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Effect of Locally Formulated Complementary Foods on Anthropometric Parameters and Micronutrient Status in Children (6–23 Months) in Enugu State, Nigeria: A Randomized Controlled Trial

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ABSTRACT: Malnutrition remains a significant challenge in low- and middle-income countries, contributing to stunting, wasting, and micronutrient deficiencies. This study investigated the effect of locally formulated complementary foods on anthropometric parameters and micronutrient status in children aged 6 to 23 months. A randomized controlled trial involving 40 infants explored the effects of experimental diets, including Maize-Soybean, Maize-Soybean-Termite flour, Maize-Soybean-Fishbone powder, and Maize-Soybean-Termite-Fishbone-Pawpaw-Pumpkin (MaSoTFPP), and a control diet on children over a period of 90 days. Anthropometric measurements of weight, height, and mid-upper arm circumference (MUAC) as well as biochemical analyses of blood samples were carried out. Dietary intake was monitored over the 90-day feeding trial period. The data obtained were analyzed using Statistical Product for Service Solution, version 23. Significance was set at $P<0.05$. The findings revealed significant improvements in the anthropometric parameters, particularly in the MaSoTFPP group, which exhibited the largest percentage increase in height and MUAC. The children fed with the experimental diets demonstrated enhanced serum hemoglobin, iron, and zinc levels, which increased most significantly in the MaSoTFPP group (by 308%, 264%, and 58%, respectively). The study underscores the potential of incorporating locally available food crops in community-based management of acute malnutrition and supports the World Health Organization's recognition of fortified staple foods in improving child growth and development.

Keywords: anthropometry, child nutrition disorders, hemoglobin, infant food, micronutrients

INTRODUCTION

Adequate nutrition during the critical period of infancy and early childhood is important for healthy growth and development. The WHO emphasized the significance of adequate nutrition, particularly for children between the ages of 6 and 23 months, as this stage marks a crucial window for physical and cognitive development (WHO, 2021). Malnutrition continues to pose a significant public health challenge among young children in many low- and middle-income countries, and it is prevalent from 6 months of age, when growth, physiological maturation, and development occur at a rapid pace. At this critical stage, it is necessary to introduce complementary foods, as breast milk is no longer adequate to meet the children's nutritional needs. The lack of access to nutrient-rich foods and the high cost of commercial complementary foods greatly contribute to inadequate nutrition, leading to stunting, wasting, and micronutrient deficiencies (Dewey, 2013; Lutter et al., 2013).

According to the Nigeria Demographic and Health Survey (NPC and ICF International, 2019), approximately 37% of Nigerian children under 5 years of age were stunted, indicating that chronic malnutrition affected their growth and development. Additionally, the prevalence of wasting within this age-group was estimated to be 7.2%. Dietary diversity has been recognized as a major contributor to nutrient adequacy. A diet that comprises variety of foods has the advantage of meeting nutrient requirements, particularly in terms of micronutrients. However, traditional complementary foods in Nigeria, being starchy and cereal-based and exhibiting low nutrient density and bulkiness, often result in a nutrient intake that is not sufficient to meet the nutritional needs of children.

In addition, the use of poor watery gruel as complementary food for infants has been implicated in the eti-

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ology of protein-energy malnutrition and micronutrient deficiency. This is further exacerbated by the small stomach capacity of children, which makes it impossible for them to consume enough gruel to meet their nutritional needs. Various nutrition interventions have been explored to address these challenges, including the formulation of local gruels using indigenous, readily available ingredients and the incorporation of fruits and vegetables to improve nutrient contents. Studies have shown that such interventions had positive outcomes in terms of enhancing the nutritional status among children in resource-limited settings (Gibson, 2011; Nwosu et al., 2014a, 2014b; Umerah et al., 2020; Adegbusi et al., 2022).

There are concerns about the affordability and accessibility of commercial complementary foods, particularly for low-income families in developing countries like Nigeria. Commercial complementary foods are often expensive, which limits their use among resource-poor households. These products may not always be tailored to the local environment and cultural preferences, which can hinder their adoption and consistent use. Moreover, the potentially high contents of sugars, fats, or artificial additives in them raise concerns about their long-term impact on child health. To address these issues, it is necessary to evaluate the feasibility of producing locally formulated complementary foods from indigenous ingredients that are both more affordable and culturally acceptable. This study sought to determine whether local formulations can provide effective alternatives for improving the anthropometric parameters, hemoglobin levels, and micronutrient status in children.

