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Healthy food design and early childhood nutrition: nutritional and food safety assessment of fermented and malted multi-grains ınstant weaning porridge fortified with defatted pumpkin (*Cucurbita pepo*) seed flour

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ABSTRACT

Poor-quality diets are one of the most significant barriers to children's survival, growth, development, and learning today. In the context of this experiment, weaning porridge from complementary flour blends of locally available foodstuffs (millet, sorghum, green beans, and pumpkin seeds) was formulated for nutritional, functional, microbiological, and sensory acceptability. The results outlined that all the developed weaning porridge complied with the energy and nutrient density (zinc, iron, and protein) criteria. Energy (2.06-2.08 Kcal/g), protein (4.09-5.44% g/100 Kcal), iron (3.96-4.59 mg/100 Kcal), and calcium (0.39-1.37 mg/100 Kcal) were the nutrient density values identified. The functional features revealed an excellent reconstitution index (5.25-4.53) with a significant difference ($P<0.05$), a swelling index ranging from 1.03% to 0.57%, and a viscosity ranging from 195.5 cp to 204.5 cp. This study provides valuable insight that complementary foods made from locally available foods are potential solutions for mitigating childhood malnutrition and providing adequate complementation to breastfeeding in resource-poor and technologically underdeveloped countries by providing the needed energy and nutrient densities for immunity, well-being, growth, and development of young children and infants without fortification.

1. Introduction

Between birth and age two, a child's body undergoes immense changes; during this time, their brain grows to 75% of adult size and creates approximately 1 million neuronal connections each second (WHO, 2015; Center on the Developing Child, 2007). Furthermore, their bodily w eight quadruples and their height extends by 75%. Given these significant changes, it is critical that children under the age of two obtain sufficient nutrition (UNICEF, 2021). They require more nutrients per kilogram of body weight than at any other period in their lives (Dewey, 2013). Children who do not receive appropriate nutrition are more likely to suffer from malnutrition, which includes stunting, wasting, micro-nutrient deficiencies, obesity, and being overweight (UNICEF, 2021). Poor diets have particularly severe implications during the first two years of life, as low nutritional intake can in the long-term

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affect a child's physical and cognitive development (UNICEF, 2021). On the other hand, the consumption of adequate nutrition at the right times can result in superior health outcomes and support their ability to thrive even in adverse conditions such as disease, disaster, or crisis (Swart et al., 2020; UNICEF, 2020). During the first six months of life, breast milk provides the best nutrients for infants. Following this period, children should get complementary foods appropriate to their development stage until they can consume family food (Swart et al., 2020).

Global efforts to achieve the global maternal, infant, and young child nutrition targets for stunting, wasting, low birth weight, anemia, and childhood obesity are falling short (Global Nutrition Report, 2021). "Children living in food poverty may only consume a few spoonful of porridge and a small cup of rice each day, which is not enough for proper nutrition," according to Catherine Russell (Executive Director, UNICEF). Children cannot survive solely on staple cereals; they must consume a variety of healthy foods, including fruits, vegetables, fish, eggs, and dairy products, to maintain their expanding brains and bodies. Nonetheless, two-thirds of children under the age of five in low- and middle-income nations are food insecure and do not obtain a broad diet of nutritional foods (UNICEF, 2022).

This malnutrition has resulted in 149.2 million stunted children, 45.4 million wasting children, and 38.9 million overweight children globally (Global Nutrition Report, 2021). Poor diets are the root cause of all types of malnutrition, yet global targets do not particularly address this issue, nor do they address micro-nutrient deficiencies. Poor diet-related fatalities have grown by 15% since 2010, accounting for nearly 12 million noncommunicable disease deaths in adults (Global Nutrition Report, 2021). Major causes of malnutrition in young children around the world such as inequality, globalization, urbanization, violence, and the socioeconomic expenses of the COVID-19 pandemic are all factors beyond the control of individual families, yet families are largely left with bearing the repercussions (UNICEF, 2022).

Despite considerable scientific evidence and international attempts to change early-life eating patterns, malnutrition remains a severe concern to the health of children worldwide. The world's population is expected to increase from 7.7 billion to around 10 billion by 2050 (United Nations in 2021). Most of the rise is projected in areas where malnutrition is rampant and nutritious meals are prohibitively expensive. A lack of sufficient nutritional interventions will almost certainly lead to a reduction in child health, resulting in less healthy future generations. As a result, to ensure a healthy future for people and the planet, inadequate diets and malnutrition must be addressed in a sustainable manner. This study is based on the assumption that sustainable healthy food design can help improve kid nutrition, particularly in the developing, world.

Breast milk alone is no longer adequate to support a developing infant's nutritional needs after six months; other meals and liquids, or complementary foods, should be provided instead (Pan American Health Organization, 2001; World Health Organization, 1998; Kung'u et al., 2009). However, empirical data shows that the introduction of complementary foods in environments with limited resources can lead to diets that are unsafe micro-biologically and nutritionally, which can result in multiple nutrient deficiencies (Kimmons et al., 2005; Hotz & Gibson, 2001; Kung'u et al., 2009) and an increased risk of gastrointestinal illnesses due to exposure to food borne pathogens (Motarjemi et al., 1993; Mosha et al., 2000; Kung'u et al., 2009). One of the breakfast dishes that is readily available and is becoming more and more popular these days, especially in the global south, is instant porridge. Porridge is a popular baby weaning dish and adult breakfast meal with a high carbohydrate content and little nutritional value (Ajifolokun et al., 2019; Taylor & Emmambux, 2008; Katunzi-Kilewela et al., 2021). The idea of using many grains in breakfast dishes might offer several advantages related to various grains (Mandge et al., 2011; Hussain, 2019). A variety of whole grains are combined in multigrain mixes to optimize their nutritional, functional, and sensory qualities. These qualities can then be further increased by additional procedures like fermentation, malting, roasting, fortification, etc. (Hussain, 2019). This research focuses on millet, sorghum, green beans, and pumpkin seeds, which can be processed using traditional methods such as malting and fermentation to improve protein availability and quality while decreasing anti-nutritional elements (Oluwamukomi et al., 2003; Gernah et al., 2012). The study's goal is to boost the nutritional density and bio-availability of weaning porridge by incorporating these protein- and micro-nutrient-rich underutilized crops.

2. Materials and methods

2.1. Sample collection, processing, and formulation

Sample collection

Millet, sorghum, green beans, and pumpkin were all acquired at the local market in Lafia, Nasarawa State, Nigeria's North central. Most of the chemicals used in the studies were acquired from local Nigerian stores and were of analytical quality. The clean maize and sesame seeds were packaged in 10 L and 5 L plastic buckets, respectively, after hand sifting and winnowing to remove stones, waste materials, and defective seeds, and the buckets were then snugly covered with lids.

Sample preparation and processing

Fermented millet (*Panicum glaucum*) flour**:** Natural lactic acid fermentation was used to produce millet flour. By soaking and removing the seeds floating on top, 2 kg of millet was sorted for stones, dirt, insects, and flaws. In a plastic basket, the aesthetically pleasing seeds were collected and drained. The millet was then steeped in 1 L of water for 3 d to allow fermentation to occur. The water was changed every 8 h during the fermenting phase. The fermented and soaked seeds were drained and sun dried. After that, the millet was dehulled in a local wooden mortar and winnowed to separate the hulls from the grain. For disinfection, the dried grains were placed in a hot air oven set to 100 °C for 2 h. The grains were then ground into a fine powder and sieved to eliminate bigger parts, yielding smooth flour (Figure 1).

Malted sorghum (*Sorghum bicolor*) flour: Malting was done according to the procedure described by Gernah et al., (2012) and shown in Figure 1. To disinfect the grains, 2 kg of raw, sorghum grains were washed in a 5% (w/v) sodium chloride (NaCl) solution. The grains were then soaked in tap water at room temperature (30±2 ºC) in a plastic bucket at a 1:3 (w/v grain:water) ratio. The steep water was changed every 4 h for a total steeping time of 12 h, then the grains were spread in a single layer on a moistened jute bag and allowed to germinate at room temperature (30±2 ºC) for 3 d while spraying with water every 12 h. At 3 d, the germinated grains were removed and dried to constant weight in an air draft oven at 100 ºC.

