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Production, Chemical, Antioxidant and Nutritional Properties of Potential Functional Foods from Yellow-Maize-Based Enriched with Animal Proteins for Rehabilitation of Malnourished Children

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Abstract

Ready-to-use therapeutic food (RUTF) has been implicated with aflatoxins contamination, high cost of production, and not well tolerated by lactose-intolerance children. Hence, this study was aimed to develop and evaluate nutritional quality of non-peanut-milk-based therapeutic foods for the management of acute malnutrition. The non-peanut-milk-based therapeutic-foods were formulated using FAO guidelines: PRD_1 (30% egg, 50% yellow maize, 20% banana, 10% carrot, and 15% vegetable oil), and PRD_2 (30% white crayfish, 50% yellow maize, 20% banana, 10% carrot, and 15% vegetable oil). RUTF (UNF: 30% full fat milk, 25% peanut, 15% soybean oil, 28% sugar, 2% mineral mix) and local complementary food (LCF: 100% yellow maize) served as controls. Nutritional, antioxidant, and organoleptic properties of the foods were determined by standard methods. Protein (20.07 - 24.73 g/100g), energy (460.36 - 491.27 kCal/100g), and minerals in PRD_1 and PRD_2 were significantly ($p<0.05$) higher than in LCF, but comparable to UNF. Minerals and phytate molar ratios, i.e., Ca/P, Na/K, Phytate/Ca, phytate/Zn, phytate/Fe and phytate*Ca/Zn were within the recommended values. Essential amino acids (mg/100g) in PRD_1 (34.29) and PRD_2 (40.47) were comparable to UNF (38.15). PRD_1 exhibited highest antioxidant activity against ABTS, DPPH, FRAP, iron-chelation, and total phenol than other foods. Biological values (80.72 - 92.33%) of experimental foods were higher than FAO/WHO (70%) recommendation. For sensory attributes, PRD_1 and PRD_2 were rated lower than UNF. However, PRD_1 exhibited highest nutrition-rehabilitation property in malnourished rats than other foods; therefore, it may be suitable as a replacement for peanut-milk-based therapeutic foods for malnourished-children.

Keywords: *Maize-based therapeutic foods, Nutrient Composition, Nutritional-quality, Antioxidant Activity, Malnourished Children*

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Introduction

Severe acute malnutrition among children (<5 years) in developing countries is increasing, and it is becoming an important health issue due to associated risk factors like high morbidity, mortality and frequent diarrhoea due to lactose intolerance (Nhampossa *et al*. 2013). Lactose intolerance occurs as a result of damage to intestinal mucosa due to nutritional injury and infectious insults to produce lactase enzyme, which is responsible for the digestion of lactose in milk.

Nutritional rehabilitation of acutely malnourished children involves high-energy and milk-based ready-to-use therapeutic diets. However, findings have shown that these diets have some health issues with lactose-intolerance children due to inability to digest lactose sugar in the milk, hence, responsible for high rate of unfavorable treatment outcomes (Nhampossa *et al*. 2013). Epidemiological reports have established that children with severe acute malnutrition commonly experience a reduction in intestinal lactase activity, which is the main enzyme responsible for the digestion of milk sugar (lactose) (Nhampossa *et al*. 2013; James, 1971). Therefore, feeding milk-based diets may retard nutritional recovery in children suffering from lactose intolerance and acute malnutrition (Nyeko *et al*., 2010).

Milk is a complete food with high-quality protein, essential micronutrients, acceptable taste and good bio-functional properties. Milk is usually used as diet therapy for nutrition intervention programmes in many developing countries to manage acute malnutrition in children. Evidence has shown that milk or milk-based products might not be well appropriate for nutritional rehabilitation of acutely malnourished children, due to inefficient lactase enzyme activity. Therefore, non-milk-based diets may serve as a substitute for milk-based therapeutic food for the management of acute malnutrition.

Several efforts to address problems of malnutrition among children include development of qualitative complementary foods, however, this effort experienced a setback in many developing countries due to poverty and lack of nutritional knowledge (Adejuwon *et al*., 2020). The onset of a new product called Ready-to-Use Therapeutic Food (RUTF) seemed to be a breakthrough for these problematic situations in developing countries. This novel food is mainly formulated from peanuts, sugar, powdered milk, vegetable oil, and micronutrients; and it is characterized by high energy density, essential nutrients (mineral salts, vitamins, amino acids, and fatty acids), prolonged shelf-life, and ability to be used without cooking.

Despite these advantages, RUTF has been implicated with some problems such as contamination of the peanut with aflatoxins, which is carcinogenic in nature, and the inclusion of powdered milk influences final cost of the RUTF production (Santini *et al*., 2013), which may not be affordable to underprivileged families (Bhutta *et al*., 2008). Besides, the product may not be well tolerated by a child suffering from lactose intolerance syndrome (Bhutta *et al*., 2008). For these reasons, UNICEF has advocated for the replacement of the powdered milk in the RUTF recipe with locally available protein-based food materials that are cheaper and well tolerated (Fetriyuna *et al*., 2023). Recently, epidemiological report has established home treatment for severe acute malnourished children using homemade therapeutic foods as more practical and desirable than in hospitals settings (Schoonees *et al*., 2013). Hence, the present study was aimed to formulate non-peanut-milk based Ready-to-Use Therapeutic Food (RUTF) using affordable and locally available food materials, and also to evaluate nutritional qualities of the products in severe-acute malnourished Wistar rats.

Materials and Methods

Study Area: The study was carried out in the Department of Food Science and Technology, Federal University of Technology, Akure, Nigeria between November 2023 and April, 2024.

Sources of materials

The food ingredients (i.e., milk, eggs, white crayfish, peanuts, carrots, banana and yellow maize) were procured from a reputable local market in Akure, Nigeria; while mineral mix was purchased from a renowned pharmacy store in Akure, Nigeria. The reagents and chemicals used for the analyses were of analytical grade.

Preparation of Flour Samples

Yellow maize grains were thoroughly cleaned and the flour was prepared as described by Ijarotimi (2022) with slight modification. The peanut flour was prepared according to the method described by Adepeju *et al*. (2024) with slight modification. Banana fingers were washed, manually peeled and sliced with a stainless-steel knife into chips, immersed in 0.5% sodium metabisulphite to prevent browning, steam blanched, drained, and then the flour was produced as described by Anajekwu *et al*. (2020). The carrots were washed, sliced manually with a stainless-steel knife, and blanched for 3 minutes in hot water (95 °C) to prevent browning and discoloration, and the flour was then produced as described by Ibidapo *et al*. (2017). The eggs were washed with distilled water, cooked at 100 ^{0}C for 25 min., shelled and sliced manually with a stainless-steel knife, and the flour was produced as described by Ikese *et al*. (2017) with slight modification. White crayfish flour was prepared as described by Ikese *et al*. (2017 with slight modification. The dried white crayfish were cleaned by hand sorting, washed with distilled water, and drained. Each of the experimental food samples was oven dried in hot-air oven (50 - 60 ^{0}C, 2 - 6 h) (Plus11 Sanyo Gallenkamp PLC, Loughborough, Leicestershire, UK), and then milled into flour using (Laboratory blender, Model KM 901 D, Kenwood Electronic, Hertfordshire, UK) and sieved (60 mm mesh sieve; British standard) to obtain respective flour sample. Each of the flour samples was stored in an airtight polyethylene bag for further analysis.

