Food Science and Applied Biotechnology, 2025, **9**(1), 14-34

UFT Academic Publishing House, Plovdiv

Food Science and Applied Biotechnology
e-ISSN: 2603-3380

Journal home page: www.ijfsab.com
https://doi.org/10.30721/fsab2026.v9.i1

Research Article

Development and evaluation of nutritionally enhanced weaning food formulations utilizing millet, soybeans, and fish meal

Ngida Maryamu Tumba[1], Jelili Babatunde Hussein[2,3*], Suleiman Dan Allison[2] and Tilahun Seyoum Workneh[3]

[1]*Department of Food Science and Technology, School of Science & Technology, Federal Polytechnic Mubi, P.M.B. 35, Adamawa State, Nigeria.*
[2]*Department of Food Science and Technology, Faculty of Agriculture, Modibbo Adama University, Yola, P.M.B. 2076, Adamawa State, Nigeria.*
[3]*Department of Bioresources Engineering, School of Engineering, University of KwaZulu-Natal, Private Bag X01, Pietermaritzburg, Scottsville, 3209, South Africa.*

Abstract
Weaning foods are essential for transitioning infants from breast milk to a mixed diet, providing vital nutrients for growth and development. This study explored the potential of developing weaning food formulations utilizing millet, soybeans, and fish meal. The formulations were evaluated for chemical and sensory qualities. The proximate contents of the weaning foods ranged 6.56 – 8.96%, 13.23 – 22.63%, 2.02 – 6.32%, 4.32 – 6.32%, 1.32 – 2.96%, and 55.62 – 69.85%, respectively, for moisture, crude protein, crude fat, ash, dietary fibre, and carbohydrate. The mineral contents ranged from 53.67 – 88.72 mg.100 g^{-1}, 313.87 – 695.93 mg.100 g^{-1}, 172.75 – 365.25 mg.100 g^{-1}, 1.15 – 3.54 mg.100 g^{-1}, 2.57 – 6.34 mg.100 g^{-1}, 43.16 – 76.42 mg.100 g^{-1}, 51.23 – 76.42 mg.100 g^{-1}, and 0.37 – 1.93 mg.100 g^{-1}, respectively. Sensory scores shows that the formulations were generally well-received by the panellist but sample O (50M:25S:10F) was preferred over others due to its balanced flavour, smooth texture, and appealing appearance. Overall, the nutritional profile of the formulations met recommended dietary guidelines, making them suitable for consumption. These locally sourced ingredients provide an adequate solution to address protein-energy malnutrition and micronutrient deficiencies prevalent in developing countries.

Keywords
weaning foods, protein-energy malnutrition, millet-soybean-fish meal, nutritional deficiencies, complementary diets

Abbreviations
PTFE – polytetrafluoroethylene

✉*Corresponding author: Jelili Babatunde Hussein, Department, Department of Food Science and Technology, Faculty of Agriculture, Modibbo Adama University, Yola, P.M.B. 2076, Adamawa State, Nigeria; and Department of Bioresources Engineering, School of Engineering, University of KwaZulu-Natal, Private Bag X01, Pietermaritzburg, Scottsville, 3209, South Africa; e-mail: husseinj@ukzn.ac.za*

Article history:
Received 12 March 2025
Reviewed 10 August 2025
Accepted 20 August 2025
Available on-line 3 December 2025

https://doi.org/10.30721/fsab2026.v9.i1.508
2025, UFT Academic publishing house, Plovdiv

Introduction

Weaning is the gradual process of introducing foods other than breast milk into a baby's diet. These weaning foods are used in the shifting phase from breastfeeding or infant formula to a mixed diet. They are used to supplement breast milk, replace it gradually, and eventually assist the child in transitioning to adult foods. Breast milk as a first food does not provide sufficient sustenance to support rapid growth and development once the child reaches six months of age (Msheliza et al. 2018a). At this point it is time to add appropriate weaning food (i.e., energy- and protein-dense food other than breast milk) to supplement breast milk for the healthy growth and development of the child. If proper food is not given to the baby, it can result in malnutrition, which is a common problem in developing countries (Asma et al. 2006; Eshun et al. 2011).

Commercially standardised foods are of a high quality and provide an adequate dietary supply for young children. Nevertheless, this type of food is expensive and mostly available only to the few rich classes who can afford to pay for them. This has led to great interest from food processors and researchers in many developing countries to formulate and develop nutritious weaning foods based on local and readily available raw materials (Alawode et al. 2017). For instance, Nkama et al. (2001) formulated weaning foods from pearl millet, cowpea, and groundnut. Weaning food was also formulated with pearl millet, cowpea, and groundnut by Badau et al. (2005). Eshun et al. (2011) evaluated the nutritional composition of weaning food from soybean, groundnut, and rice blends. Muhimbula et al. (2011) developed supplementary diets based on the staple foods maize, sorghum, and finger millet, and protein supplements including common beans, cowpeas, and green peas. Achidi et al. (2016) developed weaning foods using a mixture of cereal, legumes, tubers, vegetables, and crayfish. Tiencheu et al. (2016) produced instant weaning foods from blends of maize, pawpaw, red beans, and mackerel fish meal. Alawode et al. (2017) developed complementary foods from combinations of orange flesh, sweet potato, sorghum, and soybean. Maize-based complementary foods supplemented with black bean and crayfish flours were developed by Okoye and Ene (2018).

In addition, Okoye et al. (2021) formulated ready-to-eat complementary foods by combining malted sorghum, soybean, and Irish potato flour. Likewise, Mohammed et al. (2021) formulated a complementary food using blends of fermented yellow maize (the improved variety), soybean, and African catfish meal, among others. The list of such endeavours continues to grow. Nonetheless, chronic malnutrition remains an enduring issue among young children in sub-Saharan Africa (Asma et al. 2006; Eshun et al. 2011). Persistent hunger and malnutrition inflict significant human suffering, with protein-energy malnutrition, kwashiorkor, and marasmus being commonly observed in infants and young children (Mohammed et al. 2021). Protein-energy malnutrition, in various forms, poses the most severe nutritional deficiencies, particularly impacting young children. Iron deficiency is highly prevalent in developing countries, serving as the leading cause of anaemia in children aged 6 to 36 months, affecting 17 to 44% of this population (Lanzkowsky 2013). Iron deficiency is linked to poor development, cognitive function, and behavioural differences in children. Calcium deficiency leads to improper bone development in growing children, resulting in various skeletal deformities.

The study explores the integration of finger millet, soybeans, and fish meal in weaning foods, highlighting their nutritional benefits and potential to prevent protein-energy malnutrition and micronutrient deficiencies in infants and young children.

Materials and Methods

Materials and their preparations. Finger millet, soybeans, and catfish were procured from Jimata modern market. All samples were maintained in a moisture-free condition until required. The chemicals and reagents used were of analytical grade obtained from the laboratories of Food Science and Technology, Modibbo Adama University of Technology, Yola, and Federal Polytechnic, Mubi, both in Adamawa State. Each of the finger millet and soybean samples were manually cleaned to remove sand, foreign seeds, broken seeds, infested seeds, dirt, and other contaminants.

Methods

Processing of finger millet grains into flour. Finger millet grains were processed according to the method outlined by Usman et al. (2018). The sorted grains were steeped in thrice the weight of water at room temperature for 12 h, after which it was subjected to an air rest for 1 h at 6 h of steeping. The steeping water was replaced between every air rest. Following completion of the steeping procedure, a sterilization of the grains was conducted by placing them in a 1% sodium hypochlorite solution for 5 minutes. After sterilization, the grains were drained for germination. They were then spread over wet jute sacks, covered with a wet cotton cloth, and allowed to germinate at ambient temperature (32±2°C). The grain millet was malted by sprouting its grains and then dried at 60°C in a cabinet drier for 48 hours. The sprouted grains were squeezed between the palms to separate the germs, which were dry-cleaned by blowing air. Those grains were later milled into flour. Finely milled flour was achieved by sieving the malted millet flour through a 250 µm aperture-sized sieve. Then, the flour was bagged in low-density polyethylene and stored at room temperature until use.

Processing of soybeans into flour. The soybean flour was prepared according to the method described by Nwakalor and Obi (2014) with some modifications. The soybeans were meticulously sorted to remove stones, rot, and physical imperfections. The defect-free beans were soaked for 3 h, dehulled, and boiled for 15 min post-cleaning. Thereafter, the seeds were dried in an oven (model TO008GA-34; AKAI-TOKYO, Japan) at a temperature of 80°C for 24 h. This gold-brown colour was achieved by roasting the beans for 30 minutes under an open flame. After that, the grains were ground in a commercial grinder and converted into flour. The flour was passed through a local sieve having approximately 1 mm in diameter to obtain the fine particle size. Finally, the flour was safely stored in a plastic container and sealed until it is used.

Processing of fresh African catfish in fish meal flour. The process described in the study of Mohammed et al. (2021) was used to convert fresh African catfish into fish meal. Five hundred grams of the fresh fish was washed in salted water and cut into small pieces. The fish pieces were dried with a hot air oven (Model: TO008GA-34, AKAI-TOKYO, JAPAN) at 40°C until a constant dry weight. After the fish was dried, it was ground into flour by using a Kenwood blender (Philips HR 2001, China) to produce the fishmeal fine flour. The fishmeal flour was stored at 4°C in airtight plastic storage bags until further use.

Experimental design and formulation of weaning foods. The Response Surface Methodology (RSM) with Central Composite Rotatable Composite Design (CCRD) was adopted for prediction of responses against a few numbers of experimental data that varied all factors within the selected range (Filli et al. 2013). An experimental design based on three factors and three levels was considered for this work as illustrated in Table 1. The independent variables observed were the percentage level of millet (X_1), the percentage level of soybean (X_2), and the percentage level of fishmeal (X_3). In Table 1, the independent variables as well as their levels of variation are presented as well.

Table 1. Independent variables and levels used for central composite rotatable design

Variables	Symbol	Coded variable level				
		-1.68	**-1**	**0**	**1**	**1.68**
Finger millet [M], %	X_1	33.18	40	50	60	66.82
Soybean [S], %	X_2	16.59	20	25	30	33.41
Fishmeal [F], %	X_3	1.59	5	10	15	18.41

Transformation of coded variable (x_i) levels to uncoded variables (X_1) levels could be obtained from
$X_1 = 10x_1 + 50$; $X_2 = 5x_2 + 25$ and $X_3 = 5x_3 + 10$

According to literature information and preliminary trials, levels of each variable were set. Table 2 presents the complete design comprising 20 experimental points, including response values.

Statistical analysis was performed by using the Design Expert version 13.0 (Stat-Ease Inc., Minneapolis, MN, USA). The simultaneous optimisation of the multiple responses was performed by the Design Expert (Stat-Ease Design Expert 13.1.2.0) software. To evaluate the effects of millet (X_1), percentage level of soybean (X_2), and percentage level of fishmeal (X_3) on each objective, the response was regressed into a second-order polynomial regression equation (Equation 1), defined as:

$$Y = f(y) = \beta_0 + \sum_{i=1}^{k} \beta_i X_i + \sum_{i=1}^{k} \beta_{ii} X_i^2 + \sum_{i=1}^{k} \sum_{i=1}^{k} \beta_{ij} X_i X_j + \varepsilon \quad (1)$$

Where Y is the predicted response, which is the dependent variable, k is the number of independent variables that are taken into consideration in the experiment; $ß_o$ is the constant coefficient, and $ß_i$ and $ß_{ij}$ are the coefficients of linear interaction and square terms, respectively, whereas e is the random error term. The adequacy and fitness of the models were evaluated using the coefficient of determination (R^2) and adjusted (R^2_{adj}) and adequate precision value of the responses. Response surface and contour plots were subsequently performed using the same software after removing non-significant terms.