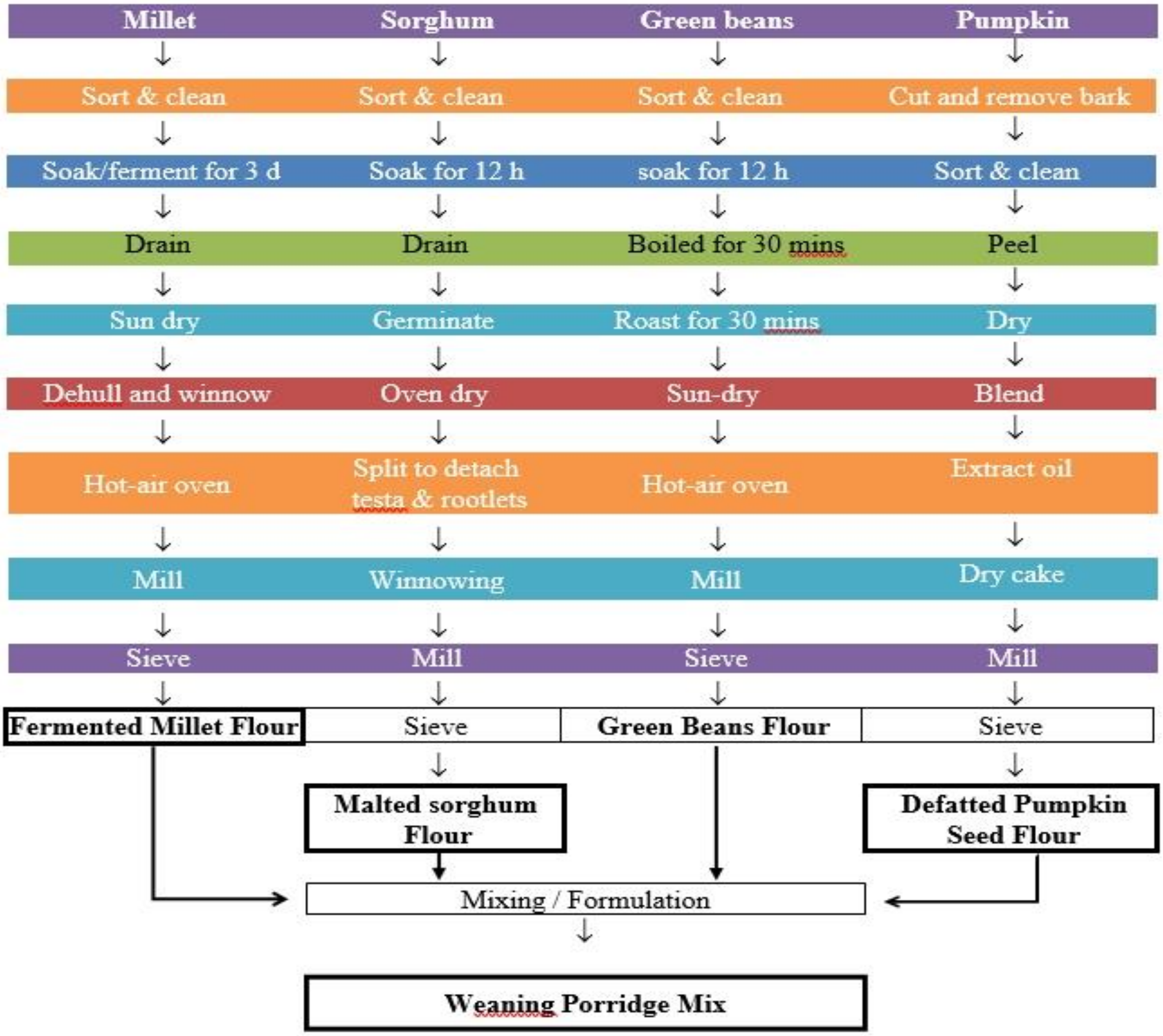

Figure 1. Flow chart on preparation of various composite flour and weaning mix

Table 1. Formulation of weaning diet

Sample	Ingredients (g/100g)					
	FMF	MSF	GBF	DPSF	Sucrose	Salt
WP 1	50	25	25	-	5	1
WP 2	45	22.5	22.5	10	5	1
WP 3	40	20	20	20	5	1
WP 4	35	17.5	17.5	30	5	1

FM = Fermented Millet; MS = Malted Sorghum; GB = Green Beans; DPF = Defatted Pumpkin Seed flour
Source: Adapted from Usha *et al*. (2010) with slight modifications

The dried seeds were split in a mortar to separate the testa and rootlets from the cotyledons, which were then removed by winnowing. The cotyledons were then crushed into flour using a bench top hammer mill and sieved to a particle size of 0.2 mm. The resulting malted sorghum flour was then packaged in low density dark-colored polyethylene bags, stored at room temperature (30±2 ºC) in 500 mL plastic containers with airtight lids, and used for product formulation and analysis within 24 h.

Green beans (*Phaseolus vulgaris*) flour**:** 2 kg of green beans were washed and tested for defects and kernel cracking before being immersed for 8 h. The soaked bean seeds were then cooked in a liter of water for 15 min before being roasted in a hot pot for 30 min. The roasted beans were sun-dried to a consistent weight before being disinfected in a hot-air oven set at 100 °C for 2 h. The dry parts were ground and sieved to make a fine powder (Figure 1).

Defatted pumpkin (*Cucurbita pepo*) flour: The bark of the pumpkin (*Cucurbita pepo*) seeds was manually removed/peeled before being dried in a tray drier at 60 °C for 24 h to a moisture content of 10-12%. The dried pumpkin seeds were coarsely pulverized in a kitchen blender before being wrapped in muslin and placed in a stainless-steel container with food grade organic solvent (N-hexane) and left for 24 h to allow the N-hexane to extract the oil. The defatted sesame cake was dried to constant weight in an air draft electric oven at 80 ºC, then milled to a particle size of 0.2 mm. The flour was subsequently packaged in a low-density dark colored polyethylene bag, maintained at room temperature (30±2 ºC) in 500 mL plastic containers with airtight lids, and used for product formulation and analysis within 24 h (Figure 1).

Preparation of weaning porridge mix

The preparation of the weaning mix as reported by Usha et al. (2010) adopted with slight modification. The weaning porridges mix, illustrated in Figure 1, was made of fermented millet (*Panicum glaucum*) flour, malted sorghum (*Sorghum vulgare*) flour, green beans (*Phaseolus vulgaris*) flour, and defatted pumpkin (*Cucurbita pepo*) flour. In the laboratory, the typical weaning mix was made by blending Fermented Millet (*Panicum glaucum*) Flour, Malted Sorghum (*Sorghum vulgare*), and Green Beans (*Phaseolus vulgaris*) in the following proportions: 2:1:1. The four mix variations were made by adding 0%, 10%, 20%, and 30% defatted pumpkin (*Cucurbita pepo*) flour to the norm. Table 1 shows the formulation of the supplemental food combination.

2.2. Analysis

Proximate analysis

The AOAC method was used to determine the moisture, ash, fat, crude protein (%N x 6.25), and crude fiber of the samples (AOAC, 2010). Moisture was calculated using AOAC Method 934.01: Air Oven Method (AOAC, 2010). AOAC Method 960.52: Micro-Kjeldahl Method was used to determine crude protein (AOAC, 2010). Fat was extracted using AOAC Method 963.15: Soxhlet Extraction Method with Hexane as the solvent (AOAC, 2010). The neutralization procedure was used to determine the crude fiber (Method 962.09) (AOAC, 2010). The ash content was calculated using AOAC Method 923.03: Dry Ashing Method (AOAC, 2010). Carbohydrate content was calculated using the Atwater's conversion factors (4.0 Kcal/g for protein, 9.0 Kcal/g for fat, and (4.0 Kcal/g) for carbohydrates) and caloric value was calculated using the Atwater's conversion factors (4.0 Kcal/g) for carbohydrates (Spackman et al., 1958; Harper, 2003).