Formulation of therapeutic foods

The complementary food samples were formulated according to WHO recipe combinations for ready-to-use therapeutic foods (Manary, 2006). The following food combinations were obtained: PRD_1 (30% egg flour, 50% yellow maize, 20% Banana flour, 10% carrot flour, and 15% vegetable oil), PRD_2 (30% white crayfish flour, 50% yellow maize, 20% Banana flour, 10% carrot flour, and 15% vegetable oil), while LCF (100% yellow maize) and UNF (30% full fat milk, 25% peanut, 15% soybean oil, 28% sugar, 2% mineral mix) served as control samples.

Chemical Composition analyses

Food Formulations: The complementary food samples were formulated according to WHO recipe combinations for ready-to-use therapeutic foods (Manary, 2006). The following food combinations were obtained: PRD_1 (30% egg flour, 50% yellow maize, 20% Banana flour, 10% carrot flour, and 15% vegetable oil), PRD_2 (30% white crayfish flour, 50% yellow maize, 20% Banana flour, 10% carrot flour, and 15% vegetable oil), while LCF (100% yellow maize) and UNF (30% full fat milk, 25% peanut, 15% soybean oil, 28% sugar, 2% mineral mix) served as control samples.

The proximate compositions, that is, moisture, ash, crude protein, crude fat and crude fiber content were determined using the methods of AOAC (2012), while carbohydrate in the food samples was calculated by difference. The energy value was calculated by Atwater's calorie conversion factors of 4 kcal/g for crude protein, 9 kcal/g for crude fat, and 4 kcal/g for available carbohydrate (Eunmi and Jinho, 2015). For the mineral composition, Atomic Absorption Spectrophotometer

(AAS Model SP9) was used to determine the concentration of Ca, Mg, Fe, Cu and Zn in the food samples, while Flame emission photometer was used to determine Na and K (AOAC, 2012). Phosphorus was determined using Vanodo-molybdate method (AOAC, 2012). The mineral molar ratios (Na/K & Ca/P) were calculated as described by Ferguson *et al., (*1988). The amino acid profiles were determined using High Performance Liquid Chromatography (HPLC). Cysteine and methionine were determined as described by Spindler *et al*. (1984). Tryptophan was determined by alkaline hydrolysis followed by cation exchange chromatography using modified method of Yust *et al*. (2004). Fatty acid compositions were extracted by the chloroform-methanol solvent, and then analysed by gas chromatography (Schäfer, 1998).

The phytochemicals in the food samples were determined as follows: the phytic acid was determined according to Lolas and Markakis (1975) method, tannin content was determined as described by Hayat *et al*. (2020), and oxalate was determined according to the method of AOAC (2012). Trypsin inhibition activity was determined by Spelbrink *et al*. (2011) method, total flavonoid content was determined according to the method of Chang *et al*. (2002). The molar Ratios of Phytate:mineral *(*zinc, calcium & iron) and Oxalate:calcium were calculated (Ma *et al*., 2007; Norhaizan *et al*., 2009).

Determination of Functional Properties of Formulated Complementary Foods

Water/oil absorption capacity was determined according to the modified method of Wani *et al.* (2015), bulk density (grams/mL) was determined according to Wani *et al*. (2013), and swelling capacity was determined according to Alawode *et al*. (2017), while least gelation concentration was determined according to Sathe *et al*. (1982).

Determination of antioxidant activity of the complementary foods

Antioxidant activities of the complementary foods were determined as follows: Ferric reducing activity power (FRAP) was determined using modified method of Yen and Chen (1995). 2.4.1. 1,1-Diphenyl-2-picryl-hydrazyl (DPPH) radical scavenging activity was determined using modified methods of Liyana-Pathiranan and Shahidi (2005), Iron II chelation was determined using modified method of Sudan *et al*. (2014), and Hydroxyl free radical scavenging activity of the samples was determined according to the method of Elizabeth and Rao (1990) with a slight modification. While 2,2'-azinobis-(3-ethylbenzothiazoline-6-sulfonic acid) (ABTS*+) radical cation scavenging activity was determined as described by Shalaby and Shanab (2013) with slight modifications.

Ethical Approval

The study protocol was considered and approved by the Ethical Committee of School of Agriculture and Agricultural Technology, Federal University of Technology, Akure, Nigeria (FUTA/SAAT/2023/037). The animal assay was strictly carried out using the Guidelines of Canadian Council on Animal Care (1993).

Nutritional Quality and Biochemical Indices of Formulated Complementary Foods in Rats

Experimental Diets: The Iso-nitrogenous of experimental complementary foods and control samples were calculated with reference to 10% of protein content (Mekuria *et al*., 2022).

Experimental Design: The Wistar rats (4 weeks old; 50 - males & females) obtained from Central Animal House, College of Medicine, Federal University of Technology, Akure, Nigeria was acclimatized for 5 days, and then grouped into five per ten rats each. The rats were separately housed in metabolic cages and underfed for 28 days with basal diets (low protein) and water *ad libitum* to condition acute malnutrition in the rats. Thereafter, the rats were nutrition rehabilitated with experimental diets and water *ad libitum* for another twenty-eight days.

Anthropometric measurements: The length (cm) and weight (g) of the rats were measured at 3 days interval, and anthropometrical indices, such as length-for-age (stunting), weight-for-length (wasting), and weight-for-age (underweight) were determined as described by Ferreira (2020).

***In-vivo P*rotein Quality Determination**: The faeces and urine voided during the last 48 hours of the experimental periods were continuously collected. The faeces were oven dried (60 ^oC, 6 h), while urine was preserved in 10% H_2SO_4. Faecal and urinary nitrogen were determined using AOAC (2012) method. The biological value (BV), feed efficiency ratio (FER), nitrogen retention (NR), net protein utilization (NPU), true digestibility (TD) and protein efficiency ratio (PER) of the diets were calculated as described by Kamau *et al*. (2017).

Haematological and Biochemical Indices Determinations

After 56 days of experimental period, Wistar rats were sacrificed under chloroform anaesthesia after fasted overnight with access to water *ad libitum.* The organ, i.e., liver, kidney and heart, of the rats were excised, and thoroughly washed and weighed. The blood samples collected through cardiac puncture were evaluated for pack cell volume (PCV), red blood cells (RBC), pack cell volume (PCV), haemoglobin concentration (Hbc), white blood cells (WBC), neutrophil (NEU) and lymphocytes (LYM). Mean corpuscular haemoglobin (MCH), mean corpuscular haemoglobin concentrated (MCHC) and means corpuscular volume (MCV) were calculated (Ijarotimi and Keshinro, 2012).

