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Formulation and Nutritional Analysis of Processed Sorghum, Soybeans, and Mango Complementary Foods

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Abstract

Malnutrition is a major threat to infant health and development in sub-Saharan Africa. With increasing costs in commercial complementary foods, infants in rural communities are often fed with unprocessed nutrient-deficient family staple foods. The aim of this study was to formulate complementary diets from locally cultivated sorghum, soybeans, and mangoes using soaking, toasting, germination, and fermentation processes. Through mass balance, eight formulations were developed, where a Codex Alimentarius recommendation of ≤5.5g protein content per 100kcal of cereals-added high-protein complementary foods was considered. Our results showed that the nutritional compositions of the formulated diets ranged from 4.64-6.44% moisture content, 1.04-1.70% ash content, 10.73-20.02% crude protein, 68.07-80.76% total carbohydrate, 0.07-3.44% crude fat, 1.35-3.40% crude fibre, 364.63-462.80kcal energy, 120.9-131.2mg/100g calcium and 1.02-6.99µg/mg vitamin A. Soaking significantly increased the nutritional value of soybeans and sorghum, and was further increased with subsequent toasting, germination, or fermentation. The functional properties of all formulations were within acceptable limits for complementary feeding as the formulations were less bulky and could easily be cooked into gruels. In addition, trained breastfeeding mothers, who served as sensory panelists, rated the overall acceptability between 7 (like moderately) and 8 (like very much) on the hedonic scale. The formulations did not differ in acceptability in terms of taste, colour, flavour, and smoothness, and those containing toasted soybean flour were rated highest for colour and flavour. This research indicated that nutrient-rich food formulations from locally acquired low-cost sorghum, soybeans, and mangoes could be used extensively in the treatment of child malnutrition in Africa.

Keywords: child malnutrition, complementary foods, food formulation, processing techniques, soaking, toasting, fermentation, germination

1. Introduction

Complementary feeding is defined as the process of starting other foods and liquids, when breast milk is no longer sufficient to meet the nutritional requirements of growing infants (WHO, 2009). It is recommended between 6-24months of age, when the mouth, nerves and muscles have sufficiently developed, allowing infants to munch, bite and chew (WHO, 2000; WHO, 2009). Complementary foods should contain balanced mixtures of foods and provide approximately 25-50% of protein, copper, and riboflavin, 50-75% of thiamine, calcium and manganese, and 75-100% of phosphorus, zinc, and iron (Abeshu et al., 2016; Dop et al., 1999; Gibson et al., 1998; Oladiran & Emmambux, 2020). In developing countries, especially in Africa, poor complementary feeding practices are widespread (Dop et al., 1999; Gibson et al., 1998; Oladiran & Emmambux, 2020; WHO, 2009). Child malnutrition, including kwashiorkor, marasmus, and marasmic-kwashiorkor is the single largest killer of children under the age of five years (Temba et al., 2016; UNICEF, 2021). In sub-Saharan Africa, where 11% of the world's children live, stunting affects 29 million children per year (UNICEF, 2021). The Sahel region is now home to more than 60% of wasted children with over 15% in some areas within the region (UNICEF, 2021).

Even though commercial complementary foods are available, most of them are priced beyond the reach of many households, particularly in sub-Saharan Africa (Kulkarni et al., 1991). Infants are fed with locally grown staple foods such as cereals, roots, and tubers (Oladiran & Emmambux, 2020; Temba et al., 2016; WHO, 2000). These staple foods are high in energy density, are bulky, and often lack proteins, vitamins, and minerals (Kulkarni et al., 1991; Oladiran & Emmambux, 2020; Temba et al., 2016). For example, pap, a popular thin gruel made from maize, contains low amounts of the essential amino acid lysine and tryptophan (Oladiran & Emmambux, 2020). Previous research has reported consequent products produced from a combination of cereals and legumes possessed superior nutritional and calorific values than those produced from either cereals or legumes (Codex, 2013; Kulkarni et al., 1991; Temba et al., 2016). Legumes and pulses are very rich plant-based proteins with higher levels of lysine; a limiting essential amino acid in cereal foods (Siulapwa & Mwambungu, 2014).

However, unprocessed cereals, legumes and pulses contain antinutrients (phytates, tannins or other phenolic materials, lectins, trypsin, and chymotrypsin inhibitors) that lower protein quality, digestibility, amino acid bioavailability, and mineral absorption in infants (Abah et al., 2020; Barman et al., 2018; Codex Alimentarius, 2013; WHO, 2000). The processing of cereals and legumes will reduce and/or eliminate antinutrients and improve nutrient availability to infants (Codex Alimentarius, 2019). For example, soaking and germination of cereals and legumes could reduce or eliminate trypsin inhibitor activity and flatulence-causing oligosaccharides (stachyose and raffinose), thus increasing protein digestibility and improving sensory properties (El-safy et al., 2013). Toasting or dry heating improves digestibility and reduces the bulkiness of formulated foods (Codex Alimentarius, 2013).

With this, there is a need for: 1) low-cost, more nutritious complementary foods which can be prepared easily in homes from locally available raw materials, and 2) simple and inexpensive processing procedures that are within the reach of rural populations. The purpose of this research was to develop nutrient-rich complementary food formulations using processed sorghum, soybeans, and mangoes. To improve nutrient availability in sorghum, soybeans and mango, this study employed simple and efficient food processing techniques of soaking, toasting, fermentation, and germination in the formulation of sorghum, soybeans, and mango complementary foods.