Determination of essential amino acid composition

The automated Technicon Sequential Multi-sample Amino acid Analyzer was used to perform a qualitative assessment of the essential amino acid composition of the food compositions (TSM, model DANA 0209). The FAO reference values for each amino acid were then used to construct amino acid scores Gernah et al. (2012).

Determination of minerals

The mineral content of the components and porridge made from complementary wheat blends was determined using the standard AOAC method (AOAC, 2010) as reported by Marcel et al. (2022). The divalent cations (calcium, iron, zinc, and magnesium) of sample minerals were determined using Atomic Absorption Spectrophotometry (AAS) Model 200A (Buck Scientific Inc., Norwalk, CT, USA) after first digestion in HCl. According to AOAC (2010), sodium and phosphorus were determined using a flame photometer (Jenway, PF 7) and a colorimetric method employing ammonium molybdate.

Antinutrient analysis

Phytate, Oxalate, Cyanide, Trypsin, and Nitrate levels were determined using AOAC (2010) techniques.

Determination of energy and nutrient density

The calorie and nutritional density of porridges made using designed complimentary flours were calculated using the procedures outlined by WHO/UNICEF (1998) and Tenagashaw et al. (2017). Notably, the amount of food ingested by young children (those older than 6 months) was determined to be 195 mL (Marcel et al., 2022). The energy density (in Kcal/g) and nutritional density were determined as follows:

$$Energy\ density = \frac{Gross\ Energy\ of\ Food}{Amount\ of\ Food} \quad (1)$$

$$Nutrient\ density = \frac{Target\ Nutrient}{Gross\ Energy} x100 \quad (2)$$

Determination of functional properties

The bulk density (BD) of weaning porridge was calculated using the method by Danbaba et al. (2014). The water absorption capacity (WAC) was calculated using the method provided by Mustapha et al. (2015). The swelling index (SI) of the weaning porridge was calculated using the method described by Elechi et al. (2022). The reconstitution index (R.I) was calculated according to the approach outlined by Banigo & Akpapunam (1987) as reported by Gernah et al. (2011). The viscosity (cp) was calculated as reported by Fagbemi et al. (2005).

Microbial analysis

The freshly manufactured compositions were immediately exposed to microbiological investigation. Bacteria, mold, and yeast were all tested for. 1 g of each sample was dissolved in 9 mL of distilled water and serially diluted. Each diluent was plated out on a plate count agar bacteria count and malt extract for yeast and mould using the pour plate method. The plates were incubated for 48 h at 37 °C for bacterial growth and three days at 27 °C for yeasts and mould. Colonies developed after incubation was counted as reported by Achidi et al. (2016).

Preparation of porridge and sensory analysis

The composite flours were used to make porridge. Each prepared diet was combined with 400 mL of boiled distilled water. For flavor, 5 g of granulated sugar and 1 g of salt were added to the porridge. The samples were left to cool at ambient temperature (25±2 °C). According to Aduni et al. (2016), the porridge were kept separate in thermos flasks to maintain the serving temperature of 50 °C. Affective testing was used to assess the sensory quality of gruel made from food compositions (Iwe, 2002). The panelists were 35 women (mainly mothers) from the College of Agriculture in Lafia who used supplemental meals daily. Each panelist was situated in a separate compartment with fluorescent lights and no distractions. The judges used a nine-point hedonistic scale to evaluate the samples for flavor, taste, color, texture, and general acceptability, with 9 being the highest score and 1 being the lowest (Watts et al., 1989). The degree to which a product was liked was expressed as follows: like extremely (9 points), like very much (8 points), like moderately (7 points), like slightly (6 points), neither like nor dislike (5 points), dislike slightly (4 points), dislike moderately (3 points), dislike very much (2 points), and dislike extremely (1 point). Each participant rated four samples provided at random during each session, with fresh tap water used for mouth rinsing in between evaluations of the samples to avoid carry over effect (Ihekoronye & Ngoddy, 1985). Thirty (30) mL of each gruel was served hot (50 ºC) in 100 mL colorless, clear plastic cups that were coded, with colorless transparent spoons provided for consuming the gruel.

2.3. Statistical analysis

The study's data were analyzed using means and standard deviation for triplicate values. Analysis of variance was utilized to determine any significant differences between the blends and the control, and the differences were separated using Duncan's Multiple Range Test (DMRT) at 5% level of significance (P<0.05). The software Graph-pad Insat 2000 version was used to calculate and express the results as Mean Standard Deviation.

3. Results and Discussion

3.1. Proximate composition of food formulations (%)

The proximate composition of designed supplemental foods is shown in Figure 2, including crude protein, moisture, fat, crude fiber, ash, carbohydrates, and energy 16.42-21.82%, 4.90-6.20%, 7.91-9.03%, 2.15-1.28%, 2.19-3.59% 66.43-58.08%, and 402.59-400.87 Kcal/100 g, respectively. The moisture content of the formulated weaning porridge was considerably lower (P<0.05) in WP1 and WP2 samples than in WP3 and WP4 samples, probably due to the latter recipes' use of fermented and malted grains such as millet and sorghum. WP1 and WP2 had moisture content that was within the permissible Codex level of 5%. Variations in flour proportion may have resulted in variations in moisture content by influencing the volume of water used during porridge preparation, thereby departing from the acceptable level (Marcel et al., 2022). Moisture content is an important quality element for prepared cereals, which should have a moisture level of 3-8% (Nelson, 1992). Lower moisture content, as demonstrated in WP1 and WP2, improves sample preservation by reducing microbial activity, whereas high moisture content promotes microbial growth and food deterioration (Tiencheu et al., 2016; Achidi et al., 2016). Controlling the amount of water used in porridge preparation is vital to avoiding over-dilution and thinning of critical limiting elements in the complementary diet (Amagloh et al., 2013; Marcel et al., 2022).

Protein is one of the most essential components in weaning diets. The protein level of the designed weaning meals was substantial and satisfied the infants' specified minimal requirements. It was discovered in the current study that the protein content of the prepared diet increases progressively as the percentage of defatted pumpkin increases. The use of fermentation and malting, as well as the use of protein-rich components (defatted pumpkin seed and green beans) as good sources of protein and minerals, has resulted in an increase in critical nutrients. Malting and fermentation, in general, boosted the PER - Protein Efficiency Ratio and NPR - Net Protein Retention of foods greatly (Gernah et al., 2012). Due to the low protein quality of most cereals, such as millet and sorghum (e.g., methionine, lysine, and tryptophan), cereal-based complementary foods derived from such ingredients should be supplemented with protein-rich (leguminous) foodstuffs to boost their nutritional relevance (Kolawole et al., 2020; Marcel et al., 2022). In most countries, baby protein requirements are met when energy intake is adequate, unless there is a predominance of low-protein foods (WHO/UNICEF, 1998; Achidi et al., 2016). Hence, the Protein Advisory Group recommends that weaning foods contain 20% protein, up to 10% fat, 5% to 10% moisture content, and no more than 5% total ash content (FAO/WHO/UNICEF/Protein Advisory Group (PAG), 2007). In this study, the protein levels in the diets WP1, WP2, WP3, and WP4 were greater (14.52%) above the minimal quantity stated in Codex Alimentarius guidelines. This means that the planned diets provide acceptable or suggested protein values for weaning foods, making them useful not just for weaning children but also for children suffering from Protein-Energy Malnutrition (PEM) (Achidi et al., 2016).

To enable maximal amino acid complementation in diets and growth, the FAO/WHO Codex Alimentarius Standards for weaning foods prescribe a protein concentration ranging from 14.52 to 37.70 g/100 g (FAO/WHO, 1994; Tiencheu et al., 2016). Protein is vital for preventing PEM, which is common among children in developing countries, particularly during weaning (Achidi et al., 2016; Abeshu et al., 2016). Protein deficiency is associated with stunting and wasting, with stunting being connected to impaired motor growth, decreased social productivity, and poor memory and learning abilities (Agbemafle et al., 2020; Bhutta et al., 2013; Marcel et al., 2022).