Liver function: The liver biomarker indices, i.e., aspartate aminotransferase (AST) and alanine aminotransaferase (ALT) activity were determined according to the methods described by Reitman and Frankel (1954). While, alkaline phosphatase (ALP) activity was determined according to the method described by Kind and King (1954).

Renal function: Serum creatinine (mg/dL) was determined as described by Toora and Rajagopal (2002). Serum urea (mg/dL) was determined according to the method described by Zawada *et al*. (2009).

Sensory Evaluation

The food samples were reconstituted (50/100 w/v, 100 ^{0}C for 30 min), coded and served warm to thirty-five nursing mothers/caregivers (panellists). The sensory attributes of the formulated foods were determined as described by Obinna-Echem *et al*. (2004), and the scoring was based on the appearance, aroma, taste, consistency and overall acceptability with reference to 9-point Hedonic scale ranged from dislike extremely (1) to like extremely (9), respectively.

Statistical Analysis

Mean± standard deviation (SD) was used for the presentation of the results, and the mean was calculated using Statistical Package for Social Sciences (SPSS, Version 20). The statistical difference between the means was performed using one-way analysis of variance (ANOVA), and the level of significant between the means were determined by Duncan's New Multiple Range Test (DNMRT) at significant level of p<0.05.

Results and Discussion

Nutrient composition of therapeutic complementary foods for Acute-Malnutrition (SAM) management

Nutrient composition of complementary foods

The nutrient composition of the therapeutic complementary foods was presented in Table 1. The moisture content (4.81 - 4.59 g/100 g) of formulated complementary foods was lower than local complementary food (LCF: 5.19 g/100 g); UNICEF produced therapeutic food (UNF: 4.85 g/100 g), and that of reference standard (<10 g/100 g). Moisture content is a determinant of shelf life of food products, and low moisture content inhibits enzyme and microbial activity by restricting substrate supply, thus prolonging storage stability of the food product Shuxiang *et al*. (2022). The protein content (g/100g) in PRD_1 (24.73) was higher than in PRD_2 (20.07), and was significantly (p<0.05) higher than that of local complementary food (11.63) and UNICEF produced therapeutic food (18.63). Interestingly, the protein in the formulated therapeutic complementary foods in this present study was about 50% higher than that of local complementary food (LCF), but comparable to that of UNICEF (UNF). Previous epidemiological studies reported that traditional complementary food is plant-based, and has been implicated to be responsible for the high prevalence of malnutrition among weaning-aged children in developing countries, Nigeria inclusive (Zlotkin and Dewey, 2021). Traditional complementary food is characterized by low protein and energy density (Ijarotimi, 2022), and this has necessitated many researchers to enrich traditional complementary food, cereal-based, with either plant or animal-based proteins (Ijarotimi, 2022; Oladiran and Naushad, 2022).

Table 1: Proximate composition (g/100g), mineral (mg/100g) and energy value (kCal/100 g) of therapeutic complementary foods for Acute-Malnutrition management

Parameters	LCF	UNF	PRD_1	PRD_2	Ref
Proximate					
Moisture	5.19±0.09^a	4.85±0.02^b	4.81±0.04^b	4.59±0.02^c	<10
Total Ash	1.22±0.03^c	2.03±0.05^b	3.99±0.02^a	4.07±0.08^a	>3
Crude Fat	10.01±0.02^c	30.96±0.11^a	22.84±0.05^b	29.03±0.10^a	<25
Crude Fibre	1.03±0.01^d	1.49±0.02^c	4.66±0.03^b	4.81±0.03^a	>5
Crude Protein	11.63±0.02^d	18.63±0.05^c	24.73±0.09^a	20.07±0.07^b	>14
Carbohydrates	70.92±0.29^a	42.04±0.16^b	38.97±0.12^c	37.43±0.42^c	64
Energy	420.29±9.11^d	521.32±7.57^a	460.36±8.42^c	491.27±5.09^b	344
Minerals					
Ca	8.33±0.02^d	44.39±0.01^c	48.36±0.02^b	53.31±0.02^a	500
Mg	13.29±0.03^c	11.73±0.02^d	14.00±0.03^b	19.98±0.02^a	76
P	1.07±0.02^d	40.37±0.02^c	45.39±0.02^b	50.22±0.03^a	456
K	17.83±0.02^d	36.94±0.03^c	39.82±0.02^b	45.87±0.02^a	516
Na	8.91±0.02^d	10.82±0.02^c	14.09±0.03^b	18.71±0.01^a	296
Fe	1.22±0.01^c	1.55±0.01^b	1.54±0.03^b	2.99±0.02^a	16
Zn	1.28±0.02^d	2.81±0.03^c	3.97±0.02^b	4.73±0.03^a	3.2
Cu	1.03±0.02^a	0.61±0.02^c	0.60±0.01^c	0.74±0.02^b	0.89
Mn	0.18±0.01^d	0.20±0.02^c	0.26±0.02^b	0.41±0.02^a	1.5
Na/K	0.49^a	0.29^d	0.35^c	0.41^b	<1.00
Ca/P	7.79^a	1.10^b	1.07^c	1.06^c	>1.00

Mean ± standard deviation. Values with different superscript in the same row are significantly different at p<0.05. (Sample replications 'n' = 12)

LCF: Local food (100% yellow maize),

UNF: 30% Full fat milk, 25% defatted peanut, 15% Soy oil, 28% sugar and 2% mineral mix

PRD_1: 30% Egg powder, 15% soy oil, 10% carrot flour, 20% banana flour, and 25% yellow maize

PRD_2: 30% Crayfish powder, 15% soy oil, 10% carrot flour, 20% banana flour, and 25% yellow maize

The energy values (kCal.) of formulated foods ranged from 460.36 to 491.27 in PRD1 and PRD_2, respectively, and were significantly ($p<0.05$) higher than traditional complementary food (LCF, a cereal-based, 420.29), but lower than that of control sample (UNF: 521.32). The disparity between the protein and energy values of formulated diets and that of control diets could be attributed to the food composition and fat content, which was incorporated during its formulation. Interestingly, it is evident from this study that the formulated diets met over 100% of daily requirement for protein and energy of weaning-aged children. The protein requirement of infants and young children increases with their age, and the protein (g/day) requirements to satisfy daily nutritional needs of the children are 9.1 g for 6 - 8 months, 9.6 g for 9 - 11 months, and 10.9 g for 12 - 23 months (Zawada *et al*., 2009). This implies that the present complementary foods contain appreciable amounts of protein and energy value, which are required for the management of moderate and severe acute malnutrition in children. Studies have advocated for homemade complementary foods with high protein and energy values for the prevention and treatment of protein-energy malnutrition in children (Ijarotimi, 2022; Obinna-Echem, 2024). Scientific studies have proven that adequate nutrition in terms of dietary protein, energy and micronutrients is essential for ensuring normal growth, cognitive development and good health status of children (Ijarotimi, 2022; Obinna-Echem, 2024). On contrary, low protein and energy intake may lead to nutritional and health challenges such as stunted growth, poor cognitive development, high prevalence of morbidity and mortality among under-five children (Zawada *et al*., 2009).