Table 2. Experimental design for formulation of weaning foods in their coded form and natural units

Design points	Independent variables in coded form			Experimental variables in their natural form		
	Finger millet	**Soybean**	**Fishmeal**	**Finger millet**	**Soybean**	**Fishmeal**
1	-1	-1	-1	40	20	5
2	1	-1	-1	60	20	5
3	-1	1	-1	40	30	5
4	1	1	-1	60	30	5
5	-1	-1	1	40	20	15
6	1	-1	1	60	20	15
7	-1	1	1	40	30	15
8	1	1	1	60	30	15
9	-1.682	0	0	33.1821	25	10
10	1.682	0	0	66.8179	25	10
11	0	-1.682	0	50	16.591	10
12	0	1.682	0	50	33.409	10
13	0	0	-1.682	50	25	1.59104
14	0	0	1.682	50	25	18.409
15	0	0	0	50	25	10
16	0	0	0	50	25	10
17	0	0	0	50	25	10
18	0	0	0	50	25	10
19	0	0	0	50	25	10
20	0	0	0	50	25	10

Determination of the proximate composition of the developed weaning blends. The proximate constituents were determined according to AOAC (2016) methods. In the preheated oven Fisher Scientific Isotemp Oven, model 655F (Chicago, USA), 2 g of each sample were dried at 105°C for 3 hours. The difference in weight was evaluated as the percentage moisture content of the sample. Protein was analysed by using the micro-Kjeldahl method. A heating tube was filled with 2 g of each of the samples followed by 10 ml of concentrated H_2SO_4. Then, one tablet (selenium catalyst) was placed into the tube and heated in a fume cupboard. The digest was then transferred to a 250 ml volumetric flask and made up to the mark with distilled water. Ten millilitres (10 ml) of the digest were added with 10 ml of 45% NaOH and distilled by Kjeldahl apparatus. The liquid produced was subsequently collected in a 4% boric acid solution containing three drops of methyl red indicator. A total of 100 ml of distillate was titrated with 0.1N hydrochloric acid, and the average value was recorded. Nitrogen concentration was measured and multiplied by 6.25 to calculate crude protein concentrations.

Fat was quantified based on the method of Soxhlet extraction. Each sample (2 g) was loosely wrapped in filter paper and inserted into the extracting thimble, which was connected to a round-bottom flask with 120 ml of n-hexane. A heating mantle heated the experimental apparatus to 70°C and allowed it to reflux for 5 hours. The weight difference was reported as mass fat, expressed as a percentage of the sample. Crucibles containing 2 g of samples were placed in a heated furnace (Fisher Isotemp Muffle Furnace, model 186A, USA) at a temperature of 600°C for 6 hours, then cooled to room temperature in desiccators and weighed. The residues were weighed as a function of ash mass.

The total dietary fiber content was determined using Enzymatic-Gravimetric method as described by AOAC (2020). The defatted dried sample (2 g) was treated with α-amylase to remove starch. Thereafter, protease was added to break down proteins, and amyloglucosidase was also added to completely digest the remaining starch in the sample. Ethanol was used in the resultant solution to precipitate soluble fibre. The residue was further filtered via vacuum filtration and dehydrated in an oven (Fisher Scientific Isotemp Oven, model 655F, Chicago, USA) at 105°C to eliminate moisture. The desiccated residue was combusted in a furnace at 550°C to eliminate any mineral impurities. The carbohydrate content was calculated as 100 – (% moisture + % protein + % fat + % fibre + % ash).

Determination of the minerals elements of the developed weaning blends. The mineral element was analysed by the technique of Atomic Absorption Spectrophotometer (AAS) (Buck 230, Buck Scientific Las Vegas, USA) as described by AOAC (2020). Five grams each of the samples were weighed and placed into Kjeldahl flasks with 25 ml of digestion acid (Aqua regia HCl: HNO_3 3:1). Swirl and heat gently initially (in a fume hood) until frothing ceases, then more vigorously until a clear pale-yellow solution is obtained; cool and transfer the digest into a 100-ml volumetric flask. Filter the solution using Whatman No. 1 filter paper and make up to the mark with distilled water. The filtrate was transferred to the AAS. A lamp for each of its desired metals was placed in position to the instrument, and the wavelength for each heavy metal was set for determinations using the air-acetylene integrated flame mode. Standards of Sodium (Na), Potassium (K), Iron (Fe), Manganese (Mn), Magnesium (Mg), Zinc (Zn), Copper (Cu) and Calcium (Ca) were run using lamps of the same standards. The concentration of each metal was determined by extrapolating from the calibration curve generated by the standards. Then concentration multiplied by 100 gave the percentage value.

Phosphorus in the sample solution is measured as a yellow phosphor-vanado-molybdate complex in a spectrophotometer. Five (5 ml) of the sample filtrates were pipetted into a 50 ml volumetric flask. Ten (10 ml) of vanado-molybadate reagent was added and mixed well. The solution was then made to the volume with distilled water, mixed, and allowed to stand for 10 min. Absorbance was measured at 470 nm on the spectrophotometer. The reading was then assessed from the standard curve.

Sensory evaluation of the developed weaning blends. The prepared powder (30 g) was mixed with warm water (about 200 ml). The mixture was stirred continuously to avoid lumps and cooked at 75°C for 5-10 min until it thickened. The resulting mixture was then allowed to cool before being served for evaluation. Twenty semi-training nursing mothers were selected from the students and staff of the Departments of Food Science and Technology, Modibbo Adama University of Technology, Yola, and Federal Polytechnic, Mubi, both in Adamawa State, Nigeria. Before the sensory test was conducted, the panellists were exposed to a two-day structured training on evaluating the sensory test. This training involved the introduction to some of the major sensory attributes, including appearance, taste, texture, aroma, and acceptability in general, with well-defined reference points. Through commercial weaning foods, practice sessions were held to aid in the calibration of their responses and equalising that of the group. The scoring mechanism and the implementation of sample identifiers in the form of code were also explained to the panellists to minimise bias.

Panellists were selected using the following criteria: familiarity with the sensory attributes of this weaning food; availability to attend every session throughout the evaluation process; interest and willingness to participate; and allergy or sensitivities to the product being evaluated. In the ranking task, panellists were asked to score weaning food products for quality attributes (appearance, taste, texture, aroma, and overall acceptability). This was achieved through a 9-point Hedonic scale, in which the score of 1 corresponds to extreme dislike and the score of 9 corresponds to extreme liking (Iwe 2010).

The weaning foods were provided in clear plastic cups to the panellists. They were asked to rinse their mouths with room-temperature water between each new serving. The samples were placed in coded containers that were kept apart before testing to avoid crowding, and the panellists performing the analysis did not know the compositions of each sample to avoid bias and ensure independent judgement.

Statistical analysis. All experiments were performed independently three times, with results shown as mean ± standard error (SE). Analysis of variance (ANOVA) was used to identify any significant differences in the measurements using the SPSS statistical software (SPSS 20.0 for Windows; SPSS Inc., Chicago, IL, USA), at a confidence level of 95%. The differences among the means were statistically analysed via Duncan's Multiple Range Test; differences were considered significant when $p < 0.05$ (Hussein et al. 2016).

Results and Discussion

Proximate compositions of the formulated weaning foods. The results of the proximate composition of the weaning foods prepared from the blends of millet, soybean, and fishmeal are shown in Table 3. The moisture levels of these samples ranged from 6.56% (Sample F [60M:20S:18.15F]) to 8.96% (Sample N [50M:25S:18.41F]). The lowest value in Sample F with high millet component (60%) and low soybean component (20%) could be explained by the lower hygroscopicity of millet as well as the high starch content which has tendency to less binding water molecules following cooking and drying. Sample N on the contrast was found to contain the highest amount of moisture, which is probably caused by the protein and lipid recovered in the fish meal that can elevate water retention when associated with protein-water binding or fat-water binding during preparation (Ween et al. 2017). Soybeans also add soluble fibers and proteins that bind and hold water, thus increasing moisture levels in soy high formulations such as Samples D (60M:30S:5F) and H (60M:30S:15F). Moisture content is a major determinant of the shelf-life, storage stability, and microbial safety of food products. Msheliza et al. (2018a) reported similar levels of moisture content in complementary foods, which ranged from 6–10%. A lesser moisture content is beneficial for better storage stability.

Protein of the samples varied from 10.63% (Sample M [50M:25S:1.59F]) to 24.95% (Sample G [20M:20S:15F]). A similar protein content variation from 11.43% to 26.72% was reported by Msheliza et al. (2018a) in a cereal-legume weaning blend. Protein is important for growth and development, so protein is an important component of weaning foods. The protein content in these formulations is significantly higher compared to conventional cereal-based weaning foods. The increased protein content of these samples (Sample G in particular) is likely due to the use of soybean and fishmeal, which are both excellent protein sources. Thus, these formulations could be more effective than traditional weaning foods in enhancing infant growth. Though a fair protein source, millet is less protein-dense than legumes such as soybeans. This is reflected in samples like Sample M, where increased millet content is associated with decreased protein level. Hence, it is important to mix millet with high-protein foods, such as soybean and fishmeal, to ensure that the protein requirement for infants' growth and development is met.

These results also demonstrated that the soy sustainably contributes to the protein enrichment of these preparations. For example, Samples G and H, with the highest soybean content, show the highest levels of protein at 24.95% and 24.12%, respectively. This is critical for weaning foods, because protein is crucial for tissue development, immune function, and overall growth in infants.

Samples that contain fish meal, especially in combination with soybean, show an increased protein content. Fishmeal delivers the high biological value protein in these formulations that is better absorbed by the body and contributes to growth and repair. Adebayo-Oyetoro et al. (2019); Msheliza et al. (2018a); Malomo and Abiose (2019) have also reported similar findings that traditional cereal-legume blends often do not supply adequate protein and fat; hence fortification is required. Consequently, the participation of soybean and fishmeal during this study plays a significant role in overcoming these shortcomings; the high amounts of protein and fat help to meet the nutrition of budding infants.

The fat percentage of these samples ranged from 2.02% (Sample I [33.15M:25S:10F]) to 3.95% (Sample D [60M:30S:5F]). Fat is an important component of weaning foods that provides energy, facilitates fat-soluble vitamin absorption, and improves sensory characteristics of the food. Our findings are consistent with the previous findings by Adegunwa et al. (2014), Adebayo-Oyetoro et al. (2019), and Msheliza et al. (2018a) that also reported fat content between 2% and 7% for similar weaning formulations. The added fat of Sample D (with more soy content) implies higher caloric density, which supports growth in older infants who need extra calories. The higher fat content of 3.95% in Sample D is directly attributed to the fat content from the addition of soybean. This fat is vital for energy and to help absorb fat-soluble vitamins (A, D, E, K), important for growing babies. Anigo et al. (2010) found that oil-rich soybeans, when included in complementary diets, not only enhance energy density but also serve as fat-soluble vitamin carriers. Furthermore, Adedeji et al. (2015) also stated that the high fat levels of the flour may provide a large amount of energy, but the presence of high fat levels in the foodstuff is susceptible to hydrolytic and oxidative rancidity, which contributes to the emergence of off-flavours compromising the overall acceptability and storage stability of the product. However, the fat contents of these products are low enough to ensure good storage stability; an ideal storage package is all that is needed to ensure they stay fresh and acceptable over time.

