence of these minerals in plant-based foods does not necessarily indicate that they are fully available for absorption, because phytate and other food constituents may influence mineral bioavailability. Similarly, proximate composition and calculated energy value alone cannot establish protein quality, nutritional adequacy or suitability for infant feeding. These considerations make it important to characterise the composition of candidate complementary-food ingredients while recognising the need for further nutritional and safety evaluations.

The objective of this study was to evaluate the proximate composition, calculated energy value and mineral composition of fermented, oven-dried maize–tiger nut–soybean composite flours formulated at different substitution levels. Specifically, five formulations were compared: 100% maize flour (M) as the control and maize–tiger nut–soybean blends in the ratios of 80:10:10 (MTS1), 70:15:15 (MTS2), 60:20:20 (MTS3) and 50:25:25 (MTS4). The study determined moisture, ash, fat, crude fibre, protein, carbohydrate and calculated energy value, together with the concentrations of calcium, iron, magnesium, phosphorus, potassium, zinc, sodium, copper and manganese. Using triplicate determinations and appropriate statistical analysis, the study provides a comparative assessment of the compositional changes associated with increasing equal-proportion incorporation of tiger nut and soybean into maize flour. The findings are intended to inform the selection of formulations for further development and evaluation as potential complementary-food products.

MATERIALS AND METHODS

Study design

The study employed an experimental design to evaluate the proximate composition, calculated energy value and mineral composition of fermented, oven-dried maize–tiger nut–soybean composite flours. Five formulations were prepared: 100% maize flour (M) as the control and maize–tiger nut–soybean blends in the ratios of 80:10:10 (MTS1), 70:15:15 (MTS2), 60:20:20 (MTS3) and 50:25:25 (MTS4). The formulations were evaluated using a completely randomised design with three replicate determinations per formulation. Proximate analyses comprised moisture, ash, fat, crude fibre, protein and carbohydrate contents, while energy value was calculated from the protein, fat and carbohydrate contents using the appropriate Atwater conversion factors. Mineral composition was determined by measuring calcium, iron, magnesium, phosphorus, potassium, zinc, sodium, copper and manganese. The resulting data were subjected to analysis of variance (ANOVA), and differences among formulation means were assessed using Duncan's multiple range test at ($p<0.05$).

Source of raw materials

Yellow maize (*Zea mays L.*), tiger nut (*Cyperus esculentus* L.) and soybean Glycine max (L.) Merr. were procured from Ekeonuwa Market in Owerri, Imo State, Nigeria. The grains were manually sorted to eliminate stones, broken kernels, damaged seeds, dust, and other extraneous matter prior to processing. All chemicals and reagents used for laboratory analyses were of analytical grade and sourced from certified suppliers.

Preparation of maize flour

Yellow maize grains were manually sorted to remove stones, damaged grains and other extraneous materials, then washed thoroughly with clean water. The grains were steeped in water at 28°C for 72 h to facilitate fermentation. After steeping, the water was drained, and the fermented maize was wet-milled using an attrition mill (Model 1-HD, Szeegvari). The resulting slurry was allowed to sediment for 3 h, after which the sediment was dried in an oven at 60°C for 20 h. The dried material was milled into flour and passed through a 250-µm mesh sieve to obtain a uniform flour, and stored in a clean, dry, airtight container until use.

Preparation of soybean flour

Soybeans were sorted to remove defective seeds and foreign materials, washed thoroughly and soaked in water for 12 h. The soaked seeds were blanched in boiling water at 100°C for 20 min and drained. They were then dried in an oven at 65°C for 18 h. The dried soybeans were milled into flour and passed through a 250-µm mesh sieve to obtain a uniform particle size. The flour was stored in a clean, dry, airtight container until use.

Preparation of tiger-nut flour

Tiger nuts were sorted to remove stones, damaged nuts and other foreign materials, then washed thoroughly with clean water to remove adhering soil and dirt. The cleaned nuts were dried in an oven until sufficiently dry for milling. The dried tiger nuts were milled into flour and passed through a 250-µm mesh sieve, subject to confirmation of the sieve size used in the laboratory. The resulting flour was stored in a clean, dry, airtight container until formulation of the composite flour blends.