There is a paucity of randomized controlled trials (RCTs) evaluating the effectiveness of locally formulated complementary foods on both anthropometric parameters and micronutrient status among infants and young children, especially in developing countries. In this study, a rigorous RCT was conducted to specifically assess the effect of such foods on weight, height, and mid-upper arm circumference (MUAC) as well as on the serum levels of key micronutrients. The findings obtained will provide important information on the effectiveness of these foods on the nutritional status of young children. It is hoped that the results will also have implications for policymakers, nutritionists, and stakeholders involved in addressing childhood malnutrition, offering evidence-based strategies to enhance child health and development.

MATERIALS AND METHODS

Study area and study design

A RCT involving four intervention groups was conducted in a motherless babies home located in Abakpa-Nike, a rural community in Enugu East Local Government Area of Enugu State in southeastern Nigeria. The Igbo are the major ethnic group in this community, and the main religion is Christianity. The population of Abakpa-Nike primarily engages in farming, trading, civil service, craftsmanship, and daily paid labor to sustain livelihoods. The predominant crops cultivated in the community include cassava, yams, and various vegetables. The RCT lasted from January to July 2021.

Study population, sample size, and sampling technique

The subjects were children aged 6 to 23 months (with a mean age of 17.00±4.42 months) living in the abovementioned motherless babies home. This type of facility was selected for the study to ensure that the children were fed relatively similar foods throughout the intervention period. There were 57 children aged 6 to 23 months at the center, 40 of which met the eligibility criteria and were thus recruited for the study. The majority of them were female (67.5%). To be eligible for the study, the children had to be 1) healthy, 2) aged between 6 and 23 months old, and 3) have no congenital abnormalities. Approval was sought and granted by managers at the center. The subjects were randomly allocated to the intervention and control groups according to a randomly generated number and were assigned unique codes according to their allocated groups. The flowchart summarizing the subject recruitment process is shown in Fig. 1.

Measurement of trial outcomes

The main outcomes of the RCT were changes in anthropometric parameters (height, weight, and MUAC), hemoglobin levels, and micronutrient status (serum iron, vitamin A, iodine, zinc, and calcium) in the children.

Procurement of the food ingredients

Yellow maize seeds, soybeans, termites, pumpkin leaves, firm ripe pawpaw, and a commercial complementary food were purchased from the Ogige Main Market in Nsukka, Enugu State, Nigeria. Fishbone was purchased from dried fish (*mangala*) sellers in the same market. Winged termites were freshly collected from a field during their nuptial flight at Ugwuoye in Nsukka.

Preparation of the experimental flours

Yellow maize (*Zea mays*) flour was obtained by fermenting maize for 48 h, with water being replaced every 6 h, followed by oven drying at 60°C for 12 h before the milling process. Fishbone powder was prepared from fishbone, which was oven-dried at 40°C for 2 h and then ground into a fine powder. Soybeans (*Glycine max*) were boiled for 1 h, oven-dried at 50°C until they turned golden-brown, and then milled into flour. Termites (*Macrotermes nigeriensis*) were de-winged, toasted at 55°C, and milled into flour. Handpicked pumpkin leaves (*Telfaria*

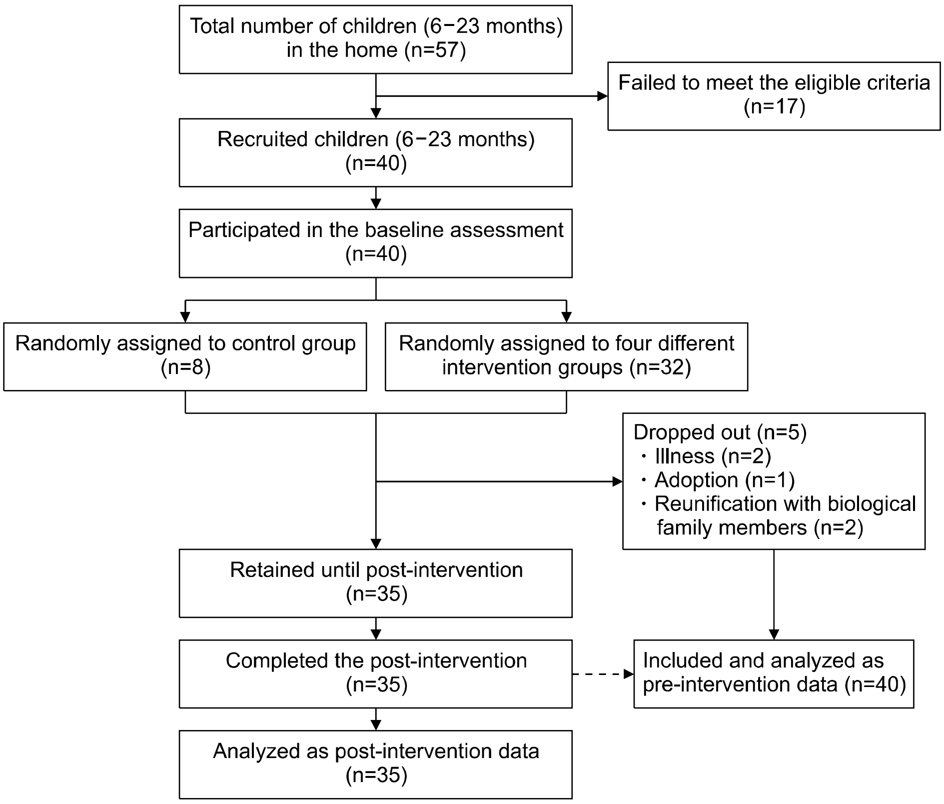

Fig. 1. Flowchart summarizing the subject recruitment process and study design.