Table 3. Proximate compositions of the weaning foods prepared from the blends of millet, soybean, and fishmeal

Samples	Moisture, %	Crude protein, %	Fat, %	Ash, %	Dietary fibre, %	Carbohydrates, %
A [40M:20S:5F]	7.00 ± 0.01^{j}	16.95 ± 0.01^{fg}	3.61 ± 0.01^{abc}	6.37 ± 0.02^{e}	2.62 ± 0.02^{b}	62.46 ± 0.05^{b}
B [60M:20S:5F]	7.51 ± 0.01^{h}	17.20 ± 0.01^{f}	3.82 ± 0.02^{ab}	6.72 ± 0.02^{de}	2.62 ± 0.02^{b}	60.15 ± 0.06^{c}
C [40M:30S:5F]	8.02 ± 0.02^{d}	19.40 ± 0.01^{e}	3.81 ± 0.01^{ab}	6.81 ± 0.01^{cde}	2.61 ± 0.01^{b}	56.36 ± 0.05^{d}
D [60M:30S:5F]	8.21 ± 0.01^{c}	21.96 ± 0.01^{d}	3.95 ± 0.01^{a}	6.97 ± 0.02^{bcd}	2.96 ± 0.01^{a}	51.96 ± 0.06^{e}
E [40M:20S:15F]	8.35 ± 0.03^{b}	22.63 ± 0.01^{cd}	3.58 ± 0.01^{abc}	7.49 ± 0.02^{ab}	2.37 ± 0.02^{e}	50.60 ± 0.07^{ef}
F [60M:20S:15F]	6.56 ± 0.01^{k}	13.96 ± 0.01^{ij}	2.65 ± 0.01^{cd}	4.73 ± 0.01^{gh}	1.32 ± 0.01^{i}	64.79 ± 0.04^{a}
G [40M:30S:15F]	7.00 ± 0.01^{j}	24.95 ± 0.01^{a}	3.61 ± 0.01^{abc}	7.37 ± 0.02^{abc}	2.62 ± 0.02^{b}	47.46 ± 0.04^{g}
H [60M:30S:15F]	7.57 ± 0.01^{g}	24.12 ± 0.01^{ab}	3.82 ± 0.01^{ab}	7.73 ± 0.01^{a}	2.97 ± 0.02^{a}	45.80 ± 0.06^{gh}
I [33.18M:25S:10F]	7.57 ± 0.02^{g}	14.84 ± 0.02^{hi}	2.02 ± 0.02^{d}	4.76 ± 0.02^{g}	1.35 ± 0.02^{i}	60.48 ± 0.08^{c}
J [66.82M:25S:10F]	7.89 ± 0.01^{e}	13.23 ± 0.98^{j}	2.67 ± 0.01^{cd}	4.32 ± 0.02^{gh}	2.43 ± 0.01^{d}	59.47 ± 0.09^{c}
K [50M:16.59S:10F]	7.12 ± 0.01^{i}	23.52 ± 0.01^{bc}	3.54 ± 0.01^{abc}	7.39 ± 0.01^{abc}	2.56 ± 0.01^{c}	44.89 ± 0.03^{h}
L [50M:33.41S:10F]	7.74 ± 0.01^{f}	24.62 ± 0.01^{ab}	3.82 ± 0.02^{ab}	4.48 ± 0.01^{k}	2.62 ± 0.01^{b}	67.72 ± 0.06^{e}
M [50M:25S:1.59F]	7.02 ± 0.02^{j}	10.63 ± 0.01^{k}	2.36 ± 0.98^{d}	4.66 ± 0.02^{j}	1.62 ± 0.01^{h}	67.71 ± 0.09^{e}
N [50M:25S:18.41F]	8.96 ± 0.01^{a}	15.84 ± 0.01^{gh}	2.28 ± 0.52^{d}	5.37 ± 0.02^{h}	1.85 ± 0.02^{g}	64.22 ± 0.07^{f}
O [50M:25S:10F]	8.35 ± 0.01b	16.80 ± 0.02^{fg}	2.86 ± 0.01^{bcd}	5.78 ± 0.01^{g}	1.93 ± 0.01^{f}	63.29 ± 0.03^{h}

All results are mean of triplicate readings. Any two-mean having same letters are not significantly different ($p \leq 0.05$)

Ash content in the food samples ranged from a minimum of 2.28% (Sample N) to a maximum of

7.73% (Sample H). The ash content is relatively high, suggesting a high mineral content, which is important for the nutrition of infants. Adepeju et al. (2011) reported ash content of complementary foods between 3% and 6%, which were lower than those found in these samples. Higher levels of ash in these weaning food formulations may be attributed to the inclusion of fishmeal, which contains a high mineral profile, particularly calcium and phosphorus, important for bone development in infants. Soybean and fishmeal addition have a significant effect on the ash content of these products. Also, the contribution of soybean to the ash content and the rich mineral composition (e.g., calcium, potassium, iron) of soybean adds some healthful characteristics to the formulations. Higher levels of ash content in Sample H (7.73%) show a minerals-rich profile necessary for the growth of bones and general health requirements of infants. Fishmeal is a significant contributor to increasing ash content (a measure of the total mineral content in the diet) due to its richness in essential minerals that play an important role in calcium and phosphorus availability for growing and developing bones in infants. Dietary fibre content of these samples ranged from 1.32% (Sample F) to 2.97% (Sample H). Samples H (60M:30S:15F) and D (60M:30S:5F) contained the highest fibre, with high inclusion of millet (60%), and soybean (30%). Millet is high in insoluble fibre whereas soy has soluble fibre in fermentable form, like oligosaccharides and hemicellulose. These fomulations have the advantage of fibre synergy that enhances gut health functionality. Sample F (60M:20S:15F) showed the lowest fibre, probably as a result of replacing fibre-rich millet with fish meal. Moreover, Sample M (50M:25S:1.59F) was low in fibre because it contained little fish and moderate soybean. These differences demonstrate the considerable impact of the proportion of millet and soy on the amount of dietary fibre. Fibre is an important part of our diet and is necessary because it helps with digestion and prevents constipation. Fibre contents of these formulations are still consistent with those reported by Msheliza et al. (2018a), who found that the fibre content of common weaning foods usually ranges from 1% to 3%. Agostoni et al. (1995) highlighted the need of maintaining adequate fibre content in weaning foods, as excessive amounts may interfere with nutrient absorption and may also be too strong for the digestive system of an infant. These formulations appear to be well balanced, providing a sufficient amount of fibre to encourage healthy digestion without overloading the infant digestive tract.

Carbohydrate contents of the samples ranged from Sample D (60M:30S:5F) at 51.96% to 64.79% in Sample F (60M:20S:15F). For weaning foods, carbohydrates are key to meeting the energy demands from the high growth rates of young infants. These levels in these samples are similar to previous findings, which indicated carbohydrates as making up 55% to 70% in weaning foods (Msheliza et al. 2018a; Abimbola et al. 2024). Samples such as K (50M:16.59S:10F) and I (33.15M:25S:10F) exhibit elevated carbohydrate content, revealing that they are energy-rich and advantageous for infants who require more energy to support both growth and an increase in activity level. These formulations contain balanced carbohydrates, indicating their capacity to provide a sustained release of energy. Sample G (40M:20S:15F) and Sample H (60M:30S:15F) with higher soybean and fishmeal content demonstrate elevated protein levels (between 24.95% and 24.12%), thus possessing nutrition that is especially beneficial for supporting healthy growth and development. But soybeans and fishmeal, being low in carbohydrates, require further addition of carbohydrate sources such as finger millet to balance the weaning foods nutritionally aside from protein content. In addition, the proteins of soybean and fishmeal are complemented by the carbohydrates of finger millet, promoting a high energy density and making these weaning foods ideal for an infant with a small stomach capacity requiring high levels of nutrients. Together, they provide the protein requirements of infants along with their growth and development.

Model fitting and validation for proximate compositions of the formulated weaning foods. The independent and response variables were fitted to the second-order polynomial equation (Equation 1), and its goodness of fit was analysed based on analysis of variance (ANOVA) and coefficient of determination (R^2 and R^2_{adj}). Equations 2 to 7, respectively, present the predictive regression models developed for the relationship between the dependent (y) and independent (X) in the proximate compositions of the formulated weaning foods. The coefficients with one factor (X_1, X_2, and X_3) represent the independent effect of a variable. While the coefficients with two factors (X_1X_2, X_1X_3, and X_2X_3) and the ones that had quadratic/second-order terms (X_{12}, X_{22}, and X_{32}) represent the interaction between the three factors and quadratic effects. The positive sign infront of the regression term, it indicates a synergetic relation, and a negative, it indicates an antagonistic relation.

In equation 2, the positive sign in the coefficients with one factor, indicates that moisture increases slightly with more millet and soybean and incraeses significantly ($+0.58x^3$) with increasing fish meal. The negative values the quadratic (squared) terms showed curvature, which implies that too much of any one ingredient decreases moisture. The higher-order interaction ($-0.74x_1^2x_3$) showed a strong negative effect when millet is squared and combined with fish. This suggests that high millet and fish content significantly reduce moisture. In equation 3, fish meal has the strongest positive effect ($+1.38x_3$) on protein (as expected), while soybean has a strong quadratic ($+3.21x_2^2$) effect, which shows that moderate soybean increases protein significantly. On the other hand, it was observed that millet reduces protein content ($-0.69x_1$), however, at certain levels, high millet combined with fish ($+2.13x_1^2x_3$) positively influences protein. Equation 4 showed that soybean significantly increases fat content ($+0.15x_2$ and $+0.47x_2^2$), especially at higher levels, while the combination of millet and fishmeal ($-0.13x_1x_3$) slightly decreases the fat contents. Jin et al. (2019) and Tomar et al. (2022) reported that lipid–starch interactions can reduce extractable fat, especially when millet is the dominant matrix.

It was observed from equations 5 and 6 that soybeans contribute significantly to the ash contents and dietary fibre in the weaning blends. A similar observation was reported by Abimbola et al. (2024) that the inclusion of soybean in weaning food blends elevates ash content because of its high mineral concentration, particularly compared to low-ash cereals like millet. These findings suggest that the inclusion of soybeans in weaning food blends not only increases ash content but also enhances dietary fibre levels, making it a beneficial ingredient for nutritional fortification. Thus, the combination of millet, fishmeal, and soybeans in weaning blends can result in a balanced nutrient profile for infants and young children.

$$Moisture = +8.35 + 0.10x_1 + 0.18x_2 + 0.58x_3 + 0.26x_1x_2 - 0.24x_1x_3 - 0.26x_2x_3 - 0.25x_1^2 - 0.36x_2^2 - 0.16x_3^2 + 0.33x_1x_2x_3 - 0.74x_1^2x_3 - 0.16x_1x_2^2 \quad (2)$$

$$Protein = +16.70 - 0.69x_1 + 0.11x_2 + 1.38x_3 + 1.27x_1x_2 - 1.54x_1x_3 + 0.66x_2x_3 - 0.34x_1^2 + 3.21x_2^2 - 0.62x_3^2 + 0.69x_1x_2x_3 + 2.13x_1^2x_3 \quad (3)$$

$$Fat = +2.82 + 0.05x_1 + 0.15x_2 - 0.12x_3 + 0.13x_1x_2 - 0.13x_1x_3 + 0.47x_2^2 \quad (4)$$

$$Ash = +5.48 - 0.19x_1 + 0.27x_2 + 0.12x_3 + 0.37x_1x_2 - 0.36x_1x_3 + 0.27x_2x_3 + 0.89x_2^2 \quad (5)$$

$$Fibre = +1.99 + 0.11x_1 + 0.17x_2 - 0.08x_3 + 0.22x_1x_2 + 0.20x_1x_3 + 0.32x_2^2 \quad (6)$$

$$CHO = +49.25 - 0.30x_1 - 0.94x_2 - 2.68x_3 - 2.24x_1x_2 + 2.40x_1x_3 - 0.98x_2x_3 + 4.07x_1^2 - 1.83x_2^2 + 2.92x_3^2 - 1.72x_1x_2x_3 - 3.61x_1^2x_2 - 0.10x_1^2x_3 + 1.03x_1x_2^2 \quad (7)$$

An analysis of variance was conducted at the 95% confidence level to assess the statistical significance of the model. In Table 4 we can find the results of the analysis of variance. The F-value is the ratio of the model mean square to the error mean square in the ANOVA table. As this ratio increases, the F-value also becomes larger, and the probability that variance attributed to the model is substantially greater than a chance error increases (Krishna et al. 2013). From Table 4, it could be seen that the model regression coefficient is significant for moisture content (F-value = 63.20, p-value = 0.0001), crude protein (F-value = 7.02, p-value = 0.0052), crude fat (F-value = 3.11, p-value = 0.0409), ash (F-value = 3.36, p-value = 0.0318), dietary fibre (F-value = 3.29, p-value = 0.0340), and carbohydrates (F-value = 63.12, p-value = 0.0001). The model coefficient that has F-values of high magnitude indicates that most of its variation could be described by the regression equations (Filli et al. 2013; Danbaba et al. 2015).