2. Materials and Methods

2.1 Testing of Seed Viability

The study was conducted using two seeds: yellow sorghum (*Sorghum bicolor*, cultivar: Safrari), and soybeans (*Glycine max*, cultivar: M5), which were obtained from the Institute of Agricultural Research for Development (IRAD), Garoua, Cameroon. The germination rates of both seeds were evaluated as described by Matthews and Holding (2005). Here, one hundred seeds were randomly collected and placed in rows of ten on 500mm thick of clean sand. A pencil was used to gently push each seed underneath the sand. Seeds were sown at 20^0C for 7days and watered twice daily. The number of seedlings on day 7 was counted and the mean of three experimental replicates was recorded as the percentage of germination. The percentage of germination is the ratio of germinated seeds to total seeds (that is, 100) times 100 (Matthews & Holding, 2005). In this research, the germination percentages for sorghum and soybean grains were 95% and 93%, respectively.

2.2 Processing of Sorghum Flours

Two types of sorghum flour were produced: soaked sorghum flour (SSM) and germinated sorghum flour (GSM). Sorghum grains were manually sorted for soil and splits. The grains were washed with running water which flushed any bacterial and fungal spores that could be present in the seeds (Luna et al., 2014). As described by El-safy et al. (2013), the seeds were soaked (1part of the seeds with 10 parts of water) for 24h until hydration. Hydration conditions were checked according to Luna et al. (2014). Initially, seeds were soaked, and periodically every 48 h, 2g was sampled and allowed to dry. The seeds were then continuously weighed until no substantial increase in weight during the additional 24-hour soaking time was observed. Thus, this indicated that the seeds had sufficiently absorb water and were fully hydrated (Luna et al., 2014).

In the production of sorghum flours, soaked sorghum seeds were separated into two portions (I and II). Portion I was oven-dried at 55-60^0C for 24h, milled, sieved with an ASTM E11 400 µm stainless steel sieve, and then packaged to obtain SSM. Portion II was spread in a seed germination cabinet (BioChambers, Canada) and germinated at 25 ± 2^0C for 72h with watering twice a day. Then it was oven dried at 55-60^0C for 24h. A soft abrasion was used between the palms to separate the sprouts from the dried sorghum grains. The dried grains were then milled, sieved, and packaged to obtain GSM.

2.3 Processing of Soybean Flours

Soybeans were processed into four flours: soaked soybean flour (SSF), toasted soybean flour (TSF), germinated soybean flour (GSF) and fermented soybean flour (FSF). Using the same procedure as for the soaking of sorghum, soaked soybean was obtained as described by El-safy et al. (2013). Soaked seeds were manually dehulled to reduce and/or eliminate fiber and antinutritional contents (Codex Alimentarius, 2013). Dehulled grains were then separated into four portions (I, II, III, and IV). Portion I was oven dried at 55-60^{0}C for 24h, milled, sieved with a 400μm sieve, and then packaged to obtain SSF. As described by Krička et al. (2003), portion II was oven dried at 55-60^{0}C for 24h and then toasted at 135^{0}C for 15mins in a fan-assisted 60cm pyrolytic oven (Miele, Germany). The toasted seeds were brought to room temperature for 30 mins, milled, sieved, and packaged to obtain TSF.

Portion III was fermented according to Kiers et al. (2000) in two steps. Firstly, to kill bacteria that could affect the fermentation process, the dehulled soybeans were cooked at 65-70^{0}C for 20 mins and then autoclaved in a glass jar at 121^{0}C for 15 mins. The beans were then allowed to cool to room temperature. Secondly, in the ratio 1g of soybeans:1ml bacterial culture (approximately 10^6 CFU/ml), sterilized soybeans were mixed with *Bacillus subtilis* ATCC 6051 and fermented at 37^{0}C for 48h in a lab mechanical stirring glass fermenter (toptionLab, China). Fermented soybeans were subsequently oven dried at 55-60^{0}C for 24h, milled, sieved with a 400μm sieve, and then packaged to obtain FSF. Portion IV was processed using the same processing steps for germinated sorghum, as described above, to obtain GSF.

2.4 Processing of Mango Fruits into Mango Powder

Ripe mangoes (*Mangifera indica*, cultivar: Kent) were locally purchased from roadside vendors in Ngaoundere, Cameroon. The freshly harvested mango fruits were physically sorted for skin defects and discoloration. The mangoes were then manually washed with running water. The skin and stones of the mangoes were peeled and discarded. Fruits were thinly sliced, spread on a tray in a DT6000 food lab electronic dehydrator (Sunbeam, USA) and oven dried at 50±2^{0}C, as described by Mwamba et al. (2017). When dried, mango flakes were milled, sieved, and packaged to obtain mango powder (MP).

2.5 Formulation of Complementary Foods

Table 1 presents eight formulations developed in this study. Each complementary food was formulated based on mass balance as described by Bello et al. (2020). The proportion of each processed flour in the different formulations was calculated based on their improved nutritional compositions in Table 2. As stated by the Codex Alimentarius standard for processed cereal-based foods for infants and children, the composition of this research formulations was estimated by considering that the protein content of cereals with added high-protein foods should not exceed 5.5g/100kcal (Codex Alimentarius, 2013). This is a protein intake recommendation for infants and young children between 6-24months of age (Codex Alimentarius, 2013).