occidentalis) were washed, shade-dried for 96 h, and milled into flour. Finally, firm ripe pawpaw fruit (*Carica papaya*) were peeled and their mesocarp was sliced and dried in a solar dryer at 55°C. Then, the dried mesocarps were milled into fine flour using a Thomas Willey mill (model ED-5).

Nutrition intervention

The complementary foods formulated with yellow Maize-Soybean, edible termite, pawpaw, pumpkin leaf, and fishbone (processed into flour) were subjected to protein content analysis using standard methods. The flours were combined in different ratios to form composite flours. The experimental diets consisted of 75% maize and 25% soybean (MaSo); 77% maize, 20% soybean, and 3% termite flour (MaSoTe); 77% maize, 20% soybean, and 3% fishbone (MaSoFi); and 68% maize, 20% soybean, 3% termite, 3% fishbone, 3% pawpaw, and 3% pumpkin leaf (MaSoTFPP). The recipes for the preparation of the complementary foods were standardized in through focus group discussion.

The daily intake of food by children was based on their recommended energy intake. The energy intake from complementary food for non-breastfed children at ages of 6 to 8 months, 9 to 11 months, and 12 to 23 months is 600, 700, and 900 kcal/d, respectively, with food to be administered 4 to 5 times daily (WHO, 2005). The diet formulation was based on the recommended standards for complementary foods for infants and young children (Codex Alimentarius Commission, 2013). According to the standards, complementary foods should supply a minimum of 4 kcal/g from carbohydrate on dry weight basis. Additionally, protein should contribute between 6% and 15% of the total energy of the product, while dietary fiber should not exceed 5 g per 100 g of the food (Michaelsen et al., 2009; Codex Alimentarius Commission, 2013). The flours were combined in different ratios, as shown in Table 1. A commercial instant complementary food consisting primarily of maize was used as the control diet.

Table 1. Formulated complementary foods and corresponding ratios of flour types used in them

Formulated complementary foods	Composite flour	Ratio
Formulation 1 (MaSo)	Maize/Soybean flour	75:25
Formulation 2 (MaSoTe)	Maize/Soybean/Termite flour	77:20:3
Formulation 3 (MaSoFi)	Maize/Soybean/Fishbone powder	77:20:3
Formulation 4 (MaSoTFPP)	Maize/Soybean/Termite/Fishbone/Pawpaw/Pumpkin leaf flour	68:20:3:3:3:3
Control	Commercial complementary food	–

Ethics approval and consent to participate

Ethical approval (UNTH/CSA/329/OL.5) was obtained from the Ethical Committee on Research Projects at the University of Nigeria Teaching Hospital, Enugu, Nigeria. The study was conducted in accordance with the ethical standards stated in the most recent version of the Declaration of Helsinki. Additionally, formal approval to conduct the study was sought from the Motherless Babies Management Board. Caregivers were provided with a comprehensive explanation with regard to the study objectives and the confidentiality of information, after which informed written consent was obtained.

Baseline data collection

Baseline data were obtained with the help of three trained research assistants before the start of the feeding trial. The children (n=40) were subdivided into five groups of eight individuals based on their age, weight, and height. Of these groups, four received one of the experimental diets (one diet per group), while the fifth received the control diet (commercial complementary food). The formulations were prepared as porridges and served to the children as breakfast during the 90-day trial period.

Blinding

Due to the visible difference between the experimental and control diets, complete blinding of the caregivers was not feasible. However, efforts were made to limit their knowledge of specific diet compositions in order to minimize any potential bias. The caregivers were informed that the study involved testing various nutritional formulations designed to support child growth and development, without providing detailed information about the intended effects of each specific diet. They were also informed that the purpose was to assess the overall nutritional adequacy without attributing specific health benefits to any of the formulations, thereby reducing expectations or bias linked to the test diets. To further reduce the risk of the placebo effect, only general guidelines were provided. These included instructions on monitoring the children's responses without associating any anticipated outcomes with the different diets. Other staff, including the research assistants and laboratory team responsible for conducting the anthropometric measurements, collecting biochemical data, and performing analyses, were blinded to the group allocations to ensure objective data collection and assessment.