Similarly, the linear and square asterisk terms of the equation were also significant for the same test ($p \leq 0.05$). This means that from the ANOVA table, the model selected is adequate for proximate composition of the weaning food formulated. The results were also used to assess the importance of the model equations and the goodness of fits based on the R^2 and adjusted R^2 metrics. The R^2 and adjusted R^2 values obtained were within the range of between 0.5891 to 0.9927 and 0.3998 to 0.9770, respectively, showing the soundness of the model equation in estimating the proximate compositions of the weaning foods when the three processing variables are combined mathematically. Hussein et al. (2023) state that the fit of an actual empirical model to data is better when R^2 approaches unity, but R^2 value must be greater than or equal to 0.8 to have a good fit of the regression model. The interrelation of dependent and independent variables was illustrated in the joint surface and contour plots (Fig. 1). The plots represent combinations of 2 test variables (percent millet and soybean), with the 3rd test variable (fishmeal) fixed at zero levels. The proximate values were increased with percentage inclusion of soybean and fishmeal.

Table 4. Analysis of variance (ANOVA) for the fitted polynomial equations for proximate compositions of the weaning food samples

	Moisture		Crude Protein		Crude Fat		Ash		Dietary fibre		CHO	
Source	F-value	p-value	F-value	p-value	F-value	p-value	F-value	p-value	F-value	p-value	F-value	p-value
Model	63.20	< 0.0001*	7.02	0.0052*	3.11	0.0409*	3.36	0.0318*	3.29	0.0340*	63.12	<0.0001*
A-Millet	5.07	0.0591	1.74	0.2240	0.1711	0.6859	0.7377	0.4072	1.12	0.3088	0.5137	0.5005
B-Soybean	42.65	0.0003*	0.16	0.6970	1.39	0.2592	1.49	0.2450	2.80	0.1180	5.03	0.0661
C-Fishmeal	187.19	< 0.0001*	7.05	0.0290*	0.9565	0.3459	0.2901	0.6000	0.6860	0.4225	40.88	0.0007*
AB	51.73	0.0002*	3.47	0.0997	0.6702	0.4277	1.57	0.2336	2.70	0.1245	40.54	0.0007*
AC	45.84	0.0003*	5.10	0.0538	0.6578	0.4320	1.54	0.2382	2.14	0.1670	46.58	0.0005*
BC	52.24	0.0002*	0.94	0.3614	---	---	0.8788	0.3670	---	---	7.75	0.0318*
A^2	89.47	< 0.0001*	0.46	0.5190	---	---	---	---	---	---	239.95	<0.0001*
B^2	180.39	< 0.0001*	39.91	0.0002*	14.81	0.0020*	17.00	0.0014*	10.30	0.0068*	48.49	0.0004*
C^2	35.45	0.0006*	1.51	0.2536	---	---	---	---	---	---	123.34	<0.0001
ABC	88.52	< 0.0001*	1.03	0.3404	---	---	---	---	---	---	23.85	0.0028
A^2B	---	---	4.07	0.0784	---	---	---	---	---	---	43.58	0.0006
A^2C	177.22	< 0.0001*	---	---	---	---	---	---	---	---	0.0364	0.8550
AB^2	8.34	0.0234*	---	---	---	---	---	---	---	---	3.52	0.1097
R^2	0.9909		0.9061		0.5894		0.6621	---	0.6030		0.9927	
Adjusted R^2	0.9752		0.7771		0.3998		0.4650	---	0.4198		0.9770	

Mineral compositions of the formulated weaning foods. The results for the proximate compositions of the weaning foods prepared from the blends of millet, soybean, and fishmeal are presented in Tables 5a and 5b. The mineral composition of weaning foods is crucial for the growth and development of infants, including various essential minerals like magnesium (Mg), potassium (K), calcium (Ca), zinc (Zn), iron (Fe), sodium (Na), manganese (Mn), and copper (Cu) for a range of physiological processes. For example, magnesium is necessary for bone and enzyme development. The content of Mg ranged between 53.67 mg.100 g^{-1} in sample L (50M:33.41S:10F) to 88.72 mg.100 g^{-1} in sample F (60M:20S:15F), with the highest values being recorded in those formulations having greater proportion of millet and fish meal. Millet contains magnesium abundantly and fish meal increases Mg concentration since it contains bone and muscle tissues. Sample L was a soy-rich blend that reflected low magnesium reading, probably because of the interference by phytate, which reduces extractability and bioavailable minerals. Osuchukwu et al. (2018) has reported a range of 5.6 to 8.0 mg.100 g^{-1} for magnesium content in weaning foods produced from the cornstarch flour enriched with soybean flour. This thus points to the greater importance of these samples, which possessed higher Mg to positively influence bone and metabolic functions in infants.

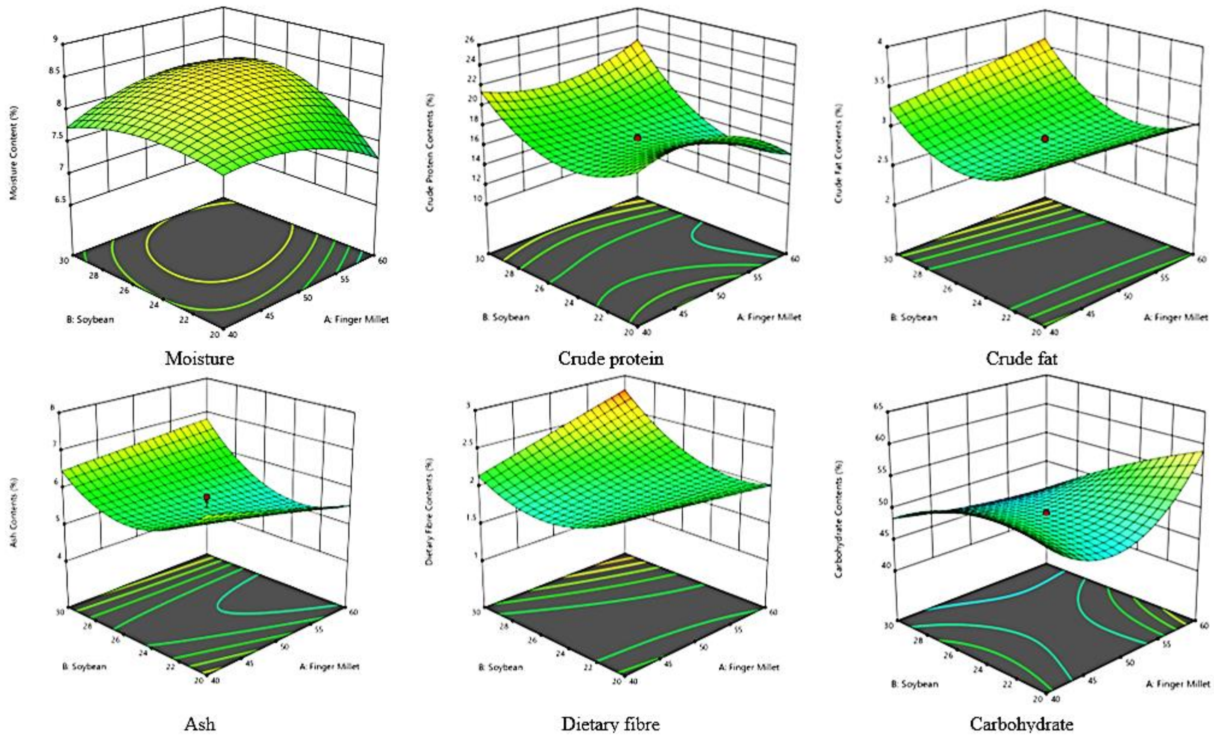

Figure 1. The combined surface and contour plot for the proximate compositions of the weaning food samples.

Potassium is necessary for the maintenance of fluid balance, muscle activity, and nerve action, with K of the samples studied varying between 313.87 mg.100 g-1(sample F) and 695.93 mg.100 g-1(sample E). Sample E (40M:20S:15F) with fish meal, millet, and soybean in significant amounts showed the highest value. However, samples with increased millet and reduced soy (e.g. sample F [(60M:20S:15F]) had a surprisingly reduced potassium, which possibly indicated the antagonism or binding impacts of phytochemicals or dilution of the formulation. As reported by Adebayo-Oyetoro et al. (2021), the potassium content of weaning foods ranges from 300 to 600 mg.100 g^{-1}. It is known that Sample E has the highest and most mineral content, possibly due to the presence of millet, soybeans, and fishmeal, providing adequate potassium levels, which is very important for the proper function of babies' muscles and nerves. Calcium plays a very significant role in the development of bones and teeth and is available at different proportions in the formulations, from 172.75 mg.100g^{-1} in sample F to 365.25 mg.100g^{-1} in sample E. According to Mario et al. (2024), the recommended calcium content of cereal-based weaning foods falls between 100 and 300 mg.100g^{-1}, providing an indication of the excellent calcium contributor that is Sample E, most likely due to the inclusion of calcium-enriched fishmeal.

Zinc is essential for immune system function and protein synthesis. Sample F had the least amount, which was 1.15 mg.100g^{-1}, and Sample E, which had the highest, of 3.54 mg.100g^{-1}. Gupta et al. (2015) reported that zinc is present in soybeans and the absorption is lower due to high contents of antinutrimental factors, including phytic acid. Also, the zinc contribution of millet was small and can be inhibitory. Therefore, zinc showed the highest value in blends in which fish meal was high and soy was not. Adebiyi et al. (2018) reported Zn in weaning foods as being from 1 to 3 mg.100g^{-1}, suggesting that Sample E may serve better than these traditional weaning foods in supporting immunity and growth. All of this gives pieces of the picture, but clearly, the Zn content of these mixtures, especially in samples E and F, indicates that they can be beneficial to babies' health in myriad ways, from forming their bones to supporting their immune systems. This makes them ideal for weaning foods. Also, the fact that the samples containing both soy and fishmeal produce a relatively high ash value indicates that the

Table 5a. Mineral compositions of the weaning foods prepared from the blends of millet, soybean, and fishmeal