Table 1. Combination of different processed flours into complementary foods

Formula	**Processed flours (%)**						
	SSM	**GSM**	**SSF**	**TSF**	**GSF**	**FSF**	**MP**
F1	43.03	-	35.42	-	-	-	21.55
F2	69.65	-	-	20.23	-	-	10.12
F3	53.94	-	-	-	28.89	-	17.16
F4	62.72	-	-	-	-	19.15	18.13
F5	-	46.75	38.77	-	-	-	14.48
F6	-	64.45	-	25.76	-	-	9.79
F7	-	72.36	-	-	23.65	-	4.03
F8	-	65.92	-	-	-	21.67	12.42

Note. F1:soaked sorghum-soaked soybeans-mangoes, F2:soaked sorghum-toasted soybeans-mangoes, F3:soaked sorghum-germinated soybeans-mangoes, F4:soaked sorghum-fermented soybeans-mangoes, F5:germinated sorghum-soaked soybeans-mangoes, F6:germinated sorghum-toasted soybeans-mangoes, F7:germinated sorghum-germinated soybeans-mangoes and F8:germinated sorghum-fermented soybeans-mangoes, SSM: soaked sorghum flour, GSM: germinated sorghum flour, SSF: soaked soybean flour, TST: toasted soybean flour, GSF: germinated soybean flour, FSF: fermented soybean flour, MP: mango powder

Table 2. Nutritional composition of the processed flours

	Moisture %	**Ash %**	**Protein %**	**Carbohydrate %**	**Fats %**	**Crude fibre %**	**Energy kcal/g**
SSM	4.78±0.49 ^{a}	0.23±0.26 ^{a}	9.89±0.64 ^{a}	78.61±0.79 ^{a}	4.69±1.40 ^{a}	1.80±1.98 ^{a}	396.21±0.94 ^{a}
GSM	2.99±0.53 ^{b}	0.45±0.09 ^{a}	11.91±0.40 ^{b}	78.21±0.59 ^{a}	5.92±0.72 ^{a}	0.52±1.84 ^{b}	413.76±0.57 ^{b}
SSF	2.88±0.05^b	1.14±0.47 ^{b}	38.69±0.03 ^{c}	33.46±0.23 ^{b}	21.93±0.12 ^{b}	1.90±0.99 ^{a}	485.97±0.13 ^{c}
TSF	3.10±0.33 ^{b}	0.86±0.28 ^{c}	44.08±0.23 ^{d}	23.03±0.48 ^{c}	27.93±0.81 ^{c}	1.00±0.04 ^{b}	519.81±0.51 ^{d}
GSF	4.88±0.27 ^{a}	0.57±0.46 ^{c}	48.61±1.86 ^{e}	18.47±0.32 ^{d}	26.27±0.42 ^{c}	1.20±1.98 ^{c}	504.75±0.87 ^{f}
FSF	2.49±0.54 ^{b}	1.16±0.89 ^{b}	48.54±1.83 ^{ef}	21.74±0.74 ^{f}	24.67±1.01 ^{d}	1.40±0.14 ^{b}	503.15±1.19 ^{f}
MP	0.99±0.04^c	2.40±0.06^d	2.23±0.19^g	91.30±0.04^g	0.19±0.04^e	2.89±0. 31^c	375.83±0.40^e

Note. SSM:soaked sorghum flour, GSM:germinated sorghum flour, SSF:soaked soybean flour, TST:toasted soybean flour, GSF: germinated soybean flour, FSF:fermented soybean flour, MP:mango powder. Means with different superscripts within the same column are significantly different at $p < 0.05$

2.6 Analysis of Nutritional Composition

The moisture, ash, protein, crude fibre, and fat contents of the processed and formulated flours were determined using the methods of AOAC (AOAC, 2010). Calcium and vitamin A contents were determined according to AOAC (AOAC, 2012). All reagents for chemical analyses were obtained from Foss Food Technology Corporation (NZ).

Moisture content was determined by oven dry method. 5g of each sample (M1) was weighed into a pre-weighed crucible (M2) and placed in a hot-air oven (Stanhope-Seta, UK) at 105^0C for 24h. The crucible was cooled to room temperature in a desiccator (Stanhope-Seta, UK), and then weighed (M3). The moisture content was obtained by the loss in weight (M1-M3) divided by the final weight (M3-M2) multiplied by 100.

Total ash was the residue after complete oxidation. 10g of each sample (M4) following moisture lose (M1-M3, as mentioned-above) was weighed into a preweighed porcelain crucible (M5). The crucible was placed in a muffle furnace (Stanhope-Seta, UK) and maintained at 550^0C for 24h. It was then transferred to a desiccator (Stanhope-Seta, UK), cooled, and reweighed (M6). The ash content was obtained by the residue after calcination (M6-M5) divided by the initial weight (M4-M5) multiplied by 100. The residues were then used for the determination of the calcium content in the sample.

Calcium content was obtained by changing the pH of the medium and subsequent precipitation of calcium oxalate. 10g of ash residues were dissolved in 2.5ml HCL and evaporated in a water bath till dryness. 2ml of HCL was then added, heated for 5mins, filtered with Whatman N^o 1 filter, and diluted with 75ml of distilled water. 2-3drops of dibromcresol green indicator was added followed by titration with Sodium acetate until a blue coloration was attained. Calcium oxalate was precipitated with sufficient oxalic acid solution, observed by a colour change from green to yellow. The solution was allowed to clear overnight, filtered, and 9ml of ammonium hydroxide was continually added till a blue coloration was obtained. 5ml of distilled water and 2.5ml of H_2SO_4 was then added. The precipitate was heated to 80^0C and titrated with 0.05N $KMnO_4$ until a faint pink end point. 1mg calcium corresponded to the titrated 1ml 0.05N $KMnO_4$.