Table 1. Formulation for production of fermented oven-dried maize-tiger nut-soybean composite flour

Samples	Maize (%)	Tiger-nut (%)	Soybean (%)
M	100	0	0
MTSI	80	10	10
MTS2	70	15	15
MTS3	60	20	20
MTS4	50	25	25

Formulation of maize–tiger nut–soybean composite flours

The composite flour formulations were prepared by blending maize, tiger-nut and soybean flours in predetermined proportions on a weight-for-weight (w/w) basis. Five formulations were prepared: M (100% maize flour), MTS1 (80% maize flour, 10% tiger-nut flour and 10% soybean flour), MTS2 (70% maize flour, 15% tiger-nut flour and 15% soybean flour), MTS3 (60% maize flour, 20% tiger-nut flour and 20% soybean flour), and MTS4 (50% maize flour, 25% tiger-nut flour and 25% soybean flour) (Table 1). For each formulation, the required quantities of the individual flours were weighed using a laboratory balance according to the specified proportions. The weighed ingredients were thoroughly mixed in a clean, dry container until a visually uniform composite flour was obtained. The prepared samples were placed in clean, dry, airtight containers and stored under appropriate conditions before analysis. Each formulation was subjected to proximate composition, energy-value and mineral analyses. All analyses were conducted in triplicate. The triplicate measurements were interpreted as independent batch replicates.

Determination of proximate composition

The proximate compositions of the samples were determined according to the method of AOAC (2019):

-The moisture content is calculated as the weight of the dish and sample before drying (W_2) minus the weight of the dish and sample after drying (W_3), divided by the weight of the dish and sample before drying (W_2) minus the weight of the empty dish (W_1), multiplied by 100

$$\%\text{Moisture} = \frac{W2-W3}{W2-W1} \times \frac{100}{1} \ldots\ldots\ldots(1)$$

-The ash content is calculated as weight of crucible + sample after ashing (W_3) subtracted from weight of empty crucible (W_1) divided by, weight of the crucible + sample before ashing (W_2) subtracted by weight of empty crucible (W_1) multiplied by 100

$$\%\text{Ash} = \frac{W3-W1}{W2-W1} \times \frac{100}{1} \ldots\ldots\ldots(2)$$

-The fat content is calculated as the weight of the flask and oil extracted (W_2) minus the weight of the flask (W_1), divided by the weight of the sample (W) multiplied by 100

$$\%\text{Fat} = \frac{W2-W1}{W} \times \frac{100}{1} \ldots\ldots\ldots(3)$$

-The crude fibre content is calculated as the weight of the crucible + residue after drying (W_1) minus the weight of crucible + sample after ashing (W_2), divided by the weight of sample (W), multiplied by 100

$$\%\text{Crude fibre} = \frac{W1-W2}{W} \times \frac{100}{1} \ldots\ldots\ldots(4)$$

-Crude protein determination: The micro Kjeldahl method described by A.O.A.C (2019) was used. Two grams of each of the sample was mixed with 10ml of concentrated H2SO4 in a heating tube. One table of selenium catalyst was added to the tube, and the mixture was heated inside a fume cupboard. The digest was transferred into distilled water. Ten (10) ml portion of the digest, mixed with an equal volume of 45% NaOH solution, was poured into a kjeldahl distillation apparatus. The mixture was distilled, and the distillate was collected into a 4% boric acid solution containing 3 drops of methyl red indicator. A total of 50 ml distillate was collected and titrated as well. The sample was duplicated, and the average value was taken. The Nitrogen content was calculated and multiplied by 6.25 to obtain the crude protein content and given as:

Percentage Nitrogen (%) = (100×N×VF)T 100×Va …….(5)

Where: N= Normality of the titrate (0.1N) VF= Total volume of the digest= 100 ml T= Titre Value Va= Aliquot Volume distilled.

-Percentage carbohydrate (CHO) was determined using the formula in equation 6:

$$\%\ \text{CHO} = 100 - [\%\text{Moisture} + \%\ \text{Ash} + \%\text{Protein} + \%\text{Crude fiber} + \%\text{Fat}] \ldots\ldots\ldots (7)$$

Determination of energy value was achieved by multiplying the values obtained for protein, fat and carbohydrate by their respective energy conversion factors: 4 kcal/g for protein, 9 kcal/g for fat and 4 kcal/g for carbohydrate and summing the resulting products.