Feeding protocol

The children were fed at 7:30 a.m. daily. Their regular meals for lunch and dinner were maintained. The quantity consumed at each meal and any leftovers were recorded, allowing for the close monitoring of daily meal intake. The caregivers were instructed to observe the children for any unusual symptoms or adverse reactions after consuming the complementary foods. They were provided with clear guidelines on the types of reactions to report, such as gastrointestinal symptoms (e.g., diarrhea, vomiting), allergic reactions, or any other health issues. Weekly health check-ups were conducted to assess the general well-being of the participants. These included monitoring the children's physical health, checking for signs of illness, and ensuring that no new health issues arose during the intervention period. Reported adverse events were documented, with details including the nature of the event, duration, and actions taken, if any.

Endline measurements

At the end of the feeding trial, endline data were obtained by measuring the anthropometric parameters (weight, height, and MUAC) and conducting biochemical analyses of blood samples (hemoglobin, iron, zinc, calcium, vitamin A, and iodine).

The children were weighed without clothing using a digital weighing scale (infantometer) and recorded to the nearest 100 g. Height was measured to the nearest 0.1 cm using a portable stadiometer, while MUAC was measured to the nearest 0.1 cm using Shakir tape. All measurements were carried out according to the procedures outlined by the WHO (1983). A blood sample (5 mL) was collected from each child through venipuncture. The collected samples were then analyzed for hemoglobin, iron, zinc, calcium, vitamin A, and iodine levels, following established methodologies (Craft et al., 2000; Wood et al., 2001; Treska et al., 2014; Razavi et al., 2015; Samarina and Proskurnin, 2015).

Participant attrition

Five children dropped out before the end of the 90-day feeding trial. The distribution of dropouts was as follows: Control group (1), MaSo group (2), MaSoTe group (1), MaSoFi group (0), and MaSoTFPP (1). The reasons for withdrawal included illness (2 cases), adoption (1 case), and reunification with family members (2 cases). Therefore, a total of 35 children out of 40 completed the study, which corresponded to a dropout rate of 12.5%. The dropout rate did not differ significantly between groups.

Statistical analysis

The data obtained were statistically analyzed using IBM SPSS (Statistical Package for Social Science) statistics, version 22 (IBM Corp.). The mean values of the baseline and endpoint measurements for each intervention were separately calculated. Descriptive statistics (mean and standard error) were used to represent the parameters examined. The normality of the data was assessed using the Shapiro-Wilk test and by visually inspecting histo-

Table 2. Energy and nutrient composition of the experimental and control diets per 100 g

Energy and nutrient composition	MaSo	MaSoTe	MaSoFi	MaSoTFPP	Control[1)]
Moisture (%)	7.70±0.35	7.00±1.41	6.75±0.35	4.50±0.70	NA
Ash (%)	1.30±0.42	2.75±0.35	6.50±0.70	2.25±0.25	NA
Fiber (%)	1.70±0.14	2.50±0.14	2.50±0.14	2.70±0.14	2.8
Protein (%)	9.22±0.08	16.33±0.31	13.34±0.44	13.24±0.64	14.5
Fat (%)	9.25±1.06	9.50±0.70	9.50±0.35	7.75±0.35	10.0
Carbohydrate (%)	70.73±0.01	62.67±2.07	62.35±0.58	69.56±0.12	64.7
Energy (kcal)	403.0	401.5	388.3	400.9	417.2
Iodine (mg/dL)	1.32±0.24	6.00±0.22	4.95±0.01	5.84±0.45	4.4
Zinc (mg/dL)	1.75±0.90	7.07±0.21	5.73±0.49	4.70±0.42	3.5
Calcium (mg/dL)	190.00±14.15	400.00±14.14	500.00±14.14	250.00±14.14	500.0
Iron (mg/dL)	3.16±0.22	10.21±0.28	10.87±0.35	14.85±0.56	8.5

[1)]Values obtained from the manufacturer's nutrition information on the product label.
Values are presented as mean±SD of triplicate determinations.
Control, commercial complementary food; MaSo, maize/soybean; MaSoTe, maize/soybean/termite; MaSoFi, maize/soybean/fishbone; MaSoTFPP, maize/soybean/termite/fishbone/pawpaw/pumpkin leaf; NA, not available.

grams and Q-Q plots. The results indicated that the primary outcome measurements approximated a normal distribution (P>0.05), which allowed the use of parametric methods. Paired samples t-tests were used to evaluate the differences between baseline and endpoint data, and these comparisons were summarized as percentage differences. Statistical significance was set at an alpha level of <0.05.