As a result, the designed diets meet the protein requirements of newborn weaning foods, potentially aiding in the prevention of PEM and its associated negative consequences.

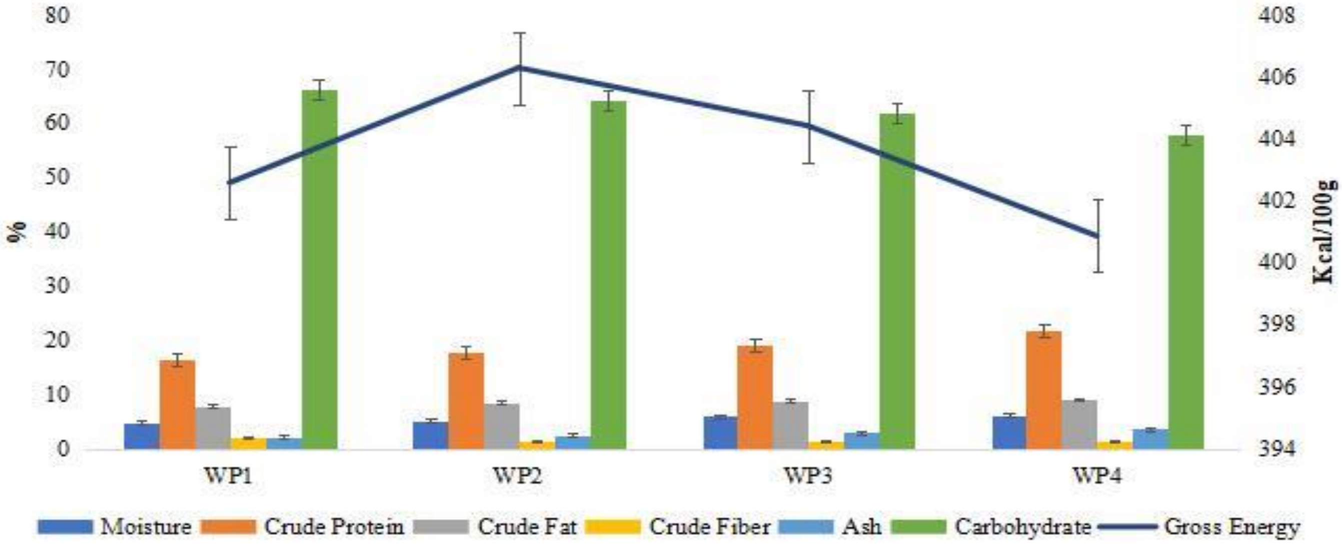

Figure 2. Proximate composition (%) and energy (Kcal/100 g) of food formulations

The study discovered that as the amount of defatted pumpkin flour grew, the fibre level of the prepared diets reduced significantly (P>0.05). When compared to the other formulated diets, WP1 had the highest fibre level (2.15%), while WP4 had the lowest (1.28%). This reduction in fibre content could be attributed to the dehulling of millet, sorghum, and green beans during flour production (Tiencheu et al., 2016). Furthermore, during seed germination, some of the seed fibre may be solubilized enzymatically, greatly reducing the amount of fibre present.

Despite the importance of fiber in nutritional absorption and nitrogen utilization, high fiber content in complementary foods can result in bulky foods that cause flatulence, which is unpleasant for newborns. Furthermore, high-fibre foods can be difficult to digest during the weaning stage, when the digestive tract is still developing (Laryea et al., 2018). As a result, all the low-fibre meals established in this study are regarded suitable weaning diets that meet the Codex standard criteria (<3%) (CAC, 2011).

Even though high-fiber diets can help prevent obesity, constipation, cardiovascular disease, diabetes, and colon cancer (Mosha et al., 2000), they can also displace energy and nutrients needed for the growth of youngsters under the age of a year (Klim et al., 2001; Obinna-Echem et al., 2018). Furthermore, in human individuals, increased dietary fibre intake can affect protein and mineral digestion and absorption (Whitney et al., 1990; Tiencheu et al., 2016). Polyphenols and non-starch polysaccharides, for example, bind minerals such as calcium, zinc, and iron, rendering them unavailable for human nutrition (Fairweather-Tait and Hurrel, 1996; Tiencheu et al., 2016). As a result, low-fiber diets are appropriate for weaning meals.

When compared to the World Health Organization's suggested value of 5% for weaning diets, the ash level of the weaning diets developed in this study was comparatively low (Achidi et al., 2016). The ash content of the formulated diets, on the other hand, was within the permissible limit suggested by the Protein Advisory Group, which says that ash concentration should not exceed 5% (Protein Advisory Group, 1972; Tiencheu et al., 2016). The ash content of the products reflects the mineral content, and while the ash content increased significantly with the addition of defatted pumpkin seed flour, it remained within the Codex regularity (<5%) (Marcel et al., 2022). This rise in ash content could be attributed to the effect of pumpkin seed flour addition following malting treatment, implying that the prepared complementary foods in this study could be mineral sources. In other research, highly regarded designed complementary foods had significantly higher ash content than control samples (Lyarea et al., 2018; Olatunde et al., 2020; Tiencheu et al., 2016; Achidi et al., 2016; Marcel et al., 2022).

When fortified with oil-rich pumpkin seeds, the crude fat content of the complementary porridge increased significantly (P<0.05), matching with the FAO/WHO (1998) guideline to incorporate vegetable oils in newborn and children's diet. This not only enhances energy density but also acts as a carrier for fat-soluble vitamins (Eka et al., 2010; Achidi et al., 2016). All the designed diets matched the recommended fat levels for weaning foods, which were less than 10% or at least 51% of the codex standard levels of 10%-25% (Protein Advisory Group, 1972; Tiencheu et al., 2016). However, because high fat level can cause oxidative degradation and spoiling, low fat content is required for prolonged shelf life (Achidi *et al*., 2016).

Fats are important in the diets of young children and infants because they provide vital fatty acids, improve absorption of fat-soluble vitamins, and increase dietary energy density (FAO, 2001; Obinna-Echem et al., 2018). Excessive fat consumption can worsen micro nutrient deficiency in vulnerable communities and lead to childhood obesity and cardiovascular disease, particularly when saturated fatty acids are consumed in large quantities (Milner & Allison, 1999; Achidi et al., 2016). Unsaturated fats, such as those present in soybean (Lanna et al., 2005) and cereals (Ngeh-Ngwainbi et al., 1997; Szalai et al., 2001; Tiencheu et al., 2016), on the other hand, do not have the same adverse consequences. As a result, modified meals including oil-rich pumpkin seeds are appropriate for weaning foods.

The carbohydrate content of the prepared weaning diets varied significantly (P>0.05). Because pumpkin seeds have a low starch content, the carbohydrate levels declined steadily as the defatted pumpkin seed flour increased. The content of foods meant for children under the age of three is strictly regulated by legislation (EU Commission Directive 2006/125/EC). As a result, the recommended energy intake of complementary meals varies according to the age of the infant, the volume of breast milk consumed, the fat content of the milk, and the frequency of complementary food feeding (Tiencheu et al., 2016). Many complementary food formulations on the African continent are cereal-based, with maize as the principal ingredient that must be supplemented with legumes to improve the formulations' other macro-nutrient components, such as proteins and fat (Laryea et al., 2018). In comparison to the Codex standard, however, the designed weaning porridge met the recommended levels (60%-75%) of Codex Alimentarius Standards (Marcel et al., 2022). The research results indicate that the prepared complementary porridge are high in utilized carbohydrates.