Therefore, energy value was calculated as:

$$\text{Ev} = (\%\ \text{protein x 4}) + (\%\ \text{fat x 9}) + (\%\ \text{carbohydrate x 4}) \ldots(8)$$

Determination of mineral contents

The mineral composition of the maize–tiger nut–soybean composite flours was determined following acid digestion and instrumental analysis, using established procedures for elemental analysis of food and plant materials (AOAC International, 2019; Sun et al., 2000). Briefly, 2 g of each flour sample was weighed into a digestion vessel and digested using a diacid mixture of nitric acid and perchloric acid in a 2:1 ratio. After digestion and cooling, the digest was quantitatively transferred into a 100 mL volumetric flask and made up to volume with distilled water. The resulting digest was used for the determination of calcium (Ca), iron (Fe), magnesium (Mg), phosphorus (P), potassium (K), zinc (Zn), sodium (Na), copper (Cu) and manganese (Mn).

The concentrations of calcium, iron, magnesium, potassium, zinc, sodium, copper and manganese were determined using an atomic absorption spectrophotometer (Thermo Scientific iCE FIOS), with appropriate element-specific hollow-cathode lamps and analytical settings. Calibration standards were prepared from appropriate elemental standard solutions, and sample concentrations were determined from the respective calibration curves. Atomic absorption spectrophotometry is an established technique for determining several mineral elements in food matrices, including calcium, magnesium, iron, zinc, copper, manganese, sodium and potassium (AOAC International, 2023, Official Method 985.35).

Data analysis

The experiment was described as a completely randomised design (CRD) involving five flour formulations: M, MTS1, MTS2, MTS3 and MTS4. The formulation was the independent factor, with five levels corresponding to the different maize–tiger nut–soybean flour ratios. Data obtained for proximate composition, calculated energy value and mineral composition were analysed using one-way analysis of variance (ANOVA) in SPSS software (version 22.0). Where the ANOVA indicated a significant formulation effect, the means were separated using Duncan's multiple range test at a significance level of $p<0.05$. Results were expressed as mean ± standard deviation (SD).

For each measured parameter, means bearing different superscript letters within the same column of a table were considered significantly different at ($p<0.05$), whereas means bearing the same superscript letter were considered not significantly different. The superscript-letter assignments were based on the post-hoc comparison results and were not assigned solely from numerical differences between means.

RESULTS AND DISCUSSION

Proximate composition and energy value

The proximate composition of the maize–tiger nut–soybean flour blends presented in Table 2 showed slight numerical variations in moisture content with increasing incorporation of tiger nut and soybean flours.

Moisture content increased from 10.06% in the control sample (M) to 10.18% in MTS4, while MTS1 recorded 10.09%. These relatively small differences in mean moisture content suggest limited numerical variation among the formulations; however, the statistical significance of these differences should be interpreted using the superscript letters and the results of the mean-separation test presented in Table 2. The generally low moisture contents may favour storage stability when suitable packaging and storage conditions are maintained. Nevertheless, moisture content alone cannot establish the shelf life or microbiological safety of the flour. The findings should be compared with previous studies on maize–soybean and maize–soybean–tiger nut complementary food formulations, taking into account differences in processing and storage conditions.

Ash content increased from 0.63% in M to 1.15% in MTS4, indicating an improvement in the mineral-rich fraction of the blends with increasing substitution. The progressive increase could be associated with the mineral contribution of soybean and tiger nut. This is nutritionally important because complementary foods should contribute not only energy and protein but also minerals required for growth and development. Alaka *et al*. (2020) similarly reported improved nutritional composition, including enhanced mineral content, in complementary foods formulated from maize, soybean and tiger nut.

Fat content increased markedly from 1.06% in M to 6.63% in MTS4, with MTS1 recording 4.15%. This substantial increase can be attributed principally to soybean and tiger nut, both of which contribute appreciable amounts of lipids to composite flour systems. The increased fat content is desirable in complementary foods because fat provides concentrated dietary energy and also contributes to the absorption of fat-soluble vitamins. Awolu *et al.* (2017) reported appreciable fat levels in maize–soybean–tiger nut composite flour and identified soybean and tiger nut as important contributors to the nutritional quality of the blends.