RESULTS

Table 2 presents the energy and nutrient composition of the experimental and control diets. Among the experimental diets, MaSoTe had the highest protein content (16.33%), followed by MaSoFi (13.34%) and MaSoTFPP (13.24%), while MaSo had the highest levels of moisture (7.7%) and energy (403 kcal). The highest fat content was observed in MaSoTe (9.50%) and MaSoFi (9.50%), followed by MaSo (9.25%). The control (a commercial product), showed the highest fat (10.0%) and fiber (2.8%) contents. MaSoTe contained the highest levels of iodine (6.00 mg/dL) and zinc (7.07 mg/dL), while MaSoFi and MaSoTFPP had the highest amounts of calcium (500 mg/dL) and iron (14.85 mg/dL), respectively. The formulation containing only MaSo had the lowest mineral (zinc, calcium, iron, and iodine) contents.

The general characteristics of the subjects at baseline are shown in Table 3. The majority (67.5%) were female individuals with a mean age of 17.0±4.4 months. The mean weight, height, and MUAC were recorded as 10.61 kg, 74.71 cm, and 12.15 cm, respectively. The effects of the formulated complementary foods and control on the children's anthropometric parameters are shown in Table 4. The percentage difference in weight was largest in the control (12.4%) and MaSoFi (12.4%) groups followed by the MaSoTe (10.3%) group. The MasoTFPP group showed the largest percentage difference in both height (19.5%) and MUAC (44.5%) measurements. Conversely, the control group exhibited the smallest percentage difference in MUAC (4.0%).

A significant difference (P<0.001) was observed in the hemoglobin, iron, and zinc concentrations between the endline and baseline data, as shown in Table 5. Specifically, the group fed with the MaSoTFPP diet exhibited the largest percentage differences in hemoglobin

Table 3. General characteristics of the participants at baseline

General characteristics	Control (n=8)	MaSo (n=8)	MaSoTe (n=8)	MaSoFi (n=8)	MaSoTFPP (n=8)	Total (n=40)
Sex						
Female	6 (75.0)	6 (75.0)	5 (62.5)	4 (50.0)	6 (75.0)	27 (67.5)
Male	2 (25.0)	2 (25.0)	3 (37.5)	4 (50.0)	2 (25.0)	13 (32.5)
Age (mon)	16.00±2.01	17.50±3.50	17.00±4.08	15.50±1.92	18.00±2.51	17.00±4.42
Weight (kg)	10.07±3.20	11.54±4.58	10.38±3.60	10.63±2.32	11.38±4.21	10.61±3.51
Length/height (cm)	70.00±13.16	79.00±12.36	73.94±14.23	73.34±15.26	74.24±14.81	74.71±13.83
Mid-upper arm circumference (cm)	12.52±0.19	12.48±0.57	12.46±0.37	12.26±0.32	11.06±0.63	12.15±0.41

Values are presented as number (%) or mean±SD.
Control, commercial complementary food; MaSo, maize/soybean; MaSoTe, maize/soybean/termite; MaSoFi, maize/soybean/fishbone; MaSoTFPP, maize/soybean/termite/fishbone/pawpaw/pumpkin leaf.

Table 4. Effect of the formulated complementary foods and control (commercial food) on anthropometric parameters in the children examined

Intervention group	Baseline (n=40)	Endline (n=35)	Growth velocity (cm/d)	Mean difference	Percentage difference (%)
Weight (kg)					
Control	10.07±3.20	11.32±5.43	0.01	1.25	12.40
MaSo	11.54±4.58	12.00±4.62	0.46	0.46	4.25
MaSoTe	10.38±3.60	11.45±3.67	0.01	1.07	10.30
MaSoFi	10.63±2.32	11.95±3.68	0.01	1.32	12.41
MaSoTFPP	11.38±4.21	12.08±4.42	7.77	0.70	6.15
Length/height (cm)					
Control	70.00±13.16	80.60±14.03	0.11	10.60	15.14
MaSo	79.00±12.36	87.14±15.32	0.09	8.14	10.30
MaSoTe	73.94±14.23	85.10±14.26	0.12	11.16	15.09
MaSoFi	73.34±15.26	86.09±22.79	0.14	12.75	17.38
MaSoTFPP	74.24±14.81	88.72±15.97	0.16	14.48	19.50
Mid-upper arm circumference (cm)					
Control	12.52±0.19	13.02±0.33	5.55	0.50	3.99
MaSo	12.48±0.57	13.64±0.05	0.01	1.16	9.29
MaSoTe	12.46±0.37	15.32±0.44	0.03	2.86	22.95
MaSoFi	12.26±0.32	13.98±0.36	0.03	1.72	14.02
MaSoTFPP	11.06±0.63	15.98±0.51	0.05	4.92	44.48

Values are presented as mean±SD.
Endline: Control (n=7), MaSo (n=6), MaSoTe (n=7), MaSoFi (n=8), MaSoTFPP (n=7).
Control, commercial complementary food; MaSo, maize/soybean; MaSoTe, maize/soybean/termite; MaSoFi, maize/soybean/fishbone; MaSoTFPP, maize/soybean/termite/fishbone/pawpaw/pumpkin leaf.