Mineral composition of therapeutic complementary foods

The mineral compositions (mg/100g) of the formulated foods (Table 1), i.e., calcium, magnesium, phosphorous, potassium, sodium, iron, zinc, copper and manganese were significantly ($p<0.05$) higher in PRD_2 than in PRD_1 and Control samples. The Ca/P and Na/K molar ratios of the formulated food samples are within the recommended values of <1.0 and <1.0, respectively. It is worth noting that mineral ratios are considered more important than individual mineral concentrations because they provide information regarding synergistic or antagonistic relationships between the mineral's bioavailability and disease conditions (Gemede, 2020). Interestingly, the high value of Ca/P molar ratio in this study indicates that the formulated complementary foods contain appreciable amounts of calcium and phosphorous. It is worth noting that diets with a high value of Ca/P ratio (>0.05) are considered good sources of calcium, and are particularly suitable for the growing aged children and aged who require a high intake of calcium and phosphorus for bone and teeth formation, and prevention of osteoporosis, respectively (Ijarotimi and Keshinro, 2013). According to Perez and Chang, 2014), if Na/K ratio of food is less than one, it indicates a large proportion of potassium compared with sodium in the diets; and this proffers some health benefits such as lowering of high blood pressure. Therefore, the observed Na/K molar ratio of the formulated complementary diets in this present study indicates that consumption of these complementary diets may not lead to high neonatal blood pressure.

It was also observed that the food samples were able to provide over 100% and 20% of zinc and iron requirements for the children, respectively. Nutritionally, adequate intakes of iron and Zinc are essential for the growing aged children, and this will ensure adequate formation of blood, and brain development, respectively (Zlotkin and Dewey, 2021). Ironically, it is evident that most of the traditional complementary foods in developing countries including Nigeria are predominantly cereal-based, a monotonous diet, which is characterized by poor essential micronutrients; hence, leading to an increase in micronutrient deficiency, morbidity and mortality in children (Dewey, 2013; Ferguson *et al*., 2015; Osendarp *et al*., 2016).

Amino Acids and Fatty Acids Compositions

Amino acid (mg/100 g protein) and Fatty acids (%) profile of therapeutic complementary foods for Severe-Acute-Malnutrition (SAM) management were presented in Table 2. The total essential amino acids of the formulated food samples were 34.29 and 40.47, while that of conditional amino acids were 41.49 and 37.82 mg/100g protein for PRD_1 and PRD_2, respectively. Interestingly, total essential amino acid composition of the formulated foods, particularly PRD_2, is suitable to meet over hundred percent of the daily requirement of infants aged 7-12 months. Histidine and arginine are present in appreciated amount in the formulated diets, and these amino acids are known to exhibit vital roles in children such as protein methylation, hemoglobin, and nitric oxide formation (Wu, 2009). Histidine and arginine are essential for infants, because they cannot be produced in sufficient amounts endogenously, and besides, they are required for rapid growth and development (Wu *et al*., 2004). Epidemiological studies have reported that children experiencing growth faltering could be due to inadequate intakes of essential amino acids, which is attributed to the poor protein quality of traditional complementary foods. A study has established that inclusion of animal-based foods, which are rich in protein and essential amino acids, is encouraged at a home level to improve the quality of traditional complementary foods that are predominantly cereal/vegetal-based (Oladiran and Naushad, 2022). It is evident that in addition to essential amino acids, animal-based foods are good sources of other essential macronutrients and micronutrients (zinc, iron, iodine, calcium, etc.) that supply building blocks as well as regulate the processes involved in growth and cognitive development in children (Dror and Allen, 2011; Flax *et al*., 2023).

The non-essential fatty acid composition of the formulated diets had myristic acid as the most abundant with concentrations ranging from 56.90 to 77.67%. Myristic acid is an important fatty acid, which the body uses to stabilize different proteins, including proteins used in the immune system. For the essential fatty acids (EFAs), linoleic had the highest concentration followed by linolenic acid. These EFAs, particularly linoleic acid were significantly present in higher amounts in the formulated diets (PRD1= 9.87%; PRD2 = 9.21%) when compared to the control samples (LCF = 5.49%; UNF = 6.59%). Evidence has shown that essential fatty acids are important for brain development during the fetal and postnatal period (Uauy and Dangour, 2006; Coti *et al*., 2006). Besides, EFAs are required for the proper functioning of many physiological activities, hence, denoted as 'essential', because of inability to synthesize them endogenously. Thus, their regular intake becomes necessary in order to meet physiological needs.

Table 2: Amino acid (mg/100g protein) and Fatty acids (%) profile of therapeutic complementary foods for Acute-Malnutrition management

Amino Acids	**LCF**	**UNF**	**PRD$_1$**	**PRD$_2$**	**Ref**
Conditional Amino acids					
Glycine	30.68±2.01^a	28.78±1.04^b	27.73±1.11^c	25.08±1.11^d	
Proline	9.33±0.32^b	9.33±0.34^b	10.51±1.01^a	8.86±0.45^c	
Arginine	1.11±0.01^c	1.65±0.02^b	1.65±0.12^b	1.97±0.03^a	
Tyrosine	1.01±0.01^d	1.75±0.01^b	1.6±0.01^c	1.91±0.02^a	
Non-Essential Amino Acids					
Alanine	7.37±0.13^c	7.86±0.29^b	10.45±1.21^a	7.33±1.03^c	
Cysteine	0.61±0.02^d	1.62±0.21^c	2.57±0.04^a	1.92±0.03^b	
Aspartic Acid	-	0.76±0.02^b	1.06±0.03^a	1.04±0.10^a	
Glutamic Acid	10.78±2.10^a	9.4±0.11^b	8.78±0.08^c	10.7±0.31^a	
Essential Amino Acids					
Valine	0.91±0.02^d	1.05±0.01^c	1.57±0.03^a	1.12±0.01^b	3.8
Threonine	0.71±0.01^d	0.84±0.01^c	1.28±0.01^a	0.94±0.01^b	3.7
Isoleucine	0.81±0.01^d	0.96±0.03^c	1.45±0.01^a	1.17±0.01^b	3.1
Leucine	1.01±0.10^d	1.4±0.01^c	2.01±0.02^a	1.72±0.10^b	7.3
Lysine	0.9±0.02^b	0.73±0.01^d	0.96±0.01^a	0.89±0.01^c	6.4
Histidine	33.14±3.01^a	30.07±2.11^c	24.25±3.03^d	31.28±2.02^b	1.0
Methionine	0.99±0.03^c	1.08±0.03^b	1.05±0.02^b	1.29±0.03^a	2.7
Phenylalanine	0.64±0.02^c	0.83±0.01^b	0.84±0.01^b	1.01±0.01^a	6.9
Tryptophan	-	1.19±0.02^a	0.88±0.01^c	1.05±0.01^b	
ΣEAAs	39.11±1.09^b	38.15±2.03^c	34.29±1.24^d	40.47±3.02^a	
ΣNEAAs	18.76±1.10^d	19.64±2.20^c	22.86±2.01^a	20.99±1.11^b	
ΣCAAs	42.13±2.33^a	41.51±1.21^b	41.49±2.21^b	37.82±2.07^c	
Fatty Acids					
Vaccinic Acid	2.53±0.03^a	1.61±0.01^d	2.10±0.03^b	1.80±0.01^c	
Capric Acid	3.47±0.01^a	2.70±0.11^c	2.93±0.02^b	2.95±0.01^b	
Myristic Acid	77.67±2.91^a	70.69±3.03^b	56.90±2.31^d	62.52±3.03^c	
Palmitic Acid	2.27±0.02^d	7.26±0.13^c	13.45±1.01^a	10.99±2.33^b	
Margaric Acid	0.00^b	0.00^b	0.57±0.02^a	0.00^b	
Stearic Acid	0.00^d	0.44±0.03^a	0.32±0.01^c	0.36±0.02^b	
Arachidic Acid	0.51±0.03^a	0.40±0.01^b	0.29±0.01^d	0.33±0.01^c	
Palmitoleic Acid	6.33±0.22^c	9.03±1.01^b	9.71±0.11^a	9.70±0.43^a	
Oleic Acid	0.57±0.01^b	0.49±0.02^c	0.98±0.01^a	0.97±0.01^a	
Linolenic Acid	1.15±0.01^b	0.69±0.01^c	2.88±0.02^a	1.17±0.01^b	
Linoleic Acid	5.49±0.12^d	6.69±0.22^c	9.87±0.31^a	9.21±0.15^b	