Protein content was determined by the Kjeldahl method through mineralization and spectrophotometry. 15ml of concentrated H_2SO_4 and a pinch of mineralization catalyst was added in a glass test tube containing 1g of the sample. This was heated to 350^0C and maintained at this temperature for 6h. After cooling, the mineralized sample (colorless) was poured in a graduated flask and completed to the 50ml mark with distilled water. Readings were conducted at 412nm through spectrophotometry (Table 3). The quantity of nitrogen in the sample (q) was obtained from the regression equation, where Absorbance = q(concentration) + constant. Crude protein was determined by multiplying the quantity of nitrogen in the sample with the conversion coefficient (6.25).

Table 3. Spectroscopic measurements of the protein content

	Standard curve							**Sample**
	T1	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**TS**
Sample (ml)	--	--	--	--	--	--	--	0.1
Standard solution (ml)	0	0.25	0.5	0.75	1	1.25	1.5	--
Sodium acetate (ml)	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Acetylacetone	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
Distilled water (ml)	7.2	6.95	6.7	6.45	6.2	5.95	5.7	7.1
Quantity of Nitrogen (q)	0	10	20	30	40	50	60	--

Note. T= number of standard tubes (1 to 7), TS: tube containing the sample, prior to the addition of distilled water in table 3, tubes were heated in a water bath (97 ± 2^0C) for 15mins and then cooled for 30mins.

Crude fibre was the insoluble carbohydrate measured after hydrolysis. 5ml of 0.255N H_2SO_4 was added in a beaker containing 5g of the sample (M). The mixture was placed in a water bath at 98 ± 2^0C for 30mins. It was then filtered using Whatman filter paper N^o 1 and the filtrate was discarded. 5ml of 0.313N NaOH was added in a test tube containing the residue. The mixture was then set to boil at 98 ± 2^0C for 30mins, cooled, filtered, rinsed 3times with distilled water and twice with acetone. The filtrate was discarded, and the residue was dried at 105^0C for 8h in a hot-air oven (Stanhope-Seta, UK). The dried residue was weighed (M1), calcinated at 550^0C for 3h, cooled and weighed (M2). Crude fibre was calculated from MI-M2 divided by M multiplied by 100.

Fat content was determined by Soxhlet solvent extraction. 5g of previously oven-dried (105 ℃ for 24h) sample (W1) was placed in a preweighed filter paper (W) and transferred into a Soxhlet extractor (Thermo Fisher Scientific, USA). Using hexane, extraction was conducted at a condensation rate of 1-2 drops/sec for 8h. The filter paper containing the sample was dried at 105^0C for 24h and weighed (W2). The fat content was obtained from (W1-W2) divided by (W1-W) multiplied by 100.

Carbohydrate content was obtained by difference, that is, % carbohydrate = 100 - % protein + %fat + %crude fibre + %ash + %moisture. The energy values were calculated by multiplying the crude protein, fat, and carbohydrate values by their physiological fuel values of 4, 9, and 4 respectively.

Vitamin A content was determined using High Performance Liquid Chromatography (HPLC) (Column: length 250 mm, ID 4.6 mm, mobile phase: methanol and water (770 + 30 v/v), stationary phase: octadea (C_{18}) groups bonded to silica). 0.1g of the sample was saponified in 200ml of 95% ethanol, 2ml of sodium ascorbate (dissolved 100g/l in water) and 50 ml of potassium hydroxide (dissolved 500g/l in water). Vitamin A was then extracted into 125ml of light petroleum (40-60 ℃). Excess petroleum was removed by evaporation under vacuum at 40^0C and the residue was dissolved in 2-propanol. 10 µl of the extract was injected into the HPLC column and the aqueous phase was extracted with 80ml of liquid petroleum. Vitamin A content in the sample was determined by dividing the retinol concentration (Absorbance at 325nm x 183 IU/ml) of the extract with the mass (g) of the sample multiplied by 20 000 (where 1IU of vitamin A = 0.300 µg of all-trans-retinol).

2.7 Analysis of Functional Properties

The functional properties (that is, bulk density, water absorption capacity (WAC), swelling capacity), of the formulated flours were determined as described by Appiah et al. (2011). Dispersibility was measured based on Kulkarni et al. (1991).

Bulk density: 50g of each formulation was placed in a 100ml graduated cylinder and gently tapped to a constant volume. The bulk density was calculated by the ratio of the weight (g) of each flour to the volume (ml) of the flour in the cylinder.

Water absorption capacity: 1g of each formulation was mixed with 10ml of distilled water in a pre-weighed 20ml centrifuge tube. The paste-like suspension was vortexed for 2mins, allowed to stand at 28^0C for 30 mins, and then centrifuged at 8000rpm for 15mins. The clear supernatant was discarded and the centrifuge tube containing the paste was reweighed and recorded as the amount of water absorbed per gram of flour. The volume of water absorbed (total volume of tube - free volume of tube) was multiplied by the density of the sample to convert into grams (Bello et al., 2020). WAC (g/g) was calculated as grams of water absorbed per gram of each formula.