(307.6%), iron (264.0%), and zinc (58.4%) concentrations. The group fed with the MaSo diet showed the smallest percentage difference in zinc (19.7%) and iron (125.5%) concentrations, while the lowest hemoglobin concentration was reported in the control group. Table 5 also illustrates a notable increase by 34.0% to 66.5% in the calcium levels among children fed with the experimental diets compared to the baseline data. In contrast, only a 18.7% increase was observed in the control group, and this difference was found to be significant at $P<0.05$. Furthermore, a significant increase ($P<0.01$) in vitamin A status was observed among the children at the end of the feeding trial, with the smallest increase (7.3%) being observed in the control group. Compared with the baseline data, the endline data revealed a substantial increase (up to 287.8%) in serum iodine levels, particularly among children fed with the MaSoTe diet. Conversely, the MaSo group exhibited the smallest percentage increase in iodine levels (49.5%). These differences were found to be significant at $P<0.01$. The adverse effects observed during the study are summarized in Table 6. Mild gastrointestinal incidents (mild diarrhea) were reported for two children, one in the control group and the other in the MaSoTFPP group. However, these incidents were resolved within 24 h without any medical intervention but under close monitoring. No severe adverse effects were recorded. A comparison of health outcomes between children consuming the experimental diets and those in the control group showed that the adverse effects were not unique to the experimental diets. Overall, the formulated complementary foods were well-tolerated by the participants.

DISCUSSION

Among the experimental groups, the MaSoFi and MaSoTe groups showed the largest percentage increases in weight, while the MaSo group showed the lowest. These results support the theory that incorporating animal-based food sources into complementary diets is effective in preventing malnutrition. Anthropometric assessment of the children revealed the largest percentage increase in height in those fed with the MaSoTFPP diet. This increase could be attributed to the inclusion of pawpaw and pumpkin leaves in the formulation. Fruits and vegetables are rich sources of essential vitamins and minerals, particularly B-complex vitamins, which play vital roles as co-enzymes in the metabolism of macronutrients, facilitating their proper utilization for growth, tissue repair, and energy supply.

Soybeans and termites are valuable protein sources and, in addition to maize, they supply the necessary macronutrients needed for the above-mentioned vital metabolic functions. The baseline MUAC measurements obtained from the experimental groups were initially below the normal cut-off point (12.5 cm) for children aged 6 to 23 months, but after the feeding trial, values in-

Table 5. Effect of the formulated complementary foods and control commercial food on serum hemoglobin and micronutrient status in the children examined

Intervention group	Baseline (n=40)	Endline (n=35)	Mean difference	Percentage difference (%)
Hemoglobin (mg/dL)				
Control	3.88±1.16	8.52±1.44**	4.64±0.31	120.0
MaSo	5.10±0.47	12.33±0.51**	7.23±0.16	141.8
MaSoTe	5.68±2.58	17.90±2.56**	12.22±0.27	215.1
MaSoFi	4.97±1.81	11.14±1.75**	6.17±0.09	124.1
MaSoTFPP	5.03±1.84	20.50±1.83**	15.47±2.42	307.6
Iron (mg/dL)				
Control	6.07±0.57	13.69±0.69**	7.62±0.49	125.5
MaSo	5.29±0.79	11.49±1.13**	6.20±0.45	117.2
MaSoTe	6.35±0.52	18.94±0.52**	12.59±0.13	198.3
MaSoFi	4.84±0.77	12.13±0.64**	7.29±0.74	150.6
MaSoTFPP	5.97±0.14	21.73±0.43**	15.76±0.36	264.0
Zinc (mg/dL)				
Control	24.57±3.05	30.77±3.04*	6.19±0.01	25.2
MaSo	25.22±2.82	30.19±2.67**	4.96±1.36	19.7
MaSoTe	25.73±2.22	37.92±2.46**	12.77±0.47	47.4
MaSoFi	19.70±6.89	26.61±6.88**	6.90±0.01	35.1
MaSoTFPP	23.81±2.41	37.71±2.44**	13.90±0.89	58.4
Calcium (mg/dL)				
Control	4.29±0.83	5.09±0.85*	0.80±0.47	18.65
MaSo	3.47±2.31	4.65±2.46**	1.18±0.29	34.01
MaSoTe	4.66±0.52	6.96±0.68**	2.31±0.20	49.36
MaSoFi	4.95±0.68	8.24±0.81**	3.29±0.52	66.46
MaSoTFPP	5.08±1.51	7.98±1.57**	2.89±0.23	57.08
Vitamin A (μg/L)				
Control	168.5±28.2	180.7±26.8**	12.3±5.85	7.25
MaSo	123.9±20.8	145.0±30.1**	21.1±1.07	17.1
MaSoTe	284.0±10.8	389.3±27.1**	105.0±17.9	36.9
MaSoFi	257.0±21.1	369.6±10.8**	112.6±13.0	43.8
MaSoTFPP	206.9±50.2	224.6±50.5**	17.7±4.91	8.6
Iodine (mg/dL)				
Control	0.53±0.04	1.33±0.04**	0.79±0.00	150.9
MaSo	1.01±0.10	1.51±0.10**	0.50±0.00	49.5
MaSoTe	0.49±0.03	1.90±0.17**	1.41±0.14	287.8
MaSoFi	0.84±0.11	0.02±0.43**	−0.82±0.37	140.5
MaSoTFPP	0.99±0.06	1.53±0.05**	0.54±0.05	54.5