Samples	Mg, mg.100 g^{-1}	K, mg.100 g^{-1}	Ca, mg.100 g^{-1}	Zn, mg.100 g^{-1}
A [40M:20S:5F]	65.06 ± 0.01^{m}	421.87 ± 0.01^{l}	231.54 ± 0.01^{h}	2.02 ± 0.02^{f}
B [60M:20S:5F]	68.79 ± 0.01^{j}	442.12 ± 0.01^{i}	243.86 ± 0.03^{gh}	2.78 ± 0.01^{e}
C [40M:30S:5F]	72.53 ± 0.03^{f}	483.66 ± 0.01^{f}	291.75 ± 0.01^{c}	2.95 ± 0.00^{c}
D [60M:30S:5F]	76.65 ± 0.01e	511.04 ± 0.01^{c}	336.01 ± 0.01^{b}	3.16 ± 0.01^{b}
E [40M:20S:15F]	84.89 ± 0.01^{b}	695.93 ± 0.00^{a}	365.25 ± 0.01^{a}	3.54 ± 0.02^{a}
F [60M:20S:15F]	88.72 ± 0.01^{a}	313.87 ± 0.01^{o}	172.75 ± 0.00^{j}	1.15 ± 0.00^{l}
G [40M:30S:15F]	83.56 ± 0.01^{c}	361.22 ± 0.01^{n}	254.66 ± 0.01^{fg}	1.67 ± 0.01^{h}
H [60M:30S:15F]	77.34 ± 0.01^{d}	437.33 ± 0.01^{j}	263.36 ± 0.01^{ef}	1.88 ± 0.01^{g}
I [33.18M:25S:10F]	71.06 ± 0.01^{h}	481.78 ± 0.01^{g}	282.73 ± 0.01^{cd}	1.33 ± 0.02^{k}
J [66.82M:25S:10F]	68.12 ± 0.01^{l}	412.62 ± 0.01^{m}	290.47 ± 0.01^{c}	1.67 ± 0.01^{h}
K [50M:16.59S:10F]	61.52 ± 0.01^{n}	511.36 ± 0.01^{b}	272.65 ± 0.01^{de}	1.43 ± 0.02^{j}
L [50M:33.41S:10F]	53.67 ± 0.02^{o}	495.35 ± 0.01^{d}	211.32 ± 0.02^{i}	1.48 ± 0.01^{i}
M [50M:25S:1.59F]	68.73 ± 0.00^{k}	492.46 ± 0.01^{e}	249.69 ± 0.01^{fg}	1.65 ± 0.02^{h}
N [50M:25S:18.41F]	69.86 ± 0.00^{i}	471.34 ± 0.00^{h}	277.22 ± 0.01^{cde}	2.77 ± 0.02^{e}
O [50M:25S:10F]	71.35 ± 0.02^{g}	426.46 ± 0.02^{k}	281.53 ± 0.02^{cd}	2.84 ± 0.02^{d}

All results are mean of triplicate readings. Any two-mean having same letters are not significantly different ($p \leq 0.05$)

Table 5b. Mineral compositions of the weaning foods prepared from the blends of millet, soybean, and fishmeal

Samples	Fe, mg.100 g-1	Na, mg.100 g-1	Mn, mg.100 g-1	Cu, mg.100 g-1
A [40M:20S:5F]	3.62 ± 0.01^{g}	43.16 ± 0.01^{m}	64.83 ± 0.01^{g}	0.37 ± 0.01^{h}
B [60M:20S:5F]	4.13 ± 0.01^{d}	46.73 ± 0.05^{k}	66.65 ± 0.01^{d}	0.42 ± 0.01^{g}
C [40M:30S:5F]	4.25 ± 0.00^{c}	53.41 ± 0.01^{j}	67.43 ± 0.01^{b}	0.46 ± 0.01^{f}
D [60M:30S:5F]	4.85 ± 0.01^{b}	53.97 ± 0.01^{i}	67.13 ± 0.01^{c}	0.64 ± 0.01^{d}
E [40M:20S:15F]	6.34 ± 0.01^{a}	78.13 ± 0.01^{a}	76.42 ± 0.01^{a}	1.93 ± 0.00^{a}
F [60M:20S:15F]	2.84 ± 0.01^{k}	44.34 ± 0.01^{l}	48.00 ± 0.00^{m}	0.37 ± 0.01^{h}
G [40M:30S:15F]	2.57 ± 0.02^{l}	44.57 ± 0.02^{l}	41.24 ± 0.02^{o}	0.47 ± 0.02^{f}
H [60M:30S:15F]	2.84 ± 0.02^{k}	58.13 ± 0.01^{h}	42.57 ± 0.02^{n}	0.44 ± 0.01^{fg}
I [33.18M:25S:10F]	3.16 ± 0.01^{j}	61.02 ± 0.02^{g}	48.46 ± 0.01^{l}	0.46 ± 0.01^{f}
J [66.82M:25S:10F]	3.63 ± 0.02^{g}	62.36 ± 0.01^{f}	56.25 ± 0.01^{h}	0.52 ± 0.01^{e}
K [50M:16.59S:10F]	3.19 ± 0.01^{ij}	68.13 ± 0.02^{b}	52.77 ± 0.01^{i}	0.52 ± 0.01^{e}
L [50M:33.41S:10F]	3.22 ± 0.01^{i}	65.04 ± 0.02^{d}	51.23 ± 0.01^{k}	0.67 ± 0.02^{d}
M [50M:25S:1.59F]	3.45 ± 0.00^{h}	64.24 ± 0.01^{e}	52.02 ± 0.02^{j}	0.75 ± 0.02^{c}
N [50M:25S:18.41F]	3.67 ± 0.01^{f}	54.12 ± 0.01^{i}	65.93 ± 0.01^{e}	0.86 ± 0.00^{b}
O [50M:25S:10F]	3.78 ± 0.01^{e}	67.46 ± 0.02^{c}	65.14 ± 0.02^{f}	0.65 ± 0.02^{d}

All results are mean of triplicate readings. Any two-mean having same letters are not significantly different ($p \leq 0.05$)

contribution of these minerals is additive possibly synergistic and especially those of calcium and zinc.

The iron content of these samples varies from 3.7 mg.100g^{-1} in Samples A (40M:20S:5F) and F (60M:20S:15F) to 19.3 mg.100g^{-1} in Sample E, and as the literature describes, complementary foods can contain 2 to 15 mg.100g^{-1} of iron (Hurrell and Egli 2010), but in this particular sample, E, the iron exceeds this range, implying it is a rich source of iron that is required for brain and hormonal development. Finally, these mineral-rich formulations, especially Sample E (40M:20S:15F), contain small-sized but significant quantities of different minerals that are crucial for supporting numerous physiological functions in infants, ensuring that these weaning foods are extremely nutritious and efficient in stimulating healthy growth and development.

Sodium (Na) is important for fluid balance and nerve function. The Na found in these samples varies from 43.16 mg.100 g^{-1} (Sample A) to 78.13 mg.100 g^{-1} (Sample E). The sodium content of weaning food met the RDA as the average was 1-2 mg.g^{-1} (Kabeer et al. 2023). These results fulfil the acceptable limits for infant foods. However, special care should be taken, and sodium should be in safe limits, as higher sodium is not good for infants. Manganese (Mn) is essential for bone formation and metabolism. The Mn content in these formulations varies from 41.24 mg (Sample G) to 76.415 mg (Sample E). Tiencheu et al. (2016) reported a typical range of 2.97 to 5.55 mg.100g^{-1} for weaning foods produced from maize, pawpaw, red beans, and mackerel fish meal blends. These results were slightly higher than those obtained for these formulations, where Sample E had a higher Mn content, which could play an important role in sustaining metabolic processes and promoting bone development in infants.

Copper, which is vital for iron metabolism and the generation of red blood cells. Sample A and Sample F have 0.37 mg.100g^{-1} Cu, while Sample E has the highest Cu content of 1.93 mg.100g^{-1}. The sample with the highest copper concentration (Sample E), may be advantageous for iron metabolism and red blood cell formation. Overall, these findings indicate that the weaning food blends have the potential to be a good source of growth and development promoting essential minerals in infants.

Overall, millet, soybean, and fishmeal together increase the mineral ingredient concentrations in weaning foods. Millet is a source of manganese, potassium, and magnesium, all of which aid in healthy bones and metabolic processes. Iron, calcium, and potassium are also amplified because of the soybeans, which act as a great addition to the essential minerals in a canine, particularly iron and calcium for their bone growth and the transfer of oxygen. When combined with fishmeal, which is rich in calcium, iron, and zinc, greater added value will be achieved, especially in Sample E, where these minerals were most abundant, preventing the appearance of deficiencies.

Model fitting and validation for mineral compositions of the formulated weaning foods. The derived predictive regression equations for the relationships between y (dependent) and X (independent) with minerals, respectively, are shown in Equations 8 to 15 for Mg, K, Ca, Zn, Fe, Na, Mn, and Cu contents. The single factor coefficients (X_1, X_2, and X_3) demonstrate the standalone effect of a given variable. On the other hand, the coefficients with two factors (X_1X_2, X_1X_3, and X_2X_3) and the coefficients with second-order terms (X_{12}, X_{22}, and X_{32}) correspond to interactions between three and quadratic impacts. Where a positive sign in front of the corresponding regression term suggests a synergetic relationship, a negative sign indicates an antagonistic relationship.

$$Mg = +70.96 + 0.04x_1 - 0.78x_2 + 3.91x_3 - 1.21x_1x_2 - 1.28x_1x_3 - 3.50x_2x_3 + 1.92x_1^2 - 2.32x_2^2 + 1.82x_3^2 \quad (8)$$

$$K = +429.34 - 27.43x_1 - 7.87x_2 - 6.29x_3 + 58.16x_1x_2 - 44.20x_1x_3 - 42.74x_2x_3 + 22.24x_2^2 + 14.65x_3^2 + 56.38x_1x_2x_3 \quad (9)$$

$$Ca = +281.31 + 2.30x_1 - 18.24x_2 + 8.18x_3 + 29.14x_1x_2 - 30.05x_1x_3 - 21.54x_2x_3 + 3.26x_1^2 - 12.52x_2^2 - 4.92x_3^2 + 21.16x_1x_2x_3 + 34.78x_1^2x_2 - 14.08x_1^2x_3 - 18.21x_1x_2^2 \quad (10)$$

$$Zn = +2.76 - 0.05x_1 + 0.02x_2 + 0.33x_3 + 0.25x_1x_2 - 0.39x_1x_3 - 0.31x_2x_3 - 0.31x_1^2 - 0.33x_2^2 + 0.39x_1x_2x_3 - 0.67x_1^2x_3 \quad (11)$$

$$Fe = +3.72 - 0.10x_1 + 0.17x_2 - 0.14x_3 + 0.48x_1x_2 - 0.54x_1x_3 - 0.64x_2x_3 + 0.46x_1x_2x_3 \quad (12)$$

$$Na = +65.89 - 1.01x_1 - 0.55x_2 + 0.80x_3 + 5.54x_1x_2 - 3.04x_1x_3 - 4.66x_2x_3 - 3.79x_1^2 - 4.68x_3^2 + 6.30x_1x_2x_3 \quad (13)$$

$$Mn = +64.13 + 2.31x_1 - 2.94x_2 + 4.14x_3 + 3.45x_1x_2 - 3.58x_1x_3 - 5.46x_2x_3 - 3.26x_1^2 - 3.39x_2^2 + 3.98x_1x_2x_3 - 11.36x_1^2x_3 - 5.51x_1x_2^2 \quad (14)$$

$$Cu = +0.65 + 0.02x_1 + 0.04x_2 + 0.03x_3 + 0.21x_1x_2 - 0.23x_1x_3 - 0.21x_2x_3 + 0.05x_1^2 - 0.02x_2^2 + 0.06x_3^2 + 0.18x_1x_2x_3 - 0.18x_1^2x_2 + 0.13x_1^2x_3 - 0.19x_1x_2^2 \quad (15)$$

The generated response surface models of the mineral content of the weaning food blends (Equations 8-15) showed the significant individual and interactive effects of millet, soybean, and fish meal. There was a pronounced positive effect of fish meal on the concentrations of various important minerals, such as Mg ($+3.91x_3$), Ca ($+8.18x_3$), Zn ($+0.33x_3$), Na ($+0.80x_3$), and Mn ($+4.14x_3$). The trend corresponds to earlier findings suggesting that a fish meal is a highly concentrated source of bioavailable minerals with a high amount of skeletal residues along with marine-sourced trace elements (Hussain et al. 2024). Soybean, despite its nutritional value, proved to behave in a more intricate way. Because its addition only raised Fe and Cu contents a little (as manifested by positive linear parameters in their related models) ($+0.17x_2$ and $+0.04x_2$), such effects may likely have been a reflection of its own unique mineral composition (Rizzo and Baroni 2018). Nonetheless, soybean also depicted great adverse effects on Mg ($-0.78x_2$), K ($-7.87x_2$) and Ca

($-18.24x_2$). It is possible to explain this inhibitory effect by the such high levels of phytic acid and the case in which it has been proven that phytic acid binds divalent minerals, proving their reduced bioavailability (Gupta et al. 2015).