Swelling capacity:1g of each formulation was mixed with 10ml of distilled water in a centrifuge tube and heated at 80 ℃ for 30mins in a precision shaking water bath (Thomas Scientific, USA). After heating, the suspension was centrifuged at 8000rpm for 20mins. The supernatant was decanted, and the weight of the paste was recorded. The swelling capacity (g/g) was calculated as a ratio of the weight of the paste to the weight of the formula.

Finally, dispersibility was measured by placing 10g of each formulation in a 100ml measuring cylinder. Distilled water was added up to the 100ml mark and stirred vigorously. The suspension was then allowed to settle for 3h. Dispersibility (%) was calculated by subtracting the volume of settled particles from 100.

2.8 Sensory Evaluation of Prepared Gruels

Complementary food formulations were coded: F1, F2, F3, F4, F5, F6, F7 and F8. Formulas were prepared according to the nutritional guidelines of the World Food Programme for processed foods aged 6-23 months (WFP, 2018). The preparation guidance included a 'rule of thumb' where, 50g of the formulated flour was cooked in 250ml of water, which corresponded to 0.8kcal/g of energy (WFP, 2018). Infant gruels were served warm to semi-trained sensory panelists who consisted of twenty breastfeeding mothers. Formulations were evaluated using a nine-point hedonic scale ranging from 1 = Dislike extremely to 9 = Like extremely. Panelists rated the colour, taste, flavour, smoothness, and overall acceptability of all eight formulations. Using yes or no responses, panelists were also asked if they will feed their babies with each formulated diet in case the raw materials and processing methods were revealed to them.

2.9 Statistical Analysis

All experiments were conducted in three replicates and analyzed using Statistical Package for Social Sciences (SPSS, Version 26). The results were expressed as mean ± standard deviation and the differences in means were determined using Analysis of variance (ANOVA). Significance was tested at the 5% probability level. Specific differences between pairs of means were measured using Duncan's multiple-range test.

3. Results and Discussion

3.1 Nutritional Composition of the Formulations

Table 4 presents the nutritional composition of eight complementary food formulations, that is, F1:soaked sorghum-soaked soybeans-mangoes, F2:soaked sorghum-toasted soybeans-mangoes, F3:soaked sorghum-germinated soybeans-mangoes, F4:soaked sorghum-fermented soybeans-mangoes, F5:germinated sorghum-soaked soybeans-mangoes, F6:germinated sorghum-toasted soybeans-mangoes, F7:germinated sorghum-germinated soybeans-mangoes and F8:germinated sorghum-fermented soybeans-mangoes.

Sorghum is a main cereal for more than 750 million people living in semi-arid tropical regions of Africa, Asia, and Latin America. It is the fifth most important cereal crop in the world after rice, wheat, corn, and barley. Sorghum Safrari grains contain 12.4% moisture, 74.3% total starch, 9.7% total protein and 0.907g/cm^3 bulk density (Nso et al., 2003).

Soybeans are commonly consumed because of their favourable agronomic characteristics, relatively low prices, high-quality proteins (39-41%) and oils (18-21%) (Barman et al., 2018; Krička et al., 2003; Siulapwa et al., 2014). There are very similar to proteins of animal origin in terms of digestibility and amino acid composition. Soybeans are deficient in sulphur amino acids (cysteine and methionine) and very rich in lysine; a limiting essential amino acid in sorghum (Codex Alimentarius, 2013).

Mangoes are abundantly available in the tropical regions of Africa and contain 10-32% carbohydrates, 0-5% proteins, 0.75-1.7% lipids, flavonoids, carotenoids, organic acids, minerals and vitamins (Maldonado-Celis et al., 2019). They contain vital amino acids such as lysine, alanine, arginine, glycine, serine, leucine, isoleucine, phenylalanine, and methionine (Maldonado-Celis et al., 2019). Maldonado-Celis et al. (2019) further reported that the edible portion of mango fruit contain 50 µg/100g of vitamin A, and the consumption of a single mango fruit (approximately 300g) will supply 15-69 retinol equivalents per day.

The moisture content of the formulated complementary foods ranged from 4.64-6.44% with F4 recording the lowest and F7 recording the highest. F7 was significantly ($p<0.05$) different from all formulations. All moisture contents were within the acceptable limit of less than 10% for produced flours (Onimawo & Akubor, 2012), and all were less than 7.60%; a moisture content value previously reported by Yusufu et al. (2013). A low moisture content of less than 7% in these research formulations will enhance stability during long-term storage by preventing the growth of moulds and subsequent biochemical reactions.

The ash content ranged from 1.04% (F3) to 1.70% (F4). Apart from F3 with the lowest ash content of 1.04%, all formulations did not differ significantly ($p <0.05$) from each other. These values were all lower than those reported by Okoye et al. (2021) and Yusufu et al. (2013). The ash content is an indication of the mineral content of a food. This therefore suggests that all formulations could be important sources of minerals. For example, the calcium values recorded in this research ranged from 120.9mg/100g (F6) to 131.2mg/100g (F1). F2, F3, F4, and F7 were not significantly ($p <0.05$) different from each other. F1 and F5 were also significantly indifferent. These calcium values were higher than those reported by Gibson et al. (1998). Adequate intake of calcium will ensure optimal bone/tissue growth and development in infants (Abeshu et al., 2016).