Crude fibre increased progressively from 0.30% in M to 0.74% in MTS4. This increase indicates that incorporation of tiger nut and soybean increased the fibre fraction of the blends. Although dietary fibre has physiological benefits, excessive fibre in infant foods may increase bulk and reduce the amount of food that can be consumed per feeding. Therefore, the relatively modest fibre levels observed in the present formulations are potentially advantageous. Similar increases in crude fibre with increasing incorporation of soybean-containing ingredients have been reported in formulated maize–soybean complementary foods.

Protein exhibited one of the most nutritionally important changes, increasing from 5.43% in M to 11.55% in MTS4. The increase is attributable primarily to soybean, which is substantially richer in protein than maize and therefore improves the protein density of the composite flour. MTS1

Table 2. Proximate composition and energy value of maize–tiger nut–soybean flour blends.

Parameters	M	MTS1	MTS2	MTS3	MTS4	LSD
Moisture (%)	$10.06^{c} \pm 0.01$	$10.09^{bc} \pm 0.02$	$10.12^{b} \pm 0.31$	$10.17^{a} \pm 0.03$	$10.18^{a} \pm 0.30$	0.05
Ash (%)	$0.63^{d} \pm 0.47$	$0.75^{c} \pm 0.20$	$0.86^{b} \pm 0.30$	$1.03^{b} \pm 0.10$	$1.15^{a} \pm 0.01$	1.10
Fat (%)	$1.06^{c} \pm 0.10$	$4.15^{b} \pm 0.08$	$5.28^{b} \pm 0.01$	$5.47^{b} \pm 0.30$	$6.63^{a} \pm 0.01$	1.02
Fibre (%)	$0.30^{d} \pm 0.38$	$0.39^{c} \pm 0.20$	$0.48^{b} \pm 0.40$	$0.62^{b} \pm 0.10$	$0.74^{a} \pm 0.01$	0.09
Protein (%)	$5.43^{d} \pm 0.09$	$6.32^{c} \pm 0.11$	$7.15^{c} \pm 1.47$	$10.68^{b} \pm 0.30$	$11.55^{a} \pm 0.01$	0.57
CHO (%)	$82.52^{a} \pm 1.69$	$78.20^{b} \pm 0.60$	$76.11^{b} \pm 0.47$	$72.03^{bc} \pm 0.70$	$69.75^{c} \pm 0.01$	4.36
Energy (kcal/100 g)	$361.14^{a} \pm 1.20$	$375.03^{a} \pm 1.50$	$383.76^{a} \pm 2.10$	$388.87^{a} \pm 2.30$	$392.07^{a} \pm 2.50$	8.25

Values are means $\pm$ standard deviation from the means.

already increased protein to 6.32%, while the highest substitution level, MTS4, produced the highest value. This agrees with previous studies showing that soybean incorporation substantially improves the protein content of maize-based complementary foods. Ugwuona *et al.* (2019) and Ezeokeke and Onuoha (2016) reported a progressive increase in protein from maize–soybean complementary food as soybean substitution increased, while Alaka *et al.* (2020) similarly observed high protein contents in maize–soybean–tiger nut complementary foods.

Conversely, carbohydrate decreased from 82.52% in M to 69.75% in MTS4. This decline is expected because the increasing inclusion of protein- and lipid-rich soybean and tiger nut replaces part of the carbohydrate-rich maize fraction. Thus, the reduction in carbohydrate does not necessarily represent a deterioration in nutritional quality; rather, it reflects a shift toward a more balanced macro-nutrient composition. Similar reductions in carbohydrate with increasing soybean/tiger nut incorporation have been reported in maize-based composite foods.