Mean ± standard deviation. Values with different superscript in the same row are significantly different at p<0.05. (Sample replications 'n' = 12)
LCF: Local food (100% yellow maize),
UNF: 30% Full fat milk, 25% defatted peanut, 15% Soy oil, 28% sugar and 2% mineral mix
PRD$_1$: 30% Egg powder, 15% soy oil, 10% carrot flour, 20% banana flour, and 25% yellow maize
PRD$_2$: 30% Crayfish powder, 15% soy oil, 10% carrot flour, 20% banana flour, and 25% yellow maize

Antinutrient composition of therapeutic complementary foods for Acute-Malnutrition management

The phytochemical composition of therapeutic complementary foods indicated that flavonoid, tannin, phytate, and oxalate as well as trypsin inhibitor were present in low concentrations, and were lower than recommended critical values (Table 3). Comparatively, phytochemicals in the formulated diets were lower in concentration, except in flavonoids, when compared with the control sa mples (LCF & UNF). The higher concentration of flavonoids in the formulated diets (PRD$_1$ = 7.77; PRD$_2$ = 9.09 mg/g) may be of health benefits like acting as anticancer, antioxidant, anti-inflammatory, and antiviral agents (Ullah *et al.*, 2020). Besides, flavonoids may also serve as neuroprotective and cardio-protective agents (Ullah *et al.*, 2020). For the phytate/minerals ratios, the finding shows that the values were lower than recommended critical values for Phytate/calcium, Phytate/zinc, Phytate/iron and Phytate*Ca/Zn (Al Hasan *et al*., 2016). The phytate/minerals molar ratios are used to predict bioavailability of minerals in the foods. The phytate/iron molar ratio >1, phytate/calcium molar ratio >0.24 and phytate/zinc molar ratio >15 are regarded as indicative of poor iron (Hallberg*et al*., 1989), calcium (Morris and Ellis, 1985) and zinc (Oberleas and Harland, 1981) bioavailability. The concentration of phytate in the formulated foods in this study may not chelate with divalent minerals like calcium, iron and zinc, thereby enhancing bioavailability of these minerals. These minerals are very important in children for physiological development and health maintenance.

Table 3: Phytochemical composition (mg/g) of therapeutic complementary foods for Acute-Malnutrition management

Parameters	LCF	UNF	PRD$_1$	PRD$_2$	*Lethal dose
Flavonoid	1.08±0.03^{d}	5.41±0.05^{c}	7.77±0.03^{b}	9.09±0.07^{a}	-
Tannin	2.01±0.05^{c}	2.50±0.04^{a}	2.48±0.03^{a}	2.10±0.04^{b}	3.0mg/kg
Phytate	4.00±0.02^{d}	7.85±0.03^{a}	6.73±0.05^{b}	5.86±0.03^{c}	50-60g/kg
Oxalate	0.53±0.03^{d}	5.47±0.03^{a}	5.03±0.03^{b}	4.39±0.08^{c}	2.5 g/kg
Trypsin Inhibitor	2.88±0.02^{b}	3.03±0.02^{a}	2.09±0.04^{d}	2.59±0.05^{c}	0.25g/kg
Phytate/mineral (Ca, Zn & Fe) millimolar ratios					
*Phytate/calcium	0.29±0.02^{a}	0.11±0.01^{b}	0.08±0.02^{c}	0.06±0.03^{d}	240
*Phytate/zinc	3.08±0.01^{a}	2.75±0.02^{b}	1.67±0.01^{c}	1.22±0.02^{d}	15,000
*Phytate/iron	2.78±0.02^{c}	4.29±0.01^{a}	3.71±0.03^{b}	1.66±0.03^{d}	>1,000
*Phytate*Ca/Zn	0.64±0.01^{d}	3.05±0.02^{a}	2.02±0.02^{b}	1.63±0.02^{c}	>200,000

Mean ± standard deviation. Values with different superscript in the same row are significantly different at p<0.05. (Sample replications 'n' = 12)
LCF: Local food (100% yellow maize),
UNF: 30% Full fat milk, 25% defatted peanut, 15% Soy oil, 28% sugar and 2% mineral mix
PRD$_1$: 30% Egg powder, 15% soy oil, 10% carrot flour, 20% banana flour, and 25% yellow maize
PRD$_2$: 30% Crayfish powder, 15% soy oil, 10% carrot flour, 20% banana flour, and 25% yellow maize

For the phenolic profile (Table 4), Quercetin and kaempferol were the most abundant in PRD$_1$ and PRD$_2$, respectively, and were significantly higher than in other food samples. This could be attributed to the amount of flavonoids that are present in the formulated food products. Quercetin and kaempferol have been shown to have antioxidant, anti-inflammatory (Crespo *et al*., 2008), and cardioprotective (antihypertensive) benefits in animals (Espley *et al*., 2014). Hence, their present in the formulated complementary foods may proffer some health benefits, such as protecting the heart of the children against neonatal hypertension.