Vitamin A content ranged from 6.99 µg/100mg (F1) to 1.02 µg/100mg (F7). These values were higher than those recorded by Yusufu et al. (2013) and Bello et al. (2020) but closer to the findings of Okoye et al. (2021). It was observed that the higher the amount of mango powder (MP) in each formulation (for example, 21.5% of MP in F1), the higher the vitamin A content in the formulated diets. It should be noted that F7, with the lowest vitamin A, contained only 4.0% MP. Although well-nourished breastfed infants require approximately zero (0 µg) of vitamin A from complementary foods (Abeshu et al., 2016), the WHO and UNICEF recommend vitamin A supplementation as a priority for 6months infants in countries with high-risk deficiencies (WHO, 2009). Unfortunately, as part of the immediate consequences of the COVID-19 pandemic, increased pressure on health-care facilities has delay the routine provision of these key micronutrients (vitamin A, iron and folic acid) to infants (UNICEF, 2021). During this COVID-19 era, initiating the consumption of complementary food formulations from this study will contribute significantly to vitamin A intake, especially for infants in Africa.

The protein content of the formulated diets ranged from 10.73% (F1) to 20.02% (F8). F8, which contained germinated sorghum and fermented soybeans, had the highest protein value (20.02%) while F1, which contained soaked sorghum and soaked soybeans, had the lowest protein value (10.73%). F3 and F7 as well as F1, F2, and F5 were not significantly ($p<0.05$) different from each other. F6 was on average different from all formulations. It was observed that the protein content increased when soaked sorghum or soybean seeds were further germinated or fermented. Bello et al. (2020) observed a similar increase from non-malted sorghum (10.45% of protein) to malted sorghum (12.13% of protein). Soaking initiates water penetration, which reduces phytic acid, and releases enzyme inhibitors that are further digested during germination or fermentation. These processes increase the availability of nutrients in cereals and legumes (El-safy et al., 2013). The protein values in all formulated diets were not different from those recorded by Yusufu et al. (2013) and Okoye et al. (2021), but were lower than the recommended range for complementary foods, that is, 21% at 6-8 months, 42% at 9-11 months and 57% at 12-23 months (Abeshu et al., 2016; Dop et al., 1999). Moreover, these protein contents indicate a daily consumption of different proportions of the formulated diets simultaneously with breast milk could solve protein-energy malnutrition in rural communities.

Carbohydrate content of the formulations varied from 68.07% (F8) to 80.76% (F1). The results showed that all formulations were significantly ($p < 0.05$) different from each other. Although similar results have been reported by Yusufu et al. (2013), Gibson et al. (1998) reported far lower carbohydrates values in various complementary foods consumed in developing countries. Starch is a major constituent of many formulated complementary foods and should be provided in its digestible forms that include simple sugars (Abeshu et al., 2016; Codex Alimentarius, 2013). Thus, the processing techniques applied in this study could be used to break down complex starch into simple sugars, an easily digestible constituent in the diets of infants.

Fat content ranged from 0.07% (F6) to 3.44% (F8). Apart from F6, formulations F2, F3, and F7 did not differ significantly ($p < 0.05$) from each other. F4 and F8 were also indifferent. These values are in agreement with Gibson et al. (1998) and Yusufu et al. (2013). Dietary fat is a source of energy and essential fatty acids in infant diets. The recommended intake in complementary foods increases from 0% at 6-8 months to 5-8% at 9-11 months, and then 15-20% at 12-23 months (Abeshu et al., 2016). As such, the presence of fat in this research formulated diets could meet the energy needs of a growing breast-fed child.

Crude fibre ranged from 1.35% (F1) to 3.40% (F2) which was within acceptable limits, that is, ≤5g/100g in complementary foods (Codex Alimentarius, 2013). Fibre contents of F2 (3.40%) and F4 (3.10%) were closer to 3.27%, as reported by Okoye et al. (2021), and F1, F5, F6 and F8 were closer to the findings of Yusufu et al. (2013). Dietary fibres are undesirable in complementary foods as they cause flatulence, decrease appetite in infants and increase stool bulkiness (Codex Alimetarius, 2013).

Finally, complementary foods are expected to have the required energy density to meet the growing needs of an infant (Abeshu et al., 2016). Energy density is the number of kilocalories of energy per gram in a food (Dop et al., 1999). In this study, the energy content ranged from 364.63kcal (F6) to 462.80kcal (F1). Apart from F2 and F3 which did not differ from each other at 370kcal, the formulated diets were significantly ($p < 0.05$) different from each other. Our results were within the World Health Organization's recommended range of 200 kcal/day at 6-8 months, 300kcal/day at 9-11 months and 500kcal/day at 12-23 months (Abeshu et al., 2016; Dop et al., 1999). Although other factors such as, the energy gap of an infant, the number of meals per day, and an infant's gastric capacity could influence the overall required energy density (Abeshu et al., 2016), this research energy values showed that all formulations are suitable for complementary feeding.