Values are presented as mean±SE.
Statistically significant at *P<0.05; **P<0.01.
Endline: Control (n=7), MaSo (n=6), MaSoTe (n=7), MaSoFi (n=8), MaSoTFPP (n=7).
Control, commercial complementary food; MaSo, maize/soybean; MaSoTe, maize/soybean/termite; MaSoFi, maize/soybean/fish-bone; MaSoTFPP, maize/soybean/termite/fishbone/pawpaw/pumpkin leaf.

Table 6. Adverse effects observed in the children fed with the diets during the study period

Adverse effect	Diet group	Number of children affected	Symptoms and duration	Intervention
None	MaSo	0	–	–
None	MaSoTe	0	–	–
None	MaSoFi	0	–	–
Mild diarrhea	MaSoTFPP	1	Loose stool; resolved within 24 h under close monitoring	None
Mild diarrhea	Control	1	Loose stool; resolved within 24 h under close monitoring	None

Control, commercial complementary food; MaSo, maize/soybean; MaSoTe, maize/soybean/termite; MaSoFi, maize/soybean/fish-bone; MaSoTFPP, maize/soybean/termite/fishbone/pawpaw/pumpkin leaf.

creased by 9% to 44%. The MaSoTFPP group exhibited the largest percentage increase in MUAC. This improvement could be attributed to the synergistic effects of maize fermentation, soybeans, and termites as well as the inclusion of fruits and vegetables in the diet.

Fermentation breaks down antinutrients and enhances their leaching into the fermenting medium. The microflora enzymes involved in fermentation contribute to increased digestibility, thereby enhancing nutrient bioavailability. Soybean, with its lysine content, combined with the appreciable amounts of methionine and cysteine in maize, and the protein and oil contents in termites, collectively contribute to a desirable nutrient profile for child growth and development. The observed improvement in MUAC aligns with previous reports of enhanced nutritional outcomes in African children fed with locally sourced complementary foods, including soybean, maize and fermented products (Bisimwa et al., 2012; Konyole et al., 2019).

The local food crops utilized in the present study could be further researched to explore their potential incorporation into community-based management strategies targeting acute malnutrition.

The children that consumed the experimental diets exhibited a larger percentage increase (124% – 308%) in hemoglobin levels compared to those in the control group, with the MaSoTFPP group showing the largest increase (by 308%). This result is consistent with the findings of the WHO (WHO, 2013), which identified staple foods fortified with fruit, vegetable, and animal food sources as having an appreciable protein quality. Such formulations have been recognized for their positive impact on improving the hemoglobin status in children (Khan et al., 2023).

Significant increases (by more than 100%) were observed in the iron status of the children in the MaSo, MaSoTe, MaSoFi, MaSoTFPP, and control groups. Specifically, the smallest increase (117%) was detected in the MaSo group and the largest in the groups fed with the two diets fortified with animal food sources, i.e., MaSoTFPP (264%) and MaSoTe (198%). The sharp increase in the hemoglobin concentration and iron status among the children suggests that deficiency in this nutrient within the population is severe. This could be due to inadequate intake of animal food sources, malaria outbreaks, or increased consumption of phytate-rich foods, which may have resulted in the disruption of iron metabolism and poor iron bioavailability (Petry et al., 2014; Al Hasan et al., 2016; Ehouman et al., 2022).

Zinc is a vital component in the blood and plays a crucial role in numerous metabolic processes. One of its many functions is to actively support the immune system in the defense against invading bacteria and viruses. It is also essential for protein and DNA synthesis, contributing to fundamental cellular processes, and plays a pivotal role in promoting effective wound healing within the body. The percentage increase in the zinc status of children in the MaSoTFPP, MaSoTe, and MaSoFi groups ranged from 35% to 58%, while that of the MaSo group was only 20%. Compared with plant food sources, animal food sources have superior nutritional density. They provide a spectrum of bioavailable micronutrients (such as iron, zinc, calcium, and vitamin A), which are generally difficult to procure in sufficient quantities solely from plant-based sources (Dror and Allen, 2011; Eaton et al., 2019).