When compared to both the control samples and the Codex standard (>400%-425%), the gross energy content of the formulated complementary porridge was significantly higher (P<0.05). This is assumed to be owing to the combined effect of ingesting energy-rich nutrients, in addition to a significant contribution from carbohydrate-rich components. Because the gross energy content exceeds 50% of the Codex recommendations, Dewey et al., (1996) stated that energy requirements from complementary foods for infants and toddlers who are still breastfed range from 200 Kcal/day at 6-8 months to 700 Kcal/day at 9-11 months and 550 Kcal/day at 12-23 months (Tiencheu et al., 2016). It suggests that the developed complementary porridges are acceptable sources of gross energy and can provide enough energy density for the target group (Abeshu et al., 2016; Codex, 2010).

3.2. Essential amino acid composition

The amino acid contents of the prepared weaning food are shown in Figure 3-6. Most of the necessary amino acids increased in abundance as more pumpkin seed flour was added. This could be due to the grain's complex poly-peptides being broken down into simpler amino acid molecules during defatting, malting, and fermentation. The findings showed that the prepared weaning food had enough essential amino acids, such as methionine, isoleucine, leucine, lysine, and tryptophan, to meet the RDA for developing infants (Satter et al., 2013). This is significant since grains and legumes, which are often used in newborn diets, lack these amino acids. These dietary compositions can address the amino acid demands of developing infants by combining cereals with legumes or oil-seeds (Gernah et al., 2012).

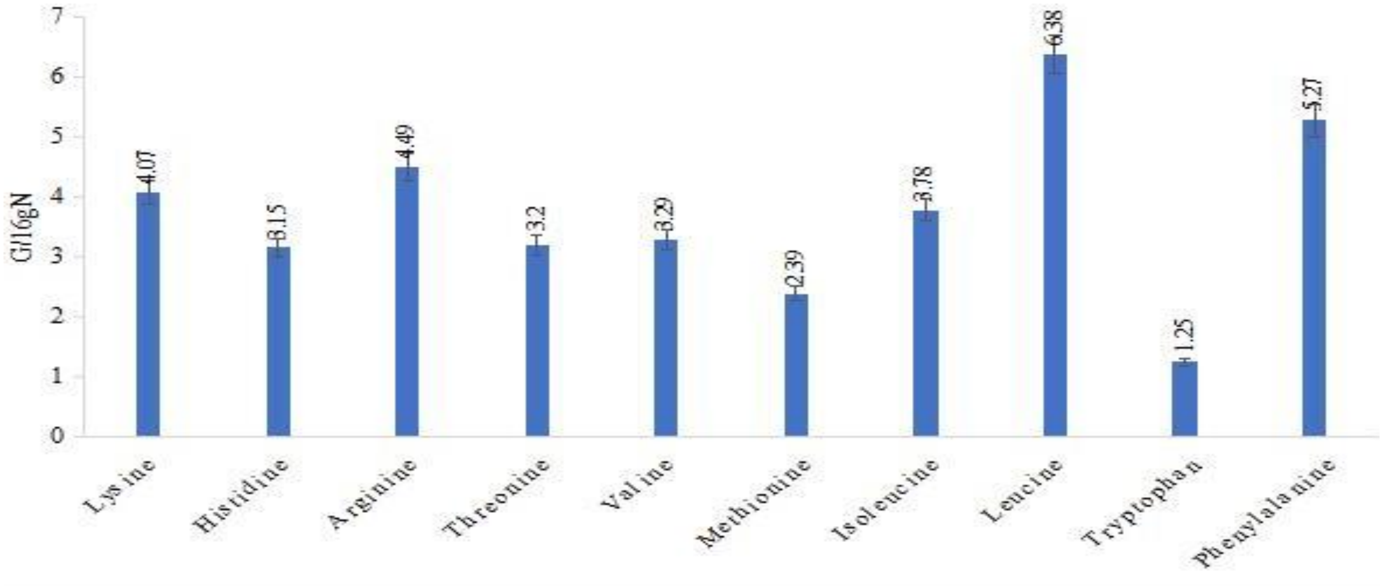

Figure 3. Essential amino acid (EAA) composition of the weaning food formulations (WP1)

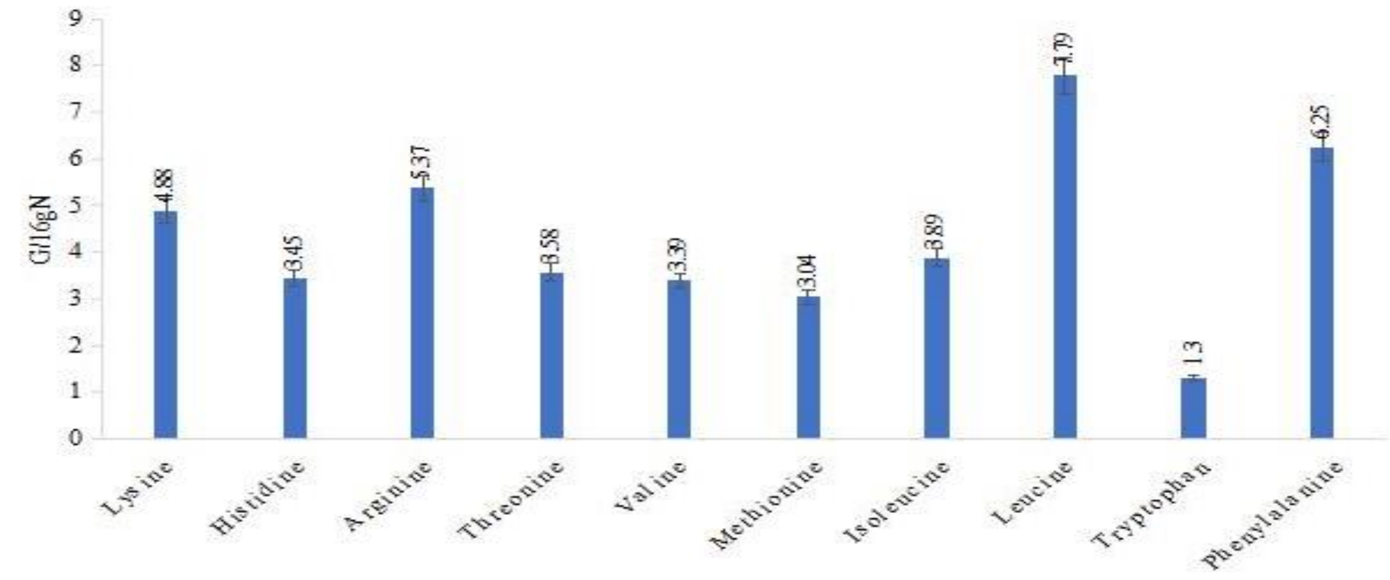

Figure 4. Essential amino acid (EAA) composition of the weaning food formulations (WP2)

Figure 5. Essential amino acid (EAA) composition of the weaning food formulations (WP3)

Figure 6. Essential amino acid (EAA) composition of the weaning food formulations (WP4)

3.3. Minerals content of the formulated diets

The mineral composition of the food samples is shown in Table 2. Some minerals were found to be lower than the needed amounts for weaning meals, whereas others, such as zinc and iron, were found to be within the RDA. A range of mineral-rich complementary meals should be included in infants' diets to guarantee adequate mineral intake, as infants and children aged 6 to 24 months consume very modest amounts of these foods (WHO/UNICEF, 1998). The sodium contents in the complementary porridge were much higher than the Codex requirement (0.37 mg/100 g), owing to the use of pumpkin seeds, which are a good source of sodium. It is crucial to note, however, that high salt consumption is not recommended for either adults or infants (Marcel et al., 2022). The formulated diets did not significantly exceed the tolerable iron intake limitations, since they were within the recommended dietary reference intake (DRI) range of 1118.60 mg/100 g. Iron is essential in an infant's diet since it aids in hemoglobin production and has an impact on their mental and physical well-being. Iron deficiency can have a negative impact on newborn growth during the weaning stage (Laryea et al., 2018).