Table 4. Nutritional composition of complementary food formulations

Formula	Moisture %	Ash %	Protein %	Carbohydrate %	Fats %	Crude fibre %	Energy kcal	Calcium mg/100g	Vitamin A µg/mg
F1	4.83 ± 0.27^{a}	1.69 ± 0.37^{a}	10.73 ± 0.34^{a}	80.76 ± 0.51^{a}	0.64 ± 0.76^{a}	1.35 ± 1.49^{a}	462.80 ± 0.54^{a}	131.2 ± 0.90^{a}	6.99 ± 0.06^{a}
F2	4.94 ± 0.41^{a}	1.55 ± 0.27^{a}	12.49 ± 0.44^{b}	75.65 ± 0.64^{b}	1.97 ± 1.11^{b}	3.40 ± 1.98^{bd}	370.29 ± 0.73^{b}	125.9 ± 0.84^{b}	3.69 ± 0.35^{b}
F3	5.83 ± 0.38^{b}	1.04 ± 0.36^{b}	18.37 ± 1.25^{c}	71.62 ± 0.56^{c}	1.14 ± 0.91^{b}	2.00 ± 1.98^{b}	370.22 ± 0.91^{b}	123.4 ± 1.68^{bc}	4.32 ± 0.37^{c}
F4	4.64 ± 0.52^{a}	1.70 ± 0.58^{a}	16.44 ± 1.24^{cd}	70.78 ± 0.77^{c}	3.34 ± 1.21^{c}	3.10 ± 1.06^{bd}	378.94 ± 1.07^{c}	127.1 ± 0.34^{d}	5.52 ± 0.71^{d}
F5	5.44 ± 0.29^{ab}	1.62 ± 0.28^{ac}	12.4 ± 0.22^{eb}	77.62 ± 0.41^{d}	1.07 ± 0.42^{d}	1.85 ± 1.42^{bc}	369.71 ± 0.35^{d}	130.7 ± 0.88^{a}	1.29 ± 0.82^{f}
F6	5.55 ± 0.43^{ab}	1.48 ± 0.19^{a}	13.20 ± 0.32^{fb}	77.80 ± 0.54^{d}	0.07 ± 0.77^{f}	1.90 ± 1.84^{bc}	364.63 ± 0.54^{e}	120.9 ± 1.75^{e}	1.16 ± 0.22^{g}
F7	6.44 ± 0.40^{c}	1.34 ± 0.27^{a}	19.37 ± 1.13^{gc}	69.11 ± 0.46^{f}	1.24 ± 0.57^{b}	2.50 ± 1.91^{b}	365.08 ± 0.72^{f}	126.2 ± 1.72^{bd}	1.02 ± 0.08^{h}
F8	5.24 ± 0.54^{ab}	1.63 ± 0.49^{ac}	20.02 ± 1.12^{fg}	68.07 ± 0.67^{fg}	3.44 ± 0.86^{c}	1.60 ± 0.99^{a}	383.32 ± 0.88^{g}	123.3 ± 0.38^{bf}	3.55 ± 0.06^{b}

Note. F1:soaked sorghum-soaked soybeans-mangoes, F2:soaked sorghum-toasted soybeans-mangoes, F3:soaked sorghum-germinated soybeans-mangoes, F4:soaked sorghum-fermented soybeans-mangoes, F5:germinated sorghum-soaked soybeans-mangoes, F6:germinated sorghum-toasted soybeans-mangoes, F7:germinated sorghum-germinated soybeans-mangoes and F8:germinated sorghum-fermented soybeans-mangoes. Values are mean ± stander deviation of three replications. Means with different superscripts within the same column are significantly different at $p < 0.05$

3.2 Functional Properties of the Formulations

Table 5 presents the function properties of the formulated diets. The swelling capacity of the different formulations ranged from 0.93-0.98g/g. F1, with the highest swelling capacity (0.98g/g), contained soaked sorghum and soaked soybean flours. F3 and F7, both containing germinated soybean flour, had the same swelling capacity of 0.93g/g. F4 and F8, containing fermented soybean flour had a 0.96g/g swelling capacity. Swelling capacity is the ability of flours to absorb moisture from their surroundings. It depends on the size of the particles, the types of flour variety, and the processing methods or unit operations.

Water absorption capacity ranged from 1.08g/g (F6) to 1.85g/g (F4). These results are in agreement with Bello et al. (2020). Formulated diets containing germinated sorghum, germinated soybean or fermented soybean had higher WAC than formulations from the flours of soaked sorghum and soybean seeds. An increase in water absorption capacity in the formulated diets could be due to an increase in soluble sugars and proteins, which enables the binding of water and fats in the processed flours (Bello et al., 2020; Yusufu et al., 2013). High values of WAC implies that all formulations will readily absorb water and gelatinize during reconstitution or cooking.

The bulk density of the formulated diets ranged from 0.51-0.60g/ml. The results obtained were higher than the findings of Yusufu et al. (2013), but lower than those reported by Bello et al. (2020). Bulk density measures the weight per unit volume occupied by a given product. The higher the fibre content, the bulkier the product and the higher the protein content, the lesser the bulk density (Codex Alimentarius, 2013). The formulations in this study were very rich in protein and very low in fibre, which explains the low weight to volume ratio. These results indicate that the formulations are very suitable for complementary feeding.

The dispersibility of the formulations ranged from 70.6% (F6) to 75.1% (F4). F1 and F6 did not differ significantly ($p< 0.05$) from each other at 70%. Similar results have been reported by Kulkarni et al. (1991). The dispersibility of flour is an index of the ease of reconstitution when mixed with water. Therefore, the higher dispersibility of 70-75% observed in this research showed that our formulated diets could be easily cooked into gruels.