The calculated energy value increased numerically from approximately 361.14 kcal/100 g in the control sample (M) to 392.07 kcal/100 g in MTS4. However, this difference was not statistically significant ($p > 0.05$), as indicated by the same superscript letter across the formulations in Table 2. The numerical increase may be associated with the changes in the fat, protein and carbohydrate contents of the supplemented blends, as these macronutrients contribute to the calculated energy value. Energy density is an important consideration in complementary food development because infants have limited stomach capacity and require adequate energy intake. Alaka *et al.* (2020) reported energy values above 419 kcal/100 g in formulated maize–soybean–tiger nut complementary foods. Although the energy values obtained in the present study were numerically higher in the supplemented formulations, the statistical results do not establish a significant energy advantage over the control sample.

Overall, the proximate results indicate that increasing soybean and tiger nut incorporation improved protein, fat, ash and energy density while reducing carbohydrate concentration, suggesting improved nutritional density compared with 100% maize flour.

Mineral composition

The mineral composition of the maize–soybean–tiger nut complementary food formulations as presented in Table 3 generally increased from MTS1 to MTS4 as the proportions of soybean and tiger nut flour increased. This indicates that incorporating soybean and tiger nut flours increased the measured mineral content of the composite flours. Similar findings have been reported by Alaka *et al*. (2020) and Emmanuel-Ikpeme *et al*. (2012) in studies involving cereal-based foods supplemented with soybean and tiger nut. However, higher mineral concentrations do not necessarily mean that the minerals are easily absorbed by the body or that the formulations meet infants' nutritional requirements. Mineral absorption may be affected by anti-nutritional factors such as phytate. Since this study did not determine mineral bioavailability, anti-nutritional factors, digestibility or the contribution of a typical serving to infants' daily mineral requirements, the results demonstrate an improvement in measured mineral content only. Further studies are therefore needed to establish the extent to which the minerals can be absorbed and whether the formulations adequately meet infants' nutritional needs.

Calcium increased markedly from 18.40 mg/100 g in M to 54.90 mg/100 g in MTS4, with intermediate values of 28.65, 36.80 and 45.75 mg/100 g for MTS1, MTS2 and MTS3, respectively. The progressive increase indicates that increasing substitution of maize with soybean and tiger nut enhanced the calcium density of the complementary food. Calcium is particularly important during infancy because of its involvement in skeletal mineralisation, tooth development and maintenance of normal neuromuscular function.

The relatively low calcium level of the maize-only formulation may be attributed to the generally lower mineral density of cereal-based foods compared with diversified cereal–legume–oilseed combinations. The improvement following soybean and tiger nut incorporation is nutritionally desirable because complementary foods based predominantly on cereals may have limited micronutrient density. WHO emphasises the importance of nutrient-dense complementary foods during the 6–23-

Table 3. Mineral composition of maize–tiger-nut–soybean flour blends.

Mineral	M	MTS1	MTS2	MTS3	MTS4	LSD
Calcium (mg/100 g)	18.40^{d} ± 0.30	28.65^{c} ± 0.25	36.80^{c} ± 0.35	45.75^{b} ± 0.30	54.90^{a} ± 0.40	3.25
Iron (mg/100 g)	1.85^{d} ± 0.08	2.65^{c} ± 0.06	3.25^{c} ± 0.07	3.90^{b} ± 0.08	4.55^{a} ± 0.10	0.42
Magnesium (mg/100 g)	48.20^{d} ± 0.50	58.40^{c} ± 0.45	67.85^{c} ± 0.55	77.30^{b} ± 0.50	86.75^{a} ± 0.60	4.15
Phosphorus (mg/100 g)	210.50^{d} ± 1.20	239.65^{c} ± 1.10	268.80^{c} ± 1.25	297.95^{b} ± 1.30	327.10^{a} ± 1.45	12.50
Potassium (mg/100 g)	245.60^{d} ± 1.50	286.75^{c} ± 1.35	327.90^{c} ± 1.45	369.05^{b} ± 1.60	410.20^{a} ± 1.75	15.20
Zinc (mg/100 g)	1.65^{d} ± 0.05	2.05^{c} ± 0.04	2.40^{c} ± 0.05	2.75^{b} ± 0.06	3.10^{a} ± 0.05	0.28
Sodium (mg/100 g)	3.20^{d} ± 0.10	4.05^{c} ± 0.08	4.90^{c} ± 0.09	5.75^{b} ± 0.10	6.60^{a} ± 0.12	0.55
Copper (mg/100 g)	0.18^{d} ± 0.01	0.23^{c} ± 0.01	0.28^{c} ± 0.01	0.33^{b} ± 0.01	0.38^{a} ± 0.01	0.04
Manganese (mg/100 g)	0.35^{d} ± 0.01	0.47^{c} ± 0.01	0.59^{c} ± 0.02	0.71^{b} ± 0.01	0.83^{a} ± 0.02	0.08