Table 4: Phenolic profile (mg/100g) of formulated therapeutic complementary foods for Acute-malnutrition management

Phenolic profile	**LCF**	**UNF**	**PRD$_1$**	**PRD$_2$**
Chlorogenic Acid	1.045^{d}	1.143^{c}	2.701^{a}	1.341^{b}
P-Hydroxybenzoic Acid	2.264^{c}	2.427^{b}	0.025^{d}	2.692^{a}
Maysin	0.538^{c}	0.584^{c}	0.756^{b}	0.812^{a}
Maizenic Acid	0.150^{d}	0.169^{c}	0.317^{b}	0.359^{a}
Caffeic Acid	0.059^{d}	0.065^{c}	0.203^{b}	0.245^{a}
Carotol	0.061^{b}	0.083^{a}	0.062^{b}	0.083^{a}
Beta-Sitosterol	-	-	0.073	-
Daucol	0.051^{b}	0.104^{a}	0.051^{b}	0.104^{a}
Orientin	-	0.052^{b}	0.069^{a}	0.052^{b}
Quercetin	-	0.055^{b}	9.524^{a}	0.055^{b}
Kaempferol	8.080^{c}	8.615^{b}	3.791^{d}	8.860^{a}
Cyclomusastenol	1.863^{d}	2.624^{c}	3.316^{a}	2.962^{b}
Myricetin	0.231^{c}	0.907^{b}	0.105^{d}	1.357^{a}
Apigenin	0.167^{b}	0.167^{b}	0.504^{a}	0.105^{c}
Capsaisin	0.105^{b}	0.105^{b}	0.057^{c}	0.591^{a}
Ferulic Acid	0.121^{a}	0.121^{a}	0.058^{b}	0.059^{b}
Luteolin	0.120^{b}	0.290^{a}	0.098^{c}	-
Succinic Acid	-	-	0.056	-
Lycopene	-	0.056^{c}	0.062^{a}	0.060^{b}
Vincosamide	0.057^{b}	0.073^{a}	-	0.073^{a}

Mean ± standard deviation. Values with different superscript in the same row are significantly different at p<0.05. (Sample replications 'n' = 12)
LCF: Local food (100% yellow maize),
UNF: 30% Full fat milk, 25% defatted peanut, 15% Soy oil, 28% sugar and 2% mineral mix
PRD$_1$: 30% Egg powder, 15% soy oil, 10% carrot flour, 20% banana flour, and 25% yellow maize
PRD$_2$: 30% Crayfish powder, 15% soy oil, 10% carrot flour, 20% banana flour, and 25% yellow maize

Functional properties of therapeutic complementary foods for Acute-Malnutrition (SAM) management

Functional properties describe the behavior of ingredients during preparation and cooking, as well as how they affect the finished food products in terms of appearance and taste. The results of functional properties of the experimental flour samples were as follows: Swelling capacity (308 - 312 g/cm^3), Water absorption capacity (0.81 - 1.05 g/g), Oil absorption capacity (0.63 - 0.88 g/g), Bulk density (0.63 - 071 g/cm^3) and Gelatinization (100 ^{o}C) (Table 5). These results were significantly ($p<0.05$) lower in PRD$_1$ and PRD$_2$ than in LCF (100% yellow maize, traditional complementary food). The disparity between the functional properties of formulated products and that of traditional complementary food and UNF (a UNICEF Ready-to-eat therapeutic food) could be attributed to the composition of food ingredients and processing techniques. This finding was in line with the reports of Awuchi *et al*. (2019), who established that functional properties of foods and flours are influenced by the components of the food materials, especially carbohydrates, proteins, fats/oils, moisture, fibre, and food additives, as well as the structures of food components. Comparatively, the low value of functional properties obtained in this present study agreed with the finding of Ijarotimi (2022), who reported low functional properties for complementary foods formulated from maize, defatted groundnut and ginger. The low value of functional properties, particularly bulk density, recorded in this study is nutritionally desirable in infant diets. This would enable the children to consume a small quantity of complementary foods with high energy-nutrient density, which would be enough to meet their daily energy and nutrient requirements (James *et al*., 2018). A study has established that low bulk-density enhances energy-nutrient density of a complementary food and economical food packaging (James *et al*., 2018).

Table 5: Functional properties of therapeutic complementary foods for Acute-Malnutrition management

Parameters	WAC (g/g)	OAC (g/g)	SC (%)	BD (g/cm^3)	GC (^{0}C)
LCF	1.35±0.02^a	0.97±0.01a	332±4.47^a	0.77±0.03^a	85±2.12^b
UNF	0.3±0.01^d	0.69±0.01^d	43±1.22^d	0.71±0.01^b	0.0^c
PRD$_1$	0.81±0.02^c	0.63±0.01^c	308±5.04^c	0.71±0.01^b	100±2.05^a
PRD$_2$	1.05±0.01^b	0.88±0.03^b	312±3.33^b	0.63±0.01^c	100±1.91^a

Mean ± standard deviation. Values with different superscript in the same row are significantly different at p<0.05. (Sample replications 'n' = 12)
LCF: Local food (100% yellow maize),
UNF: 30% Full fat milk, 25% defatted peanut, 15% Soy oil, 28% sugar and 2% mineral mix
PRD$_1$: 30% Egg powder, 15% soy oil, 10% carrot flour, 20% banana flour, and 25% yellow maize
PRD$_2$: 30% Crayfish powder, 15% soy oil, 10% carrot flour, 20% banana flour, and 25% yellow maize
WAC: Water absorption capacity, OAC: Oil absorption capacity, EC: Emulsion capacity, SC: Swelling capacity, FC: Foaming capacity, BD: Bulk density, GC: Gelation capacity

Antioxidant Activity of therapeutic complementary foods for Acute-Malnutrition management

The antioxidant activity of the formulated therapeutic foods was presented in Table 6. The result shows that PRD$_1$ exhibited highest antioxidant activities against ABTS (2.68 mMol/g), DPPH (59.5%), FRAP (6.79 mg/g), metal chelation (54.66%), and total phenol (69.51 mg/g) when compared to PRD$_2$, and control samples. The observed variation in antioxidant activity of the formulated products and the control food samples could be attributed to the nature of food components and total phenolic contents, which is significantly higher in the formulated food samples than controls. In recent decades, a regular intake of natural antioxidants is gaining more interest due to the presumed safety and potential therapeutic value (Hazra *et al*., 2008). Therefore, regular intakes of antioxidant in food or as supplements may prevent oxidative stress and other related chronic diseases. A study has linked several human diseases on oxidative stress, which is as a result of imbalance between the free radical formation and neutralization of pro-oxidants (Sreeramulu *et al*., 2009). Hence, these experimental foods in this study may be a good source of antioxidants to prevent oxidative stress particularly in malnourished children.

Table 6: Antioxidant activities of therapeutic complementary foods for Acute-Malnutrition management

Parameters	LCF	UNF	PRD$_1$	PRD$_2$
ABTS (mMol/g)	1.98±0.03^c	2.45±0.07^b	2.68±0.09^a	2.50±0.05^b
DPPH (%)	40.75±0.14^d	52.71±0.12^b	59.50±0.10^a	46.99±0.08^c
FRAP (mg/g)	4.88±0.09^c	5.99±0.10^b	6.79±0.28^a	5.69±0.47^b
OH (%)	50.80±0.10^d	68.90±0.21^b	72.60±0.15^a	63.29±0.27^c
Fe^{2+} Chelation (%)	30.75±0.15^d	49.39±0.16^b	54.66±0.26^a	45.37±0.09^{bc}
Total Phenol (mg/g)	50.53±0.08^d	55.95±0.13^c	69.51±0.07^a	58.60±0.10^b