The calcium levels in the prepared weaning porridge increased dramatically, probably as a result of the addition of calcium-rich components such pumpkin seeds (Marcel et al., 2022). The calcium concentration was, however, lower than the recommended daily intake (DRI) of 260-400 mg/100 g. The zinc level in all the weaning porridge, on the other hand, met the World Food Program's (2018) DRI of 3-8.40 mg/100 g. As a result, porridge are regarded as a good source of zinc, as they can supply at least 50% of the DRI (Adisehu et al., 2016; Codex, 2010). They are appropriate for the target demographic of children and women of reproductive age. Stunting, anemia, and increased susceptibility to illnesses are all connected to zinc deficiency, as is iron deficiency (Agbemafle et al., 2020; Bhutta et al., 2013). It has the potential to permanently harm immunological function, motor and cognitive development, as well as intellectual and behavioral performance (Adisehu et al., 2016; Brown, 2009). Furthermore, the magnesium levels in the weaning porridge exceeded the DRI (54-75 mg/100 g), which is critical for newborn health. Magnesium aids in heart rhythm regulation, bone strength, immune system support, and appropriate muscle and neuron function (Ndife et al., 2020).

3.4. Anti-nutritional factors of formulated diet (mg/100 g)

The anti-nutritional factors of the designed diets are depicted in Figure 7. The lowest amounts of oxalate (0.21 mg/100 g), phytate (6.25 mg/100 g), cyanide (0.48 mg/100 g), nitrate (2.00 mg/100 g), and trypsin inhibitor (0.06 mg/100 g) were found in the diet including 35% germinated sorghum, 17.5% rice flour, 17.5% germinated green beans, and 30% defatted flour (WP4). Among the designed diets, the control diet (WP1) exhibited the highest concentration of anti-nutrients. The current study found that as the percentage of defatted pumpkins grew, the concentration of antinutrients reduced.

Table 2. Minerals scores of the formulated weaning diet (mg/100g)

Minerals	WP1	WP2	WP3	WP4	DRI*
Calcium	195.93±1.82^{c}	196.51±3.10^{bc}	197.00±1.80^{b}	199.50±2.82^{a}	260–400
Magnesium	276.64±1.12^{b}	277.73±1.27^{b}	279.23±2.30^{a}	281.12±1.50^{a}	54–75
Iron	16.81±2.00^{c}	17.40±2.00^{bc}	18.91±2.00^{ab}	19.49±2.00^{a}	11–18.60
Phosphorus	248.58±4.00^{b}	249.08±4.00^{b}	249.97±1.00^{b}	251.50±1.22^{a}	275
Sodium	89.43±3.00^{b}	90.04±3.00^{ab}	90.86±3.00^{a}	91.61±3.00^{a}	0.37
Zinc	1.64±2.32^{c}	2.49±2.82^{bc}	3.72±1.28^{b}	5.82±1.20^{a}	3–8.40

*DRI: World Food Program (2018) dietary reference intake for a 6- to 12-month-old child. Thevalues reflect the mean ± standard deviation of three determinations. Means in the same rowthat are not followed by the same superscript differ considerably (P≤0.05).

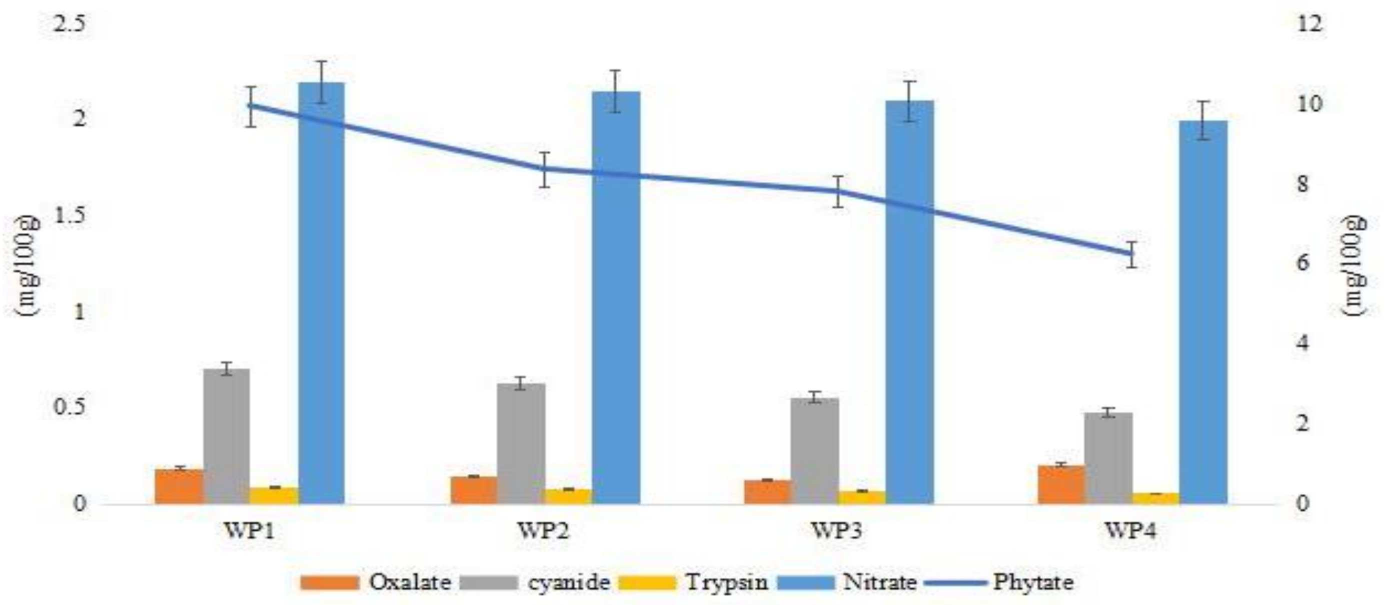

Figure 7. Anti-nutrient composition (mg/100g)

Soaking, dehulling, fermentation, heating, and germination are examples of processing processes that can increase the nutritional content of food products by lowering or eliminating anti-nutritional elements. The decrease in anti-nutrient qualities seen in this study could be attributed to leaching in the soaking water during the manufacturing of fermented millet, malted red sorghum, and defatted pumpkin flour.

Oxalate can interact with minerals such as calcium, magnesium, and iron, leading in the creation of insoluble oxalate salts and the formation of oxalate stones (Onwuka et al., 2005; Agbaje et al., 2017). This also impedes mineral consumption. In diet, phytic acid can create insoluble compounds with important minerals such as calcium, iron, magnesium, and zinc, rendering them unavailable for absorption into the bloodstream (Onwuka et al., 2005). According to the findings of this study, there is an increase in the availability of mineral components in meals that can be absorbed into the bloodstream (Agbaje et al., 2017).

3.5. Energy and nutrient density of the formulated porridges

The calorie and nutritional density of weaning porridge are shown in Table 3. Weaning porridge had an energy density ranging from 2.06 to 2.08 Kcal/g, with no significant difference (P<0.05) between the values. This meets the targeted newborn group's minimal daily energy requirement of ≥0.8 Kcal/g, as reported by WHO/UNICEF (1998) and WHO (2002). Several studies have found that complementary foods have varying energy density (Oladiran & Emmambux, 2020; Marcel et al., 2022). The energy density of weaning food is a significant component in estimating the amount of food required to meet infants' energy needs (Oladiran & Emmambux, 2020). A higher energy density indicates that less food is required to meet the infant's energy requirements (Marcel et al., 2022).