Calcium plays an important role in supporting the growth and development of bones and teeth. Inadequate calcium intake during the first 1,000 days of an infant's life may contribute to suboptimal bone and teeth development, potentially leading to growth-related issues. Persistent low calcium levels over time could be associated with a heightened risk of conditions such as osteoporosis later in life. These facts underscore the significance of ensuring a sufficient calcium intake during this critical developmental period to promote optimal skeletal health throughout the lifespan. In the present study, a significant increase (34% – 66%) in serum calcium levels was observed in the children fed with the experimental diets (baseline vs. endline data). In contrast, only a 19% increase was observed in the control group. The percentage increase was largest in the group whose diet included fishbone powder. This is an indication that fishbone powder can be a natural and cheap source of calcium in complementary food. Fishbone has a high calcium content of 17,400 mg/100 g (Jensen et al., 2024) and can easily meet the requirement for children between 6 and 23 months of age.

Provitamin A carotenoids are significant dietary sources of vitamin A predominantly present in dark-green leafy vegetables like spinach as well as in orange and yellow vegetables and fruits, such as carrots, mangoes, and pawpaw. Vitamin A deficiency remains a prominent cause of preventable childhood blindness. It is linked to compromised immune function and increased risk of mortality from gastrointestinal diseases and measles (Amimo et al., 2022). The urgent need to address vitamin A deficiency is underscored by its potential impact on both visual health and overall well-being in children. In this study, the subjects fed with experimental diets exhibited a significant increase (9% – 44%) in vitamin A status; however, it was surprising to observe that the MaSoTFPP group showed the smallest increase in this parameter. The MaSoTFPP diet contained pawpaw and pumpkin leaf, which are good sources of provitamin A. This counterintuitive result could be attributed to factors such as the form in which the pawpaw and pumpkin leaves were administered (Kullamethee et al., 2020), which potentially lowered nutrient bioavailability. It is also possible that certain compounds in the dried pawpaw and pumpkin leaves interacted with other nutrients in a way that hindered the absorption of provitamin A or that variations in metabolism and absorption among the subjects influenced how their bodies responded to the diet (Olson, 1980; Haskell, 2012; Suzuki and Tomita, 2022). However, further research is needed to explain the observed result.

A significant percentage increase in serum iodine levels was observed across all groups compared with their baseline data, except for the MaSoFi group. The smallest percentage increase in this parameter was observed in the MaSo group, possibly due to the low iodine content in this diet, as shown in Table 2. The MaSoTe group exhibited the highest iodine level, which was twice as high as that observed in the other groups. While the MaSoTFPP group had an increased serum iodine level, the MaSoFi group showed a decrease in this parameter, which could be attributed to several factors. One possibility is that the additional ingredients in the MaSoTFPP diet, i.e., pawpaw, pumpkin, and termite flour, improved iodine absorption and nutrient metabolism. Additionally, the fiber content in the MaSoFi diet may have bound to iodine, reducing its bioavailability. The synergy of nutrients in the MaSoTFPP diet could have helped mitigate these effects, leading to better iodine retention in this group. Iodine plays a vital role in the synthesis of thyroid hormones, which are essential for growth, development, and the prevention of mental retardation (Sorrenti et al., 2021).

The experimental diets incorporating animal-based sources, i.e., the MaSoFi, MaSoTe, and MaSoTFPP formulations, had positive impacts on weight, height, MUAC, and serum nutrient (iron, zinc, calcium, and vitamin A) status, emphasizing the effectiveness of the formulations in preventing child malnutrition. Different responses were observed in terms of the vitamin A status, which prompts further research into the factors that affect the bioavailability of provitamin A sources.

Limitations of the study

While the study provided valuable insights into the effects of locally formulated complementary foods, it is important to acknowledge its limitations. The study did not include a group that received a diet consisting only of maize. The inclusion of such group would have allowed for direct comparisons to determine the effectiveness of food fortification on the measured parameters. However, the decision to exclude the maize-only group was based on the well-documented nutritional inadequacy of maize when used alone as a complementary food, which raised ethical concerns with regard to providing a diet that may not have met the children's nutritional needs.

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AUTHOR DISCLOSURE STATEMENT

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Concept and design: NMN, PNA, NEC. Analysis and interpretation: NMN, PNA, NEC. Data collection: NMN, PNA, NEC. Writing the article: PNA, NEC. Critical revision of the article: NMN, PNA, NEC. Final approval of the article: All authors. Statistical analysis: PNA. Overall responsibility: NMN.

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