Millet showed a strong influence on some minerals like Mn ($+2.31x_1$) and an insignificant impact on other minerals like Fe ($-0.10x_1$) and K ($-27.43x_1$). These findings concur with the literature findings on millet as a moderate cereal grain in respect to minerals, but which is also susceptible to interference of antinutrients (Bheemaiah Balyatanda et al. 2024). The synergistic effect, especially the three-way interaction term ($x_1x_2x_3$) was positive in K (+56.38) and Cu (+ 0.18), indicating that an optimal formulation can positively influence the mineral bioavailability. Thus, the data highlights the necessity of the precise optimization of the proportion settings in order to achieve the maximal density of minerals and reduce the loss that occurs with the opposition in interaction. The addition of fish meal seems to be especially useful to improve the micronutrient quality of the mixture, as this should be counterbalanced by the effects of phytate-high constituents such as soybean. This supports the importance of response surface methodology in the formulation of weaning foods that are nutritionally adequate and of functional quality.

The 95% confidence level was set to analyse the significance of the model using analysis of variance. The analysis of variance results is presented in Tables 6a and 6b. In the ANOVA table, the F-value is the ratio of the model mean square to the related error mean square. A greater ratio leads to a larger F-value and increases the likelihood of variance assigned by the model being significantly greater than random error (Krishna et al. 2013). It was observed from Tables 6a and 6b that the regression coefficient of the model was significant for potassium content (F-value = 51.93, p-value = 0.0001), calcium content (F-value = 92.53, p-value = 0.0001), zinc content (F-value = 3.55, p-value = 0.0348), iron content (F-value = 7.02, p-value = 0.0018), manganese content (F-value = 6.82, p-value = 0.0057), and copper content (F-value = 3130.25, p-value = 0.0001). Whereas the model was not significant for magnesium (F-value = 0.9404, p-value = 0.5321) and sodium content (F-value = 2.84, p-value = 0.0595). High F-value of the model coefficient implies that most of the variation is being explained by regression equations (Filli et al. 2013; Danbaba et al. 2015).

Additionally, the linear and square terms with an asterisk were also significant ($p < 0.05$). Thus, from the ANOVA Table, we can infer that the appropriate model satisfactorily establishes the data for mineral contents of the formulated weaning food. The model equations were assessed for their strength using the R^2 and adjusted R^2 for goodness of fit. R^2 and adjusted R^2 values of the derived model were found to be 0.8037 to 0.9999 and 0.6892 to 0.9995, respectively, suggesting homogeneity of the model equation in predicting the weaning foods mineral properties on a mathematical combination of the three processing variables. Hussein et al. (2023) reported that the closer R^2 to unity, the better the empirical model that describes the actual data, and for the regression model to fit well, R^2 must be at least 0.8. The combined surface and contour plots also demonstrate the interrelation between dependent and independent variables (Fig. 2).

Table 6a. Analysis of variance (ANOVA) for the fitted polynomial equations for mineral compositions of the weaning food samples

	Magnesium Contents		Potassium Contents		Calcium Contents		Zinc Contents	
Source	F-value	p-value	F-value	p-value	F-value	p-value	F-value	p-value
Model	0.9404	0.5321	51.93	< 0.0001*	92.53	< 0.0001*	3.55	0.0348*
A-Millet	0.0003	0.9862	46.21	< 0.0001*	1.17	0.3214	0.1312	0.7255
B-Soybean	0.1297	0.7262	3.8	0.0797	73.24	0.0001*	0.0219	0.8857
C-Fishmeal	3.3	0.0994	2.43	0.1503	14.76	0.0085*	2.79	0.1292
AB	0.1843	0.6768	121.69	< 0.0001*	264.58	< 0.0001*	2.3	0.1635
AC	0.2075	0.6585	70.27	< 0.0001*	281.25	< 0.0001*	5.5	0.0437*
BC	1.55	0.241	65.73	< 0.0001*	144.58	< 0.0001*	3.35	0.1004
A^2	0.8419	0.3805	---	---	5.95	0.0505*	6.23	0.0341*
B^2	1.23	0.2942	32.36	0.0002*	87.91	< 0.0001*	6.85	0.0279*
C^2	0.7537	0.4056	14.05	0.0038*	13.61	0.0102*	---	---
ABC	---	---	114.34	< 0.0001*	139.43	< 0.0001*	5.5	0.0437*
A^2B	---	---	---	---	156.09	< 0.0001*	---	---
A^2C	---	---	---	---	25.57	0.0023*	6.54	0.0308*
AB^2	---	---	---	---	42.76	0.0006*	---	---
R^2	0.4584		0.9791		0.9950		0.7979	
Adjusted R^2	-0.029		0.9602		0.9843		0.5734	

Table 6b. Analysis of variance (ANOVA) for the fitted polynomial equations for mineral compositions of the weaning food samples

	Iron Contents		Sodium Contents		Manganese Contents		Copper Contents	
Source	F-value	p-value	F-value	p-value	F-value	p-value	F-value	p-value
Model	7.02	0.0018*	2.84	0.0595	6.82	0.0057*	3130.25	< 0.0001*
A-Millet	0.6445	0.4377	0.2715	0.6137	1.42	0.2676	29.52	0.0016*
B-Soybean	2.04	0.1789	0.0793	0.784	5.52	0.0467*	205.16	< 0.0001*
C-Fishmeal	1.29	0.2789	0.1676	0.6909	4.53	0.0659	129.05	< 0.0001*
AB	9.16	0.0105*	4.76	0.0541*	4.47	0.0675	6803.31	< 0.0001*
AC	11.52	0.0053*	1.43	0.2586	4.79	0.06	8080.35	< 0.0001*
BC	16.11	0.0017*	3.36	0.0967	11.18	0.0102*	7049.93	< 0.0001*
A^2	---	---	4.05	0.072	7.25	0.0274*	808.42	< 0.0001*
B^2	---	---	---	---	7.82	0.0233*	76.49	0.0001*
C^2	---	---	6.16	0.0324*	---	---	938.13	< 0.0001*
ABC	8.37	0.0135*	6.14	0.0327*	5.94	0.0407*	4781.27	< 0.0001*
A^2B	---	---	---	---	---	---	2080.35	< 0.0001*
A^2C	---	---	---	---	20.04	0.0021*	1106.56	< 0.0001*
AB^2	---	---	---	---	4.71	0.0617	2215.7	< 0.0001*
R^2	0.8037		0.7190		0.9037		0.9999	
Adjusted R^2	0.6892		0.4662		0.7713		0.9995	

Plots show combinations between the two test variables (percent millet and soybean), retaining levels of the other variable fishmeal at zero. As the percentages of soybean and fishmeal increased, so did the mineral values. Compared to that, it gained with adding millet until a certain level and then dropped. The response demonstrated the importance of including both soybean and fishmeal in weaning products.

Sensory evaluation of the formulated weaning foods. Table 7 presents the sensory scores of the weaning foods produced from the blends of millet, soybean, and fishmeal. Some optimal sensory properties of developed food formulations can help us to better understand our product acceptability. It is these factors that play a pivotal role in whether the formulations will be accepted by infants/parents/carers. When it comes to weaning

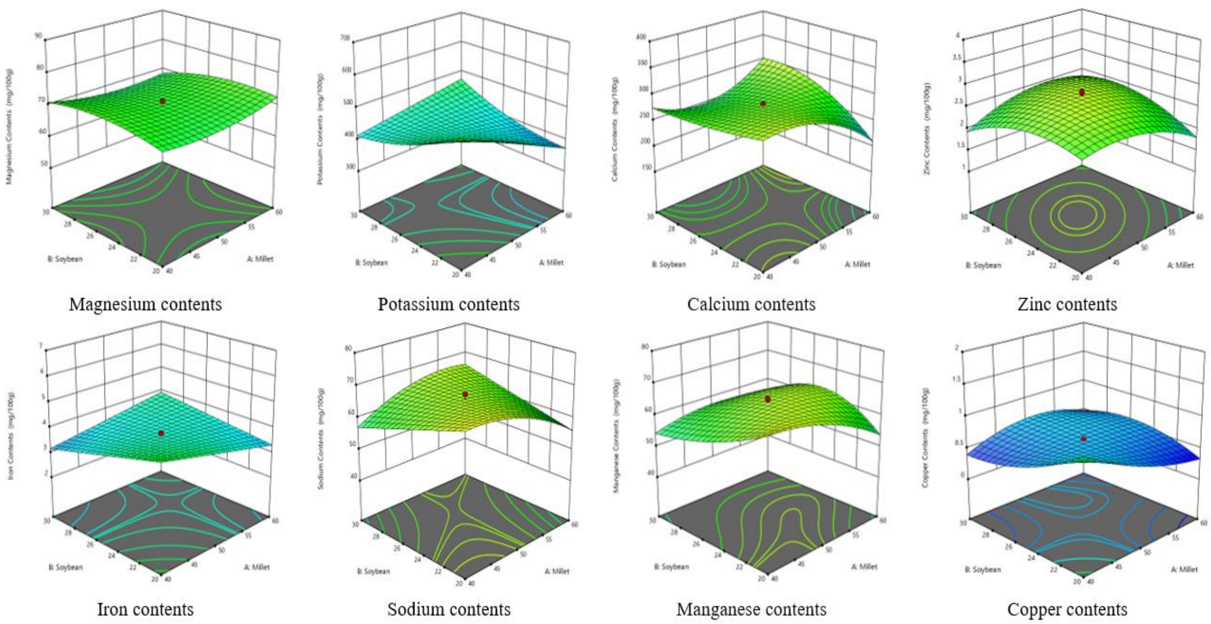

Figure 2. The combined surface and contour plot for the mineral compositions of the weaning food samples

foods, appearance is especially important, as presentation can heavily influence both what carers choose to offer and whether an infant is willing to eat. The appearance ratings ranged from 5.27 for Sample M (50M:25S:1.59F) to 6.97 for Sample O (50M:25S:10F), where the very high score of Sample O likely indicates a more visually appealing appearance. In the case of Sample M, the lowest scoring sample, its appearance may not have been as attractive, possibly due to the colour or texture issues. Msheliza et al. (2018b) reported that weaning foods that are coloured to indicate freshness or health, such as golden yellow in millet or soy-based products, tend to be preferred. These observations are consistent with these results, as the colour of Sample O is likely used to describe a more favoured colour compared to Sample K (50M:16.59S:10F), contributing to a higher appearance score.

The aroma is an important factor in food acceptability and can make a more pleasant or less pleasant impression on a meal. The aroma ratings in these weaning formulations vary from 4.8 in Sample C to 6.6 in Sample O, where the highest score, indicating a pleasant smell, is again given to Sample O, which may be attributed to a balanced montage of ingredients or aromatic compounds originating from the fishmeal or soybean. The lowest aroma score recorded was Sample C (40M:30S:5F), which may have had an unpleasant odour or low aromatic intensity. According to Oyarekua et al. (2023), the formulae used significantly affect the aroma of weaning foods, with some legume-based products presenting a stronger and less preferred aroma. These results show that Sample O was well-balanced in aroma, making said formulations more palatable. Additionally, Amankwah et al. (2009) fish meal has been shown to successfully enhance the aroma of weaning foods when used in ideal proportions; they found that fish meal improved the aroma of weaning foods when used in appropriate proportions, which may account for the higher aroma scores for fish meal-containing samples. Overall, Sample O has appealing characteristics in terms of both visual and olfactory characteristics, which, based on previous studies, may play a role in the preference of infants and carers. The nutritional composition of these formulations, along with their sensory characteristics, highlights the opportunity to create balanced weaning foods with the potential to fulfil both nutritional and sensory requirements.