Protein density ranged from 4.09 to 5.44 g/100 Kcal in the formulated weaning porridge (WP1-WP4), which is above the recommended range for complementary foods. However, protein quality is affected by ingredient composition and processing methods, as low protein density can result in low protein quality food (Marcel et al., 2022). Also, Richter et al. (2019) stated, in a strict sense, just nitrogen and the nine essential amino acids are needed instead of protein. For practical reasons, reference values for daily protein consumption were calculated, primarily because protein is the most essential source of nitrogen and amino acids in daily nutrition. It may be presumed that consumption of various protein sources meets needs for all essential amino acids as reference values are computed using mean protein requirements plus a variance coefficient (Richter et al., 2019). Besides, protein requirement of a newborn is greater per unit of body weight than that of an adult with daily protein requirement of 2.0-2.2 g/kg of body weight. Accordingly, Richter et al. (2019) in consideration of reference body weights, estimated reference values (g/kg body weight per day) for protein intake to be 2.5 for infants at the age of 0 to under 1 month, 1.8 for infants at the age of 1 to under 2 months,1.4 for infants at the age of 2 to under 4 months, and 1.3 for infants at the age of 4 to under 12 months. However, it is important to avoid protein excess for weaning porridge in order to reduce the risk of obesity in adulthood especially in full term infants. In comparison to what is typically provided to them during their first postnatal days, preterm newborns require a much higher amount of protein to ensure normal intrauterine development rates (Hay & Thureen, 2010). Several weeks after delivery are frequently needed to maintain normal development rates by continued protein supplementation. The majority of extremely preterm children experience growth restriction by term, with lean body mass exceeding fat, since they do not acquire the protein required to generate the 2-3 kg of body mass during a 12- to 16-week stay in the NICU (Hay & Thureen, 2010). However, premature and small-for-gestational-age-infant should be fed with breast milk fortified with additional proteins, vitamins and minerals present in special formulas developed to meet their particular needs. 30% more protein per fluid volume than standard formulas are required for premature and small-for-gestational-age-infant. Therefore, the protein density of the weaning porridge obtained in this study could helpful for a wide range of infants and children during the weaning period.

Weaning porridge's calcium, iron, and zinc densities ranged from 46.10 to 46.94 mg/100 Kcal for calcium, 3.96 to 4.59 mg/100 Kcal for iron, and 0.39 to 1.37 mg/100 Kcal for zinc (Table 3). According to WHO/UNICEF (1998) and WHO (2002), all the weaning porridge met the minimum suggested limits for iron and zinc concentrations with the exception of WP1 as the control sample fails to meet the standard value. The increased iron density in the developed complementary porridge could be attributed to the removal of iron inhibitors like phytates during sorting, malting, fermentation, and defatting (Marcel et al., 2022). Overall, the designed weaning porridge meet the required energy and nutrient (protein, zinc, andiron) densities and are excellent suppliers of iron and zinc, which are regarded as problematic nutrients in developing-country children's and infants' meals.

3.6. Functional properties of the food samples

The functional qualities of food components are critical for maintaining a healthy diet, especially in growing children. The functional qualities of formulated food samples are shown in Table 4. The results show that the viscosity of the food samples ranges between 204 and 195.5 cp. Viscosity is an important feature of weaning meals since it affects both the amount of food ingested by a child and their energy intake (Kikafunda et al., 1997; Mosha & Svanberg, 1990). An ideal viscosity is one that allows for easy consumption while keeping an acceptable solids content. Unfortunately, substantial swelling of starch granules during the heating process has been found to limit the solids content of weaning porridges to 5-10%, resulting in low-energy density porridge (Rombo et al., 2001; Nabubuya et al., 2017). The findings of this study, however, show that weaning porridge have an appropriate low viscosity, which is suitable for weaning food.

The bulk density of food samples ranged from 1.09 to 0.60 (g/mL), which shows the load that a sample can carry if placed directly on top of other samples. The density of processed products affects factors such as container or package requirements, texture, and mouthfeel (Lewis, 1990). With a reduced loose bulk density, less food can be packaged in the same container, resulting in more cost-effective packing. Furthermore, decreased bulk density allows more flour particles to stick together, enhancing the food's energy content (Ikpeme-Emmanuel et al., 2009; Achidi et al., 2016).

Table 3. Energy and nutrient density of the formulated complementary porridge

Sample	Energydensity (Kcal/g)	Protein density (g/100 Kcal)	Iron density (mg/100 Kcal)	Zinc density (mg/100 Kcal)	Calcium density (mg/100Kcal)
WP1	2.06^{a}	4.09^{d}	3.96^{b}	0.39^{d}	46.10^{c}
WP2	2.08^{a}	4.39^{c}	4.09^{b}	0.59^{c}	46.24^{b}
WP3	2.07^{a}	4.73^{b}	4.45^{a}	0.88^{b}	46.35^{b}
WP4	2.06^{a}	5.44^{a}	4.59^{a}	1.37^{a}	46.94^{a}
***Recommended standard**	≥0.8	0.7–1.0	2.4–4.5	0.5–1.6	-

*Published references of WHO/UNICEF (1998) and WHO (2002)

Table 4. Functional properties of formulated complementary foods

Properties	WP1	WP2	WP3	WP4	LSD
Viscosity (cp)	204.5±0.90^{a}	198±0.08^{b}	196.5±1.00^{c}	195.5±0.07^{dc}	1.27
Bulked density (g/mL)	1.09±0.01^{a}	0.87±0.01^{b}	0.65±0.00^{c}	0.60±0.01^{d}	0.04
Swelling Index (%)	1.03±0.01^{a}	0.97±0.10^{b}	0.77±0.10^{c}	0.57±0.07^{d}	0.12
W. A. C. (mL/g)	4.04±0.01^{a}	3.54±0.01^{b}	3.30±0.04^{c}	3.04±0.07^{d}	0.25
R. I (%)	5.25±0.1^{a}	5.08±0.05^{ab}	5.03±0.01^{ab}	4.53±0.06^{c}	0.34

Values are mean ± standard deviation of triplicate determinations Means in the same row not followed by the same superscript are significantly different (P≤0.05). R.I = reconstitution index; WAC = Water absorption capacity

According to several studies, larger bulk density flours are preferable for easier dispersibility (Basman & Koksel, 2003). High bulk density, on the other hand, can limit caloric and nutrient intake per feeding, which can lead to growth difficulties. Low bulk density, on the other hand, is useful in the formulation of newborn complementary foods since it allows for a higher energy nutrient density and semi-solid consistency that can be easily fed to an infant with minimum water (Ugwu & Ukpabi, 2002; Tiencheu et al., 2016). When the loose bulk density is low, more food particles can remain together, making digestion easier for children with immature digestive systems (Onimawo & Egbekun, 1998; Mosha et al., 2000; Tiencheu et al., 2016).

A food product's water absorption capacity (WAC) specifies the maximum quantity of water that it can absorb and retain. The WAC values for the Diets in Table 4 ranged between 4.04 and 3.04 mL/g. At P>0.05, all values were statistically different from one another. WAC is useful for calculating the amount of water required to prepare gruel suitable for newborn feeding. Carbohydrates have been discovered to influence the WAC of foods (Echendu et al., 2004). WAC discrepancies between weaning porridge could be attributed to variances in carbohydrate quantity, protein concentration, degree of contact with water, and structural features (McWatters et al., 2003; Tiencheu et al., 2016). McWatters et al. (2003) reported that lower WAC may be related to fewer availability of polar amino acids in flours, which could be caused by the loss of starch association's original granule structure (Lorenz & Collins, 1990; Tiencheu et al., 2016). Giami & Bekeham (2003) reported that Foods with low WAC have lower microbial activity, which can help them last longer. As a result, weaning meals with lower WAC are preferable for producing thinner gruel and are more suited for weaning diets.

Food samples' swelling capacity is an important feature that governs how much water they can absorb and how much they swell over time. The swelling index ranged from 1.03 to 0.57%, as shown in Table 4. The swelling indices for the weaning diets did not differ substantially (P<0.05). Water absorption capacity and swelling index are critical characteristics that influence the consistency of food samples (whether solid, semi-solid, or liquid). Flours with high WAC and SI values can absorb a lot of water and expand a lot while cooking, but they have a poor energy and nutrient density. The values obtained in this investigation were lower than those found in previous studies by Ikpeme et al. (2009) and Tiencheu et al. (2016) for formulated diets based on cereal and legumes/oil-seed. Infants receive more nutrient-dense food from samples with lower swelling index values.