Mean ± standard deviation. Values with different superscript in the same row are significantly different at p<0.05. (Sample replications 'n' = 12)
LCF: Local food (100% yellow maize),
UNF: 30% Full fat milk, 25% defatted peanut, 15% Soy oil, 28% sugar and 2% mineral mix
PRD$_1$: 30% Egg powder, 15% soy oil, 10% carrot flour, 20% banana flour, and 25% yellow maize
PRD$_2$: 30% Crayfish powder, 15% soy oil, 10% carrot flour, 20% banana flour, and 25% yellow maize

Quality and rehabilitation of rats fed on therapeutic complementary foods

Protein digestibility of therapeutic complementary foods: The protein digestibility of formulated therapeutic complementary foods was presented in Table 7. The result indicated that Wistar rats fed on PRD_1 (42.75 g) had the highest weight gained followed by rats fed on PRD_2, (35.46 g), and were significantly ($p<0.05$) higher than those rats fed on UNF (33.28 g) and LCF (3.50 g), respectively. This observation could be attributed to the food compositions and the nutritional quality of the formulated foods compared to the traditional complementary food (LCF) and that of UNICEF produced ready-to-eat therapeutics food (UNF). The biological values (BV), net protein utilization (NPU), and protein efficiency ratios (PER) of the formulated diets ranged from 80.72 to 92.33%, 83.81 to 84.77%, and 2.34 to 2.50 for PRD_2 and PRD_1, respectively. Interestingly, the parameters of protein quality exhibited by the formulated complementary foods in the present study were significantly higher than in LCF, and recommended values of 70% for an ideal food (Kopeć *et al*., 2014), however, the values were comparable to that of UNF. This indicated that the formulated complementary foods may adequately provide the require protein for the growth and development of infants. Epidemiological studies have established that those traditional complementary foods from cereals are usually low in essential nutrients and energy value, hence, prone children to the risks of malnutrition, growth faltering, lifelong cognitive impairment and poor health being due to low immunity (Marcel *et al*., 2022; Akinsola *et al*., 2017).

Comparatively, The BV and NPU of the present study formulations are higher than the report of Adejuwon *et al*. (2020) on the complementary diets formulated from sorghum, soybean, and orange flesh sweet potato. Scientific study has established that BV indicates the proportion of protein digested, absorbed and utilized by the cells for tissues formation in an organism (Adejuwon *et al*., 2020).

The relative organ (kidney, liver & heart) weight of the experimental rats fed on formulated diets ranged from 0.58 to 0.70 g, 4.55 to 5.08 g, and 0.63 to 0.69 g, respectively. These organs were significantly higher in rats fed on the formulated complementary foods than in rats fed on LCF (0.32g, 2.15 g & 0.42g, respectively), but similar to that of rats fed on UNF. These findings further established that the formulated diets exhibited better nutritional quality, and that the diets were not loaded with high protein that may cause a burden on the immature kidneys and liver of the infants. A study has established that formula-fed infants usually experience increased kidney size as an adaptive response to high renal solute load as a consequence of higher protein intake through infant formula intakes (Escribano *et al*., 2017). Hence, these therapeutic diets may be suitable to support growth, normal organs development and managing acute malnutrition in children.

Table 7: Protein quality of therapeutic complementary foods for Acute-Malnutrition management

Parameters	LCF	UNF	PRD_1	PRD_2
Weight gained (g)	3.50 ± 0.02^d	33.28 ± 0.10^c	42.75 ± 0.30^a	35.46 ± 0.21^b
Food intake (g)	424.20 ± 0.09^d	903.10 ± 0.50^b	936.54 ± 1.21^a	752.80 ± 0.70^c
FER	0.01 ± 0.00^e	0.04 ± 0.00^c	0.06 ± 0.00^a	0.05 ± 0.00^b
NR (%)	22.86 ± 0.13^d	40.27 ± 0.41^b	47.66 ± 0.07^a	35.43 ± 0.06^c
BV (%)	55.09 ± 0.60^d	85.26 ± 0.02^b	92.33 ± 0.07^a	80.72 ± 0.03^c
NPU (%)	45.86 ± 0.21^c	79.96 ± 0.51^b	84.77 ± 0.16^a	83.81 ± 0.28^a
TD (%)	23.11 ± 0.33^d	45.60 ± 2.15^a	41.85 ± 0.24^b	38.99 ± 0.31^c
PER	1.73 ± 0.03^d	2.43 ± 0.01^b	2.50 ± 0.01^a	2.34 ± 0.01^c
Relative weight of organ				
Kidney	0.32 ± 0.01^c	0.56 ± 0.01^b	0.70 ± 0.02^a	0.58 ± 0.03^b
Liver	2.15 ± 0.01^d	6.60 ± 0.03^a	5.08 ± 0.03^b	4.55 ± 0.02^c
Heart	0.42 ± 0.02^c	0.67 ± 0.02^a	0.69 ± 0.02^a	0.63 ± 0.02^b

Mean ± standard deviation. Values with different superscript in the same row are significantly different at $p<0.05$. (Sample size 'n' = 42 Wistar rats).
Biological value (BV), feed efficiency ratio (FER), nitrogen retention (NR), net protein utilization (NPU), true digestibility (TD) and protein efficiency ratio (PER)
LCF: Local food (100% yellow maize),
UNF: 30% Full fat milk, 25% defatted peanut, 15% Soy oil, 28% sugar and 2% mineral mix
PRD_1: 30% Egg powder, 15% soy oil, 10% carrot flour, 20% banana flour, and 25% yellow maize
PRD_2: 30% Crayfish powder, 15% soy oil, 10% carrot flour, 20% banana flour, and 25% yellow maize

Biochemicals and haematological properties of malnourished rats fed on therapeutic complementary foods

The biochemical indices of malnourished rats fed on therapeutic complementary foods was presented in Table 8. The pack cell volume (PCV), red blood cells (RBC) and haemoglobin concentration (Hbc), and white blood cells (WBC) of the rats fed on the therapeutic diets ranged from 43.69 to 47.66%, 7.55 to 7.84 x10^{3}mm^{-3}, 14.83 to 15.96 g/dL, and 9.07 to 9.10 x10^{3}mm^{-3}, respectively. The PCV, Hbc, RBC of rats fed on PRD1 and PRD2 were significantly higher than those rats that were fed on LCF, but comparable to that of UNF. This finding could be attributed to the protein quality and iron content of the formulated diets. A study has established that those diets containing quality protein and iron are usually good for hemoglobin and immune production in animals (Guoyao, 2016). The high concentration of PCV, Hbc, and RBC of the experimental rats fed on PRD_1 and PRD_2 further established nutritional adequacy of these formulated therapeutic complementary foods. This finding agrees with the report of Adejuwon *et al*. (2020). Scientific studies have reported that haematological constituents (Packed Cell Volume and Haemoglobin) reflect the physiological responsiveness of the animal to quality of dietary intakes (Schmidt *et al*., 2004; Daramola *et al*., 2005).