Table 7. Sensory evaluation of the weaning foods prepared from the blends of millet, soybean, and fishmeal

Sample	Appearance	Aroma	Taste	Texture	Overall acceptability
A [40M:20S:5F]	5.93 ± 0.35[ab]	4.87 ± 0.39[d]	5.47 ± 0.35[a]	5.80 ± 0.41[ab]	6.30 ± 0.38[ab]
B [60M:20S:5F]	5.93 ± 0.35[ab]	5.60 ± 0.41[abcd]	5.63 ± 0.40[a]	5.40 ± 0.39[ab]	6.07 ± 0.39[ab]
C [40M:30S:5F]	6.07 ± 0.45[ab]	4.80 ± 0.37[d]	5.60 ± 0.33[a]	5.93 ± 0.31[ab]	6.23 ± 0.34[ab]
D [60M:30S:5F]	5.43 ± 0.52[b]	5.27 ± 0.35[bcd]	5.73 ± 0.43[a]	5.63 ± 0.37[ab]	5.77 ± 0.36[b]
E [40M:20S:15F]	6.00 ± 0.39[ab]	5.17 ± 0.46[cd]	5.77 ± 0.43[a]	5.43 ± 0.45[ab]	6.40 ± 0.33[ab]
F [60M:20S:15F]	5.63 ± 0.45[ab]	5.20 ± 0.44[cd]	6.17 ± 0.31[a]	5.93 ± 0.34[ab]	5.70 ± 0.40[b]
G [40M:30S:15F]	5.80 ± 0.44[ab]	5.17 ± 0.40[cd]	5.50 ± 0.36[a]	6.20 ± 0.44[ab]	6.63 ± 0.43[ab]
H [60M:30S:15F]	6.10 ± 0.47[ab]	5.37 ± 0.39[abcd]	5.97 ± 0.40[a]	5.77 ± 0.38[ab]	6.13 ± 0.40[ab]
I [33.18M:25S:10F]	6.30 ± 0.36[ab]	6.47 ± 0.26[ab]	5.93 ± 0.40[a]	5.93 ± 0.31[ab]	6.97 ± 0.23[ab]
J [66.82M:25S:10F]	6.03 ± 0.38[ab]	5.93 ± 0.34[abcd]	6.60 ± 0.33[a]	6.03 ± 0.36[ab]	6.53 ± 0.41[ab]
K [50M:16.59S:10F]	5.90 ± 0.51[ab]	6.30 ± 0.37[abc]	6.23 ± 0.42[a]	5.90 ± 0.41[ab]	6.37 ± 0.42[ab]
L [50M:33.41S:10F]	5.47 ± 0.50[b]	5.90 ± 0.39[abcd]	6.03 ± 0.39[a]	6.07 ± 0.36[ab]	5.90 ± 0.49[b]
M [50M:25S:1.59F]	5.27 ± 0.47[b]	5.14 ± 0.41[cd]	6.33 ± 0.43[a]	5.00 ± 0.46[b]	5.67 ± 0.41[b]
N [50M:25S:18.41F]	5.87 ± 0.37[ab]	5.73 ± 0.42[abcd]	5.97 ± 0.37[a]	5.60 ± 0.38[ab]	5.97 ± 0.40[b]
O [50M:25S:10F]	6.97 ± 0.37[a]	6.60 ± 0.38[a]	6.23 ± 0.31[a]	6.53 ± 0.34[a]	7.30 ± 0.34[a]

All results are mean of triplicate readings. Any two-mean having same letters are not significantly different ($p \leq 0.05$)

Taste may be the most important sensory property with a direct effect on food acceptance by the infant. For these formulations, the lowest taste score was observed at Sample A at 5.47 and the highest taste score in Sample J at 6.60. The highest taste score observed at Sample J indicates that Sample J had a delightful flavour profile owing to a good balance of ingredients. In contrast, Sample A, which scored lowest, might have had a less satisfactory taste, perhaps due to one particular ingredient overpowering or an imbalance in taste. Balasubramanian et al. (2014) reported that fats and proteins in weaning foods often improve taste acceptability, causing a fuller taste. This corresponds with these results, as higher-scoring samples for taste may have contributed to a balanced taste, potentially as a result of the presence of soybean and fishmeal, providing umami tastes and fat. More palatable millet-based complementary foods for infants can be developed by adding fishmeal to the mixture in proportion to millet and soybean, which could be the reason for the highest score for Sample J.

Texture is crucial in weaning foods, as it affects how easily the baby eats and the overall mouthfeel. The texture scores range from 5.00 in Sample M to 6.53 in Sample O. Sample O, having the highest texture score, suggests that this formulation has a somewhat smooth and consistent texture, facilitating easier consumption for infants. Sample M, having the least texture score, on the other hand, may show some better texture also but may not be good for the mouthfeel, possibly due to coarseness or non-homogeneous mixing. According to Adepeju et al. (2011), the texture of weaning foods should be smooth without any lumps to facilitate swallowing by infants. Additionally, these results propose that ideally, Sample O would have reached such a texture that is most suitable. Higher texture scores suggest that the formulation, especially in Sample O, was processed to a fine and smooth mass, which is critical for infant foods.

Overall acceptability is a composite score that combines the joint effect of appearance, aroma, taste, and texture on the perception of food quality. These samples had overall acceptability scores ranging from 5.67 for Sample M to 7.30 for Sample O, the most preferred of the three and highest in overall acceptability, all attributable to high scores across all sensory attributes evaluated. On the other hand, sample M, which presented the lowest general acceptability, could undergo reformulation or alteration in order to enhance its sensory characteristics. Balasubramanian et al. (2014) and Msheliza et al. (2018b) reported that the overall acceptability of weaning foods is highly correlated with taste and texture, and typically well-accepted foods score highly in these parameters. Sample O achieved the highest overall score, lending credence to this idea, since a well-balanced combination of flavours, smooth texture, and appealing appearance results in a product more likely to be accepted by both infants and carers. In addition, the sample with the best sensory attribute is sample O, in which all sensory attributes are balanced, thus showing the common concept of good weaning food formulations without extensive bitter or pungent attributes.

Conclusion

Weaning foods were successfully developed and evaluated from composite blends of millet, soybean, and fishmeal, illustrating their potential nutrient density, sensory characteristics, and their acceptance and appeal as a complementary infant food. It was shown in the analysis that:

- Optimal blends, particularly the 50M:25S:10F formulation, achieved high protein, mineral density, and sensory appeal, meeting essential dietary requirements.
- Ingredient interactions significantly influenced moisture retention, nutrient bioavailability, and organoleptic properties. Fishmeal consistently enhanced mineral content, especially Ca, Zn, and Fe, while millet and soybean contributed dietary fibre, Mg, and texture.
- Sensory evaluation by semi-trained nursing mothers showed general acceptability across formulations, with the blend containing 50% millet, 25% soybean, and 10% fish meal receiving the highest scores in appearance, taste, texture, and overall acceptability.
- The use of RSM facilitated the identification of optimal ingredient ratios to maximise nutritional content without compromising sensory attributes. The RSM also confirmed significant effects of component proportions, which demonstrated the practical utility of RSM in refining formulation parameters.

Despite improved gene profiles, long-term studies on their impact on infant health and growth still need to be performed. Further investigation should take place to scale up the production of these weaning foods to determine their viability in mass production. Carers and parents should also be educated on the advantages of the use of available ingredients such as millet, soybean, and fishmeal in the production of weaning foods.

Acknowledgements

The authors express gratitude for the postdoctoral fellowship awarded to Dr. J.B. Hussein by the College of Agriculture, Engineering, and Sciences at the University of KwaZulu-Natal, South Africa.

Author Contributions

Conceptualization, N.M., J.B., S.D. and T.S.; methodology, N.M. and J.B.; formal analysis N.M. and J.B.; investigation, N.M., J.B., S.D. and T.S.; resources, S.D. and T.S.; data curation, N.M., J.B., S.D. and T.S.; writing - original draft preparation, N.M. and J.B.; writing – N.M., J.B., S.D. and T.S., review and editing, J.B., S.D., and T.S., visualization, S.D. and T.S.; supervision, J.B., S.D. and T.S.; project administration, J.B., S.D. and T.S.; funding acquisition, S.D. and T.S. All authors have read and agreed to the published version of the manuscript.

Funding

Not applicable.

Institutional Review Board Statement

Ethical approval was obtained from the Institutional Review Board of Modibbo Adama University, Yola, Nigeria.

Informed Consent Statement

Informed consent was obtained from all participants prior to inclusion in the study.

Data Availability Statement

All data associated with this study are reported in the manuscript and no other data are deposited in any public or closed database.

Conflicts of Interest

The authors declare no conflicts of interest.

References

Abimbola, O.G., Lamidi, B.O., Oyetunji, K.O., Adedoyin, B.A., Bamidele, K.F., Abimbola, K.O., Folagboye, E.A., Ogunremi, O.R., Adeyemo, S.M.. Assessment of the nutritional quality of weaning food prepared from fermented blends of sorghum (ogi) and soybean. *GSC Biological and Pharmaceutical Sciences*, 2024, 27(02), 001-012. https://doi.org/10.30574/gscbps.2024.27.2.0142

Achidi, A.U., Tiencheu, B., Tenyang, N., Womeni, H.M., Moyeh, M.N., Ebini, L.T., Tatsinkou, F.B. Quality evaluation of nine instant weaning foods formulated from cereal, legume, tuber, vegetable and crayfish. *International Journal of Food Science and Nutrition Engineering*, 2016, 6(2), 21-31. https://doi.org/10.5923/j.food.20160602.01

Adebayo-Oyetoro, A.O., Adeyeye, S.A.O., Olatidoye, O.P., Ogundipe, O.O., Adenekan, O.E. Effect of co-fermentation on the quality attributes of weaning food produced from sorghum (sorghum bicolor) and pigeon pea (cajanus cajan). *Journal of Culinary Science & Technology*, 2019, 17(2), 1405860. https://doi.org/10.1080/15428052.2017.1405860

Adebayo-Oyetoro, A.O., Olatidoye, O.P., Bamikole, T. J., Igene, C.O., Coker, O.J. Quality characteristics of complementary food from locally fermented maize flour blended with sprouted velvet bean (mucuna utilis) flour in nigeria. *European Journal of Nutrition and Food Safety*, 2021, 13(1), 79-92. https://doi.org/10.9734/ejnfs/2021/v13i130351

Adebiyi, J.A., Obadina, A.O., Adebo, O.A., Kayitesi, E. Fermented and malted millet products in Africa: Expedition from traditional/ethnic foods to industrial value-added products. *Critical Review in Food Science and Nutrition*, 2018, 58(3), 463-474. https://doi.org/10.1080/10408398.2016.1188056

Adedeji, E.O., Jegede, E.D., Abdulsalam, K.O., Umeobia, U.E., Ajayi, A.O., Iboyi, J.E. Effect of processing treatments on the proximate, functional and sensory properties of soy-sorghum-roselle complementary food. *British Journal of Applied Science and Technology*, 2015, 6(6), 635-643. https://doi.org/10.9734/BJAST/2015/14707

Adegunwa, M.O., Adebowale, A.A., Bakare, H. A., Kalejaiye, K.K. Effects of treatments on the antinutritional factors and functional properties of bambara groundnut (*Voandzeia subterranea*) flour. *Journal of Food Processing and Preservation*, 2014, 38(4), 1875-1881. https://doi.org/10.1111/jfpp.12159

Adepeju, A.B., Gbadamosi, S.O., Adeniran, A. H., Omobuwajo, T.O. Functional and pasting characteristics of breadfruit (*Artocarpus altilis*) flours. *African Journal of Food Science*, 2011, 5(9), 529-535. https://doi.org/10.5897/AJFS.9000143

Agostoni, C., Riva, E., Giovannini, M. Dietary fiber in weaning foods of young children. *Pediatrics*, 1995, 96(2), 1002-1005. https://doi.org/10.1542/peds.96.5.1002