The reconstitution index values ranged from 5.25 to 4.53%, with a statistically significant ($P<0.05$) difference between samples. A diet's dispersibility in water reveals how well it can be reconstituted. Because of their high dispersibility values, formulated diets are more suited for preparing weaning foods. The values obtained in this study are within the range reported by Ijarotimi & Keshinro (2012) and Gernah et al. (2012) for reconstitutability properties.

3.7. Microbiological qualities

The microbial communities of the samples are depicted in Figure 8. The total plate count (TPC) represents the total number of viable microorganisms present in a particular sample, which includes bacteria, yeast, and mold. A greater TPC may indicate a higher amount of microbiological contamination in the product, which may be a cause for concern about product quality and safety. The TPC values in the provided findings range from 2.0×10^3 to 1.0×10^3 cfu/g, indicating a moderate amount of microbial contamination and falling within the permissible criteria for complementary meals (Codex Alimentarius, 2008). For bacteria contamination in food, the international microbiological standard specifies a limit of less than 10^6cfu/ml (Anon, 1974; Achidi et al., 2016). Yeasts and molds are frequent spoilage bacteria that can cause health problems if present in large quantities. All of the samples had low yeast and mold counts, which is positive because levels above 10.0 cfu/g can cause food illness and potentially liver cancer in humans due to the development of harmful compounds like aflatoxin (Salje et al., 2006). The low bacteria counts were achieved by a high quality of personal cleanliness, a high drying temperature (80 °C-100 °C), and appropriate manufacturing standards observed during the food formulation process (Achidi et al., 2016). The low counts also suggest an adequate heating process, acceptable raw material quality, and a variety of processing parameters used in food production (Satter et al., 2013).

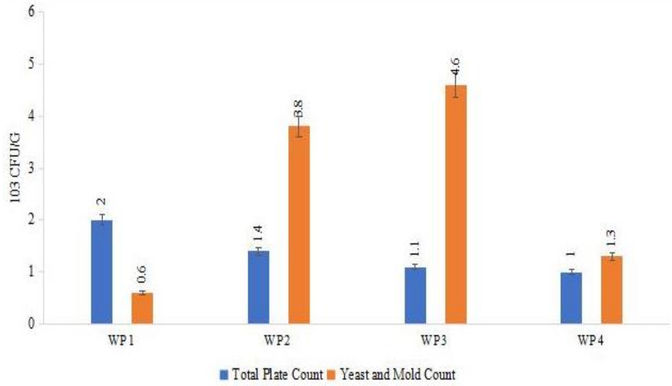

Figure 8. Microbiological qualities of the instant weaning porridge samples (cfu/g)

3.8. Sensory attributes of the formulated food samples

The hedonistic ratings for color (7.04-7.53), taste (7.42-8.05), scent (7.55-8.33), and overall acceptability (7.15-7.81) are shown in Table 9. Color, taste, and aroma changes were found to be significant ($P<0.05$) across all food formulations. However, there was no significant difference in overall acceptance between WP1 and WP2. The products containing 10% pumpkin obtained the highest ratings in all sensory aspects. Nonetheless, the respondents hated none of the weaning diet samples across all sensory qualities, including overall acceptability. Products having an overall acceptability score of higher than 5 are considered outstanding quality in sensory evaluation by Knuckles et al. (1997) and Elechi et al. (2022). All fortified weaning porridge in this study had a mean score of 7 or higher in all sensory measures, indicating an acceptable level of quality.

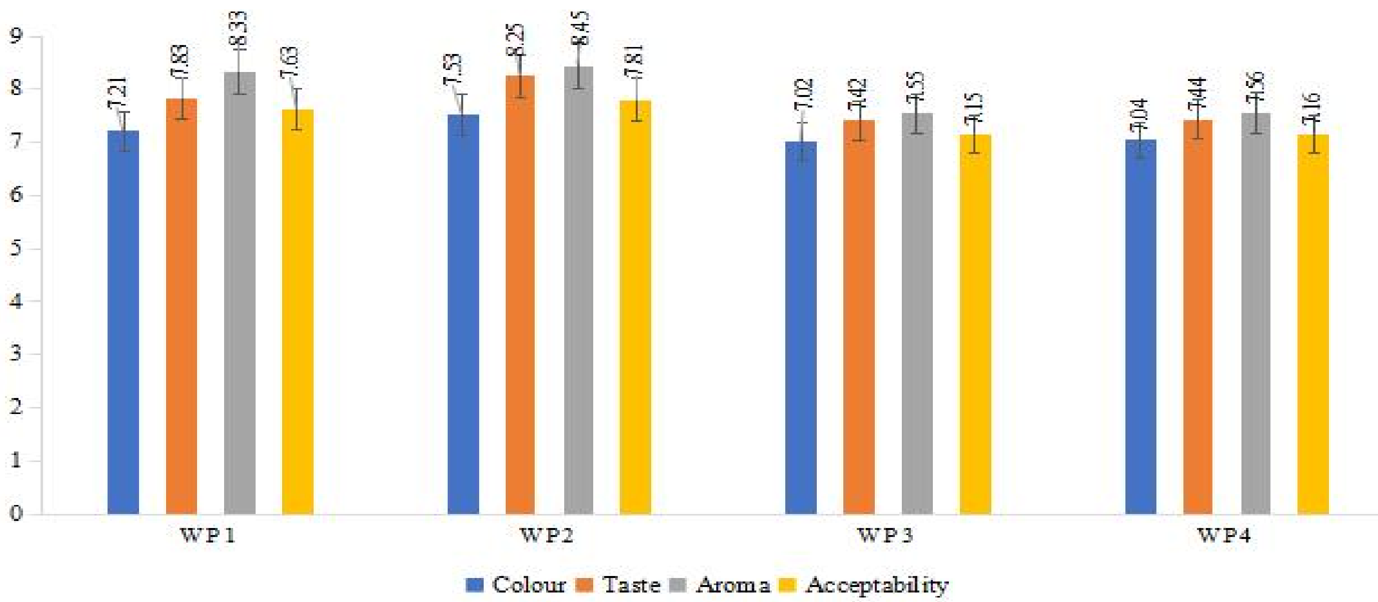

Figure 9. Sensory scores for formulated weaning samples

4. Conclusions

The nutritional composition of weaning porridge produced from fermented millet, malted sorghum, green beans, and defatted pumpkin seed flours was investigated in this study. Our findings indicate that these items can be used to produce a nutritious and pleasant weaning diet that fulfills prescribed nutrient levels. We discovered that fermentation, malting, and fat extraction methods improved protein density, iron availability, calcium availability, and zinc availability while decreasing anti-nutrient levels in weaning diets. The proportion of ingredients also had a substantial impact on the porridge calorie and nutritional densities. The sensory evaluations of the manufactured weaning foods were also evaluated and determined to be satisfactory, with all values above 7 on a 9-point hedonistic scale. Our research demonstrates how important this product could be used in meeting the nutritional needs of children aged 6 to 12 months. As a result, we recommend that fermented millet, malted sorghum, green beans, and defatted pumpkin seed flours be promoted as weaning foods to communities in the global south. Finally, the powder fluid properties and particle sizes of the products produced could also have analyzed in another study.

Author Contributions

Conceptualization, Elechi Jasper Okoro Godwin and Adamu Cornelius Smah.; methodology, Elechi Jasper Okoro Godwin, Adamu Cornelius Smah; software, Oboh Emmanuel J, Adamu Cornelius S; formal analysis, Elechi Jasper Okoro Godwin and Adamu Cornelius Smah; investigation, Nwiyi Ikechukwu U. Oboh Emmanuel J.; resources, Adgidzi Eunice A. and Sule Juliana I; writing—original draft preparation, Elechi Jasper Okoro Godwin and Adamu Cornelius Smah.; writing—review and editing, Sule Juliana I, Nzuta Rimamcwe A, Sampson Eno-Obong, Ekoja-Smah Omeyi Faith, Ezike Onyekajah, Nwiyi Ikechukwu U. Oboh Emmanuel J. and Akinkurolere Justin Adeleke. All authors have read and agreed to the published version of the manuscript.

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Declaration of Competing Interest

The authors declare no conflict of interest.

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