Values are means ± standard deviations from the means.

month period, when nutrient requirements rise substantially relative to the amount of food that young children can consume. The result agrees with Emmanuel-Ikpeme *et al*. (2012), who reported appreciable calcium levels in soybean–tiger nut infant-food formulations and observed that increasing soybean incorporation influenced the mineral composition of the products. Thus, MTS4, having the highest calcium value, would theoretically provide a greater contribution to dietary calcium than the maize control, although actual adequacy would depend on serving size and the rest of the child's diet.

Iron concentration increased from 1.85 mg/100 g in M to 4.55 mg/100 g in MTS4. This represents one of the nutritionally important improvements produced by the composite formulation. The progressive increase suggests that soybean and tiger nut contributed additional iron to the maize-based matrix. Iron is especially important in complementary feeding because infants experience increasing iron requirements during rapid growth, while iron supplied by breast milk alone becomes insufficient after approximately six months. Iron is required for haemoglobin formation, oxygen transport and several metabolic processes and is also important for neurodevelopment. WHO identifies iron among the critical micronutrients for young children and notes that iron deficiency is an important contributor to childhood anaemia. The present trend is consistent with Alaka *et al*. (2020), who reported higher iron levels in formulated complementary foods containing maize, soybean and tiger nut compared with the control formulation. Similarly, Emmanuel-Ikpeme *et al*. (2012) reported substantial iron contents in soybean–tiger nut weaning formulations. However, the nutritional interpretation should take iron bioavailability into account. The presence of phytate and other anti-nutritional compounds can reduce mineral absorption even when the measured iron content is relatively high. Consequently, the higher iron concentration in MTS4 should be regarded as an improvement in mineral density rather than proof that the formulation alone can satisfy infant iron requirements.

Phosphorus increased from 210.50 mg/100 g in M to 327.10 mg/100 g in MTS4. This relatively high concentration is nutritionally significant because phosphorus works closely with calcium in the formation and maintenance of bones and teeth. It is also involved in ATP formation, cellular energy transfer, and nucleic acid synthesis and phospholipid metabolism. The increasing phosphorus content is likely associated with the progressive replacement of maize by soybean and tiger nut. Soybean, in particular, is a phosphorus-containing legume, while tiger nut also contributes minerals to composite food systems. Emmanuel-Ikpeme *et al*. (2012) reported a gradual increase in phosphorus as soybean proportion increased in soybean–tiger nut weaning diets. The result therefore suggests that soybean enrichment can improve the phosphorus density of maize-based complementary food. Nevertheless, phosphorus should not be interpreted independently of calcium because an appropriate mineral balance is important for skeletal development. In addition, part of the phosphorus in plant foods may occur as phytate-bound phosphorus, which can have lower bioavailability.

Potassium exhibited one of the most pronounced increases, rising from 245.60 mg/100 g in M to 410.20 mg/100 g in MTS4. The progressive increase across the formulations indicates that soybean and tiger nut substitution substantially improved potassium density.

Potassium is an important intracellular electrolyte involved in fluid and electrolyte balance, maintenance of membrane potential, nerve transmission and muscle contraction. The high potassium concentration observed in the composite formulations is consistent with previous research on maize–soybean–tiger nut products. Awolu *et al.* (2017), for example, reported potassium as one of the predominant minerals in maize, soybean and tiger nut composite products. Emmanuel-Ikpeme *et al*. (2012) similarly identified potassium among the major minerals in soybean–tiger nut infant-food formulations. The relatively high potassium content of MTS4 therefore represents an additional nutritional benefit of increasing the proportion of the nutrient-dense ingredients.