Table 5. Functional properties of complementary food formulations

Formula	Swelling capacity g/g	WAC (g/g)	Bulk Density (g/ml)	Dispersibility (%)
F1	0.98 ± 0.01^{a}	1.54 ± 0.30^{a}	0.52 ± 0.04^{a}	70.9 ± 0.06^{a}
F 2	0.94 ± 0.02^{b}	1.17 ± 0.02^{b}	0.52 ± 0.05^{a}	72.2 ± 0.01^{b}
F 3	0.93 ± 0.02^{c}	1.75 ± 0.05^{c}	0.51 ± 0.01^{b}	71.5 ± 0.03^{c}
F 4	0.96 ± 0.01^{d}	1.85 ± 0.31^{d}	0.60 ± 0.04^{c}	75.1 ± 0.04^{d}
F 5	0.97 ± 0.01^{e}	1.45 ± 0.36^{a}	0.52 ± 0.04^{a}	71.2 ± 0.01^{e}
F 6	0.94 ± 0.01^{b}	1.08 ± 0.04^{e}	0.51 ± 0.04^{b}	70.6 ± 0.02^{a}
F 7	0.93 ± 0.02^{c}	1.66 ± 0.10^{c}	0.53 ± 0.04^{d}	74.4 ± 0.01^{f}
F 8	0.96 ± 0.02^{d}	1.76 ± 0.36^{ac}	0.60 ± 0.04^{c}	72.8 ± 0.04^{g}

F1: soaked sorghum-soaked soybeans-mangoes, F2:soaked sorghum-toasted soybeans-mangoes, F3:soaked sorghum-germinated soybeans-mangoes, F4:soaked sorghum-fermented soybeans-mangoes, F5:germinated sorghum-soaked soybeans-mangoes, F6:germinated sorghum-toasted soybeans-mangoes, F7:germinated sorghum-germinated soybeans-mangoes and F8:germinated sorghum-fermented soybeans-mangoes. Values are mean ± standard deviation of three replications. Means with different superscripts within the same column are significantly different at $p <0.05$

3.3 Sensory Attributes of the Formulations

In Table 6, F6 was rated highest (8.73) for flavour as opposed to F1 and F4 who were rated lowest at 6.03. Although all formulations were within acceptable limits for taste and smoothness, F3 was rated the highest in taste and F7 the highest in smoothness. Taste could be attributed to the presence of simple sugars arising from the processed seeds and mango powder. In addition, formulated diets containing toasted soybeans (F2 and F6) were rated highest for colour and flavour. The appreciation of colour and flavour by the panelists showed the major role played by toasting in improving the colour, taste, shelf-life, and flavour of foods (Navicha et al., 2018; Shin et al., 2013). Finally, all formulations were within overall acceptability between 7 (like moderately) and 8 (like very much) on the hedonic scale. Thus, it indicates that this research formulated diets could be used confidently in complementary feeding as they met the 'targeted' sensory qualities of breastfeeding mothers.

Table 6. Sensory evaluation of formulated gruels

Formula	Colour	Taste	Flavour	Smoothness	Overall acceptability
F1	7.03 ± 0.08^{a}	7.11 ± 0.02^{a}	6.03 ± 1.10^{a}	7.42 ± 0.99^{ad}	7.41 ± 0.04^{a}
F2	8.34 ± 0.66^{b}	7.22 ± 0.25^{a}	7.13 ± 0.88^{a}	7.51 ± 0.97^{b}	8.63 ± 0.01^{b}
F3	7.58 ± 0.25^{c}	7.90 ± 0.28^{b}	7.29 ± 0.92^{b}	8.03 ± 0.98^{c}	7.63 ± 0.74^{c}
F4	7.35 ± 0.04^{d}	7.68 ± 1.28^{c}	6.03 ± 0.98^{a}	7.13 ± 0.06^{a}	7.53 ± 0.42^{c}
F5	7.82 ± 0.01^{e}	7.49 ± 0.27^{d}	7.38 ± 0.45^{b}	8.57 ± 0.09^{c}	7.85 ± 0.65^{c}
F6	8.93 ± 0.08^{f}	6.99 ± 0.55^{e}	8.73 ± 0.05^{c}	7.69 ± 0.07^{ad}	7.36 ± 0.06^{d}
F7	7.10 ± 0.05^{g}	7.57 ± 0.18^{c}	7.43 ± 0.06^{a}	7.58 ± 0.48^{e}	7.25 ± 1.28^{b}
F8	7.50 ± 0.12^{c}	6.89 ± 0.38^{e}	7.96 ± 0.01^{b}	7.20 ± 0.54^{f}	7.61 ± 0.03^{c}

F1:soaked sorghum-soaked soybeans-mangoes, F2:soaked sorghum-toasted soybeans-mangoes, F3:soaked sorghum-germinated soybeans-mangoes, F4:soaked sorghum-fermented soybeans-mangoes, F5:germinated sorghum-soaked soybeans-mangoes, F6:germinated sorghum-toasted soybeans-mangoes, F7:germinated sorghum-germinated soybeans-mangoes and F8:germinated sorghum-fermented soybeans-mangoes. Values are mean ± standard deviation of three repeated sensory sessions. Means with different superscripts within the same column are significantly different at $p < 0.05$

4. Conclusion

This study formulated complementary diets using processed sorghum, soybeans, and mangoes. With Formula 6 (germinated sorghum-toasted soybeans-mangoes) rated as the most desirable, the results showed that inexpensive processing techniques of soaking, toasting, germination, and fermentation could improve the nutritional, functional, and sensory properties of complementary foods. Therefore, readily available, and affordable sorghum, soybeans, and mangoes could significantly reduce or eliminate protein-energy malnutrition among infants in rural and urban communities, especially in Africa

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