Alawode, E.K., Idowu, M.A., Adeola, A.A., Oke, E.K., Omoniyi, S.A. Some quality attributes of complementary food produced from flour blends of orange flesh sweet potato, sorghum, and soybean. *Croatian Journal of Food Science and Technology*, 2017, 9(2), 122-129. https://doi.org/10.17508/cjfst.2017.9.2.06

Amankwah, E.A., Barimah, A.K.M., Nuamah, J. H., Oldman, W., Nmaji, C.O. Formulation of weaning food from fermented maize rice, soybeans and fish meal. *Pakistan Journal of Nutrition*, 2009, 8(11), 1747-1752. https://doi.org/10.3923/pjn.2009.1747.1752

Anigo, K.M., Ameh, D.A., Ibrahim, S., Danbauchi, S.S. Nutrient composition of complementary food gruels formulated from malted cereals, soybeans and groundnut for use in North-Western Nigeria. *African Journal of Food Science*, 2010, 4(3), 65-72. https://doi.org/10.5897/AJFS.9000200

AOAC. *Official method of analysis of aoac international* 2016, (20th ed.). Association of Official Analytical Chemist. https://www.aoac.org/official-methods-of-analysis/

AOAC. *Official methods of analysis of aoac international* 2020 (20th ed.). Association of Official Methods of Analysis. https://www.aoac.org/official-methods-of-analysis/

Asma, M.A., Elfalil, E.B., Eltinay, A.H. Development of weaning food from sorghum supplemented with leagues and oil seeds. *Food and Nutrition Bulletin*, 2006, 27(1), 26-34. https://doi.org/10.1177/156482650602700104

Badau, M.H., Jideani, I.A., Nkama, I.. Production, acceptability and microbiological evaluation of weaning food formulations. *Journal of Tropical Pediatrics*, 2005, 52(3), 166-172. https://doi.org/10.1093/tropej/fmi079

Balasubramanian, S., Kaur, J., Singh, D. Optimization of weaning mix based on malted and extruded pearl millet and barley. *Journal of Food Science and Technology*, 2014, 51(4), 682-690. https://doi.org/10.1007/s13197-011-0579-6

Bheemaiah Balyatanda, S., Gowda, N.A.N., Subbiah, J., Chakraborty, S., Prasad, P. V.V., Siliveru, K. Physiochemical, bio, thermal, and non-thermal processing of major and minor millets: A comprehensive review on antinutritional and antioxidant properties. *Foods*, 2024, 13(22), 13223684 . https://doi.org/10.3390/foods13223684

Danbaba, N., Nkama, I., Badau, M.H. Application of response surface methodology (RSM) and central composite design (CCD) to optimize minerals composition of rice-cowpea composite blends during extrusion cooking. *International Journal of Food Science and Nutrition Engineering*, 2015, 5(1), 40-52. https://doi.org/10.5923/j.food.20150501.06

Eshun, G., Baffour, N.K., Ackah, P.Y. Nutrient content and sensory acceptability of a wearing diet formulated from mixtures of soya bean, groundnut and rice. *African Journal of Food Science*, 2011, 5(17), 870-877. https://doi.org/10.5897/AJFS11.121

Filli, K.B., Nkama, I., Jideani, V.A., Abubakar, U.M. Application of response surface methodology for the evaluation of proximate composition and functionality of millet-soybean fura extrudates. *Wudpecker Journal of Food Technology*, 2013, 1(5), 074-092. Available at: https://wudpeckerresearchjournals.org/WJFT/pdf/2013/August/Filli et al.pdf

Gupta, R.K., Gangoliya, S.S., Singh, N.K. Reduction of phytic acid and enhancement of bioavailable micronutrients in food grains. *Journal of Food Science and Technology*, 2015, 52(2), 676-684. https://doi.org/10.1007/s13197-013-0978-y

Hurrell, R., Egli, I. Iron bioavailability and dietary reference values. *The American Journal of Clinical Nutrition*, 2010, 91(5), 1461S-1467S. https://doi.org/org/10.3945/ajcn.2010.28674F

Hussain, S.M., Bano, A.A., Ali, S., Rizwan, M., Adrees, M., Zahoor, A.F., Sarker, P.K., Hussain, M., Arsalan, M.Z., Yong, J.W. H., Naeem, A. Substitution of fishmeal: Highlights of potential plant protein sources for aquaculture sustainability. *Heliyon*, 2024, 10(4), e26573. https://doi.org/10.1016/j.heliyon.2024.e26573

Hussein, J.B., Oke, M.O., Adeyanju, J.A., Sanusi, M.S. Modeling drying kinetics of tomato slices under convective hot-air using artificial neural network (ANN) and adaptive neuro-fuzzy inference system (ANFIS) models. *Agricultural Engineering International: CIGR Journal*, 2023, 25(2), 263-284. Available at: https://cigrjournal.org/index.php/Ejounral/article/view/8421/4061

Hussein, J.B., Usman, M.A., Filli, K.B. Effect of hybrid solar drying method on the functional and sensory properties of tomato. *American Journal of Food Science and Technology*, 2016, 4(5), 141-148. https://doi.org/10.12691/ajfst-4-5-4

Iwe, M.O. Some Sensory Methods and Data Analysis. In *Handbook of Sensory Methods and Analysis* (Second Edition). Rojoint Communication Services LTD. 2010, pp. 80-85. Print ISBN: 978-32124-8-6

Jin, Z., Bai, F., Chen, Y., Bai, B.. Interactions between protein, lipid and starch in foxtail millet flour affect the in vitro digestion of starch. *CyTA - Journal of Food*, 2019, 17(1), 640-647. https://doi.org/10.1080/19476337.2019.1628107

Kabeer, S., Govindarajan, N., Radhakrishnan, P., Alharbi, H.F., Essa, M.M., Qoronfleh, M.W. Formulation of fortified instant weaning food from *Musa paradisiaca* (banana) and *Eleusine coracana*. *Frontiers in Nutrition*, 2023, 10(6), 1203955. https://doi.org/10.3389/fnut.2023.1203955

Krishna, D., Krishna, K.S., Sree, R.P. Response surface modeling and optimization of chromium (vi) removal from aqueous solution using Borasus flabellifer coir powder. *International Journal of Applied Science and Engineering*, 2013, 11(2), 213-226. Available at: https://ir.lib.cyut.edu.tw/retrieve/31154/6_ACB-1211-001.pdf

Lanzkowsky, P. Problems in diagnosis of iron deficiency anemia. *Pediatric Annals*, 2013, 14(9), 618-636. https://doi.org/10.3928/0090-4481-19850901-07

Malomo, A.A., Abiose, S.H. Protein quality and functional properties of masa produced from maize, acha and soybean. *Food Research*, 2019, 3(5), 556-563. https://doi.org/10.26656/fr.2017.3(5).223

Mario, E., Belay, A., Amare, E. Evaluation of the quality and safety of commercial complementary foods: Implications for nutrient adequacy and conformance with national and international standards. *PLoS ONE*, 2024, 19(2), e0294068. https://doi.org/org/10.1371/journal.pone.0294068

Mohammed, Z.K., Petrol, B.B., Ahmad, U. Formulation and nutritional evaluation of a complementary food blend made from fermented yellow maize (improved variety), soybean and african cat fish meal. *Nigerian Journal of Biotechnology*, 2021, 38(1), 98-108. https://doi.org/10.4314/njb.v38i1.12

Msheliza, E.A., Hussein, J.B., Ilesanmi, J.O.Y., Nkama, I. Effect of fermentation and roasting on the physicochemical properties of weaning food produced from blends of sorghum and soybean. *Journal of Nutrition and Food Sciences*, 2018a, 8(2), 681. https://doi.org/10.4172/2155-9600.1000681

Msheliza, E.A., Ilesanmi, J.O.Y., Hussein, J.B., Nkama, I. Effect of pretreatments on the microbial and sensory quality of weaning food produced from blends of sorghum and soybean. *African Journal of Food Science*, 2018b, 12(12), 353-359. https://doi.org/10.5897/AJFS2018.1691

Muhimbula, H.S., Issa-Zadana, A., Kinabo, J. Formulation and sensory evaluation of complementary foods from local, cheap and readily available cereals and leagues in iringa, tanzania. *African Journal of Food Science*, 2011, 5(1), 26-31. https://doi.org/10.5897/AJFS.9000142

Nkama, I., Dagwanna, F.N., Ndahi, W.B. Production, proximate composition and consumer of weaning foods from mixtures of pearl millet, cowpea and groundnut. *Journal of Arid Agriculture*, 2001, 11(1), 165-169.

Nwakalor, C.N., Obi, C.D. Formulation and sensory evaluation of sorghum-based weaning foods fortified with soybean and unripe plantain flours. *International Journal of Nutrition and Food Sciences*, 2014, 3(5), 387-390. https://doi.org/10.11648/j.ijnfs.20140305.14

Okoye, J.I., Egbujie, A.E., Ene, G.I. Evaluation of complementary foods produced from sorghum, soybean and irish potato composite flours. *Science World Journal*, 2021, 16(3), 206-211. Available at: https://www.ajol.info/index.php/swj/article/view/221727

Okoye, J.I., Ene, G.I. Evaluation of nutritional and organoleptic properties of maize-based complementary foods supplemented with black bean and crayfish flours. *Global Advanced Research Journal of Food Science and* , 2018, 6(1), 001-009. Available at: https://garj.org/articles/8816501610072018

Osuchukwu, C.O., Abiodun, I.K., Obijuru, N. T., Ikonne, P., Ukachi, C.I., Osuchukwu, A.A. Comparative study of the nutritional and sensory qualities of a traditional and a commercial weaning food. *International Journal of Interdisciplinary Research and Innovations*, 2018, 6(4), 108-112. Available at: https://www.researchpublish.com/papers/comparative-study-of-the-nutritional-and-sensory-qualities-of-a-traditional-and-a-commercial-weaning-food

Oyarekua, M.A., Oni, K.O., Sanni, T.A. Evaluation of nutrition properties of co-fermented maize/ carrot/pigeon pea and millet/ sweet potato/ pigeon pea as infant complementary food. *African Journal of Agriculture and Food Science*, 2023, 6(1), 1-16. https://doi.org/10.52589/AJAFS-VOIPEQFJ

Rizzo, G., Baroni, L. Soy, soy foods and their role in vegetarian diets. *Nutrients*, 2018, 10(1), 43. https://doi.org/10.3390/nu10010043

Tiencheu, B., Achidi, A.U., Fossi, B.T., Tenyang, T., Ngongang, E. F. T., Womeni, H.M. Formulation and nutritional evaluation of instant weaning foods processed from maize (*Zea mays*), pawpaw (*Carica papaya*), red beans (*Phaseolus vulgaris*) and mackerel fish meal (scomber scombrus). *American Journal of Food Science and Technology*, 2016, 4(2), 149-159. https://doi.org/10.12691/ajfst-4-5-5

Tomar, M., Bhardwaj, R., Verma, R., Singh, S. P., dahuja, A., Krishnan, V., Kansal, R., Yadav, V. K., Praveen, S., Sachdev, A. Interactome of millet-based food matrices: A review. *Food Chemistry*, 2022, 385(8), 132636. https://doi.org/10.1016/j.foodchem.2022.132636

Usman, M.A., Bolade, M.K., Hussein, J.B. Selected anti-nutritional factors and in-vitro protein digestibility of some sorghum types as influenced by germination time during malting. *International Journal of Food Science and Biotechnology*, 2018, 3(2), 40-45. https://doi.org/10.11648/j.ijfsb.20180302.11

Ween, O., Stangeland, J.K., Fylling, T.S., Aas, G.H. Nutritional and functional properties of fishmeal produced from fresh by-products of cod (*Gadus morhua* L.) and saithe (*Pollachius virens*). *Heliyon*, 2017, 3(7), e00343. https://doi.org/10.1016/j.heliyon.2017.e00343