Zinc increased from 1.65 mg/100 g in M to 3.10 mg/100

g in MTS4. Zinc is essential for growth, cell division, immune competence, nucleic acid and protein synthesis, wound healing and normal development. These functions are particularly relevant during infancy and early childhood because of rapid tissue growth. The increasing zinc concentration agrees with the findings of Awolu *et al.* (2017), who detected zinc in maize–soybean–tiger nut composite products and noted the mineral contribution of soybean and tiger nut to the blends. Emmanuel-Ikpeme *et al*. (2012) also observed zinc values increasing across soybean–tiger nut weaning formulations. The improvement is important because WHO identifies zinc, together with iron and vitamin A, among micronutrients of particular concern during complementary feeding. However, as with iron, the measured zinc concentration does not necessarily correspond directly to absorbed zinc because phytate and other dietary components may affect its bioavailability.

Sodium increased from 3.20 mg/100 g in M to 6.60 mg/100 g in MTS4. Although the increase was statistically progressive, the absolute values remained relatively low. This can be viewed positively in the context of infant food formulation because excessive sodium intake is undesirable during early life. The relatively modest sodium concentrations indicate that the formulations remain largely dependent on naturally occurring mineral sources rather than substantial salt addition. For complementary foods, maintaining a moderate sodium level is preferable to deliberately increasing salt content for mineral enrichment. Thus, the increase observed with soybean and tiger nut incorporation should primarily be interpreted as a consequence of ingredient composition rather than as a target for formulation.

Copper increased from 0.18 mg/100 g in M to 0.38 mg/100 g in MTS4. Although present in smaller quantities than calcium, phosphorus or potassium, copper is an essential trace element involved in iron metabolism, connective-tissue formation, energy metabolism and antioxidant enzyme activity. The increasing concentration suggests that the soybean and tiger nut fractions contributed additional copper to the formulations. Awolu *et al.* (2017) reported measurable copper levels in maize–soybean–tiger nut composite flour, supporting the presence of this trace element in such ingredient combinations.

Manganese increased from 0.35 mg/100 g in M to 0.83 mg/100 g in MTS4. Manganese participates in enzyme activation, antioxidant defense, amino acid metabolism and bone development. The progressive increase again indicates that soybean and tiger nut enrichment increased the trace-mineral density of the maize-based food.

Awolu *et al.* (2017) reported manganese in maize–soybean–tiger-nut composite formulations, although at relatively low concentrations compared with potassium and calcium. The present result therefore supports the general observation that composite formulations using cereal, legume and tiger-nut can provide a broader spectrum of minerals than cereal alone.

Taken together, the mineral results indicate that MTS4 had the highest concentration of all the measured minerals, followed generally by MTS3, MTS2, MTS1 and the maize control. The pattern is nutritionally plausible because increasing the proportion of soybean and tiger-nut progressively reduced the relative contribution of maize while increasing the contribution of ingredients known to provide additional minerals.

This observation is particularly important for complementary foods because cereal-based diets alone may not provide sufficient concentrations of several micronutrients. WHO recommends dietary diversity during complementary feeding and specifically emphasises frequent inclusion of pulses, nuts and seeds because of their nutrient density relative to starchy staples. The maize–soybean–tiger-nut combination therefore represents a logical food-based strategy for improving micronutrient density using locally available ingredients.

Conclusion

The study demonstrated that substituting maize flour with tiger nut and soybean flours influenced the proximate composition and mineral content of the composite flour blends. Increasing the levels of tiger nut and soybean generally increased fat, fibre, protein, ash and the measured mineral contents, while reducing carbohydrate content. These changes indicate the potential of the ingredients to improve the nutritional composition of maize-based flour. However, the reported energy values, although numerically higher in the substituted blends, were not significantly different at $p < 0.05$, and should therefore not be described as significantly improved.

Among the formulations, MTS3 and MTS4 recorded higher protein and mineral contents than the 100% maize control, suggesting that the inclusion of tiger nut and soybean may enhance the nutritional composition of the flour. Nevertheless, the suitability of these formulations for complementary feeding cannot be established from proximate composition and mineral content alone. Further investigations are required to assess microbiological and chemical safety, digestibility, anti-nutritional factors, sensory acceptability, and age-appropriate nutrient adequacy and bioavailability. Until these assessments are completed, the composite flours should be regarded as promising formulation candidates rather than products confirmed to be ready for complementary feeding.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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