Table 8: Biochemical indices of malnourished rats fed on therapeutic complementary foods for Acute-malnutrition management

Parameters	LCF	UNF	PRD_1	PRD_2	*NR
PCV%	26.59±0.01^{c}	43.81±0.02^{b}	47.66±0.04^{a}	43.69±0.15^{b}	37.6-50.6
RBC (x10^{3}mm^{-3})	5.39±0.02^{d}	7.39±0.02^{c}	7.84±0.03^{a}	7.55±0.03^{b}	6.76-9.75
Hbc (g/dl)	10.21±0.03^{d}	14.48±0.03^{c}	15.96±0.02^{a}	14.83±0.03^{b}	11.5-16.1
WBC (x10^{3}mm^{-3})	5.22±0.02^{d}	8.65±0.03^{c}	9.10±0.03^{a}	9.07±0.01^{b}	6.6-12.6
MCHC (g/dL)	25.27±0.03^{d}	31.00±0.04^{c}	33.63±0.02^{a}	31.58±0.03^{b}	28.2-34.1
MCH (pg)	15.74±0.02^{d}	19.66±0.03^{c}	19.95±0.02^{b}	22.71±0.02^{a}	16.0-23.1
MCV (fL)	41.85±0.02^{d}	68.36±0.03^{c}	72.50±0.04^{a}	70.44±0.03^{b}	50.0-77.8
Neutrophils (%)	2.78±0.02^{d}	15.96±0.01^{c}	19.54±0.02^{a}	17.63±0.02^{b}	5.3-38.1
Lymphocytes (%)	49.68±0.03^{d}	62.17±0.02^{c}	69.42±0.02^{a}	64.33±0.02^{b}	56.7-93.1
Monocytes (%)	3.11±0.02^{d}	5.89±0.01^{c}	6.27±0.02^{a}	5.77±0.02^{d}	0.00-7.7
Eosinophils (%)	1.22±0.03^{c}	2.59±0.02^{c}	3.11±0.02^{a}	2.90±0.01^{b}	0.0-3.4
Serum Protein (mg/dL)	4.83±0.02^{d}	6.81±0.02^{c}	7.15±0.03^{a}	6.97±0.02^{b}	6.0 - 8.0
Albumin (mg/dL)	2.63±0.02^{d}	3.97±0.03^{c}	4.60±0.02^{a}	4.07±0.02^{b}	3.5 - 5.0
Globulin (mg/dL)	2.20±0.02^{d}	2.84±0.02^{b}	2.55±0.03^{c}	2.90±0.03^{a}	-
Creatinine (mg/dL)	3.86±0.08^{a}	0.59±0.01^{b}	0.41±0.01^{d}	0.49±0.01^{c}	0.7 - 1.4
Kidney function indices					
Urea (mg/dL)	10.38±0.03^{a}	8.29±0.04^{b}	6.55±0.02^{d}	7.08±0.03^{c}	7 - 20
Urea/Creatinine	2.69±0.02^{d}	14.05±0.02^{c}	15.98±0.01^{a}	14.45±0.02^{b}	8 - 15
Liver function indices					
AST (U/L)	67.95±0.02^{a}	45.60±0.02^{c}	43.25±0.03^{d}	50.13±0.02^{b}	45.7 - 80.8
ALT (U/L)	41.96±0.02^{a}	21.06±0.02^{c}	19.81±0.03^{d}	23.70±0.02^{b}	17.5 - 30.2
ALP (U/L)	129.11±0.09^{a}	89.36±0.04^{b}	71.18±0.02^{c}	65.95±0.04^{d}	56.8 - 128

Mean ± standard deviation. Values with different superscript in the same row are significantly different at p<0.05. (Sample size 'n'= 42 Wistar rats)
LCF: Local food (100% yellow maize),
UNF: 30% Full fat milk, 25% defatted peanut, 15% Soy oil, 28% sugar and 2% mineral mix
PRD_1: 30% Egg powder, 15% soy oil, 10% carrot flour, 20% banana flour, and 25% yellow maize
PRD_2: 30% Crayfish powder, 15% soy oil, 10% carrot flour, 20% banana flour, and 25% yellow maize.

The mean cell hemoglobin concentration (MCHC), mean cell hemoglobin (MCH) mean cell volume (MCV), lymphocytes and neutrophils of the experimental rats fed on the formulated food samples ranged from 31.58 to 33.63 g/dL, 19.95 to 22.71 pg, 70.44 to 72.50 fL and 64.33 to 69.42%, respectively, and were significantly (p<0.05) higher than control samples (LCF & UNF). This finding is of health benefits, because, low concentration of this hematological parameter in animals is indicative of haemolytic anemia, while an increase is a suggestive of massive intravascular haemolysis (Sridhar *et al*., 2018).

The serum protein, albumin and globulin concentration of the rats fed on therapeutic complementary foods ranged from 6.97 to 7.15 mg/dL, 4.07 to 4.60 mg/dL and 2.55 to 2.90 mg/dL, respectively, and these biochemical parameters, particularly total serum protein and albumin of the formulated diets were significantly higher than in animals fed on the control samples. However, the values fell within the recommended values

(Giannini, *et al*., 1999 Ewuola and Egbunike, 2008); and agreed with the report of Adejuwon *et al*. (2020) on rats fed on complementary diets formulated from sorghum, soybean, and orange flesh sweet potato.

The kidney (creatinine (0.41 - 0.49 mg/dL; urea (6.55 - 7.08 mg/dL)) and liver (aspartate transaminase (AST = 43.25 - 50.13 m/L), alanine transaminase (ALT =19.81 - 23.70 m/L), and alkaline phosphatase (ALP = 65.95 - 71.18 m/L)) functional indices of rats fed on the formulated diets were lower than LCF, but were comparable to that of UNF in concentrations. Interestingly, these enzyme concentrations are within the recommended values reported by Giannini *et al*. (1999) and Ewuola (2008). This observation implies that the formulated diets were free from pathogenic organisms and hazardous chemicals that may affect liver and kidney function. Hence, the formulated diets are suitable as complementary foods, and that consumption of these diets may not impair or damage liver or kidney cell functions. A study has established that concentration of aspartate transaminase, alanine transaminase, and alkaline phosphatase are useful biomarkers of liver function Ewuola (2008), while that of kidney are creatinine and urea [81]; and that high concentration of these enzymes in the blood is an indication of liver or kidney damage (Kasarala, G., & Tillmann, 2016; Agidew *et al*., 2023).

Nutritional Rehabilitation of malnourished rats fed on therapeutic complementary foods

The nutritional rehabilitation of malnourished rats fed on therapeutic complementary foods was presented in Fig. 1(a-b). The nutritional rehabilitation was commenced after 28 days of starving the animals by reducing their daily food intakes as indicated between the slopes AB in Figs. 1a-b. The finding showed that the rats fed on diet PRD_1 exhibited highest growth performance, and better nutrition rehabilitation of the malnourished animals than UNF (a ready-to-eat therapeutic food), and LCF (a traditional complementary food). The best nutrition rehabilitation property exhibited by diet PRD_1 in terms of weight-for-age (underweight), length-for-age (stunting) and weight-for-length (wasting) nutritional indices could be attributed to food composition, and bioavailability of the essential nutrients such as protein, and energy value. Hence, it could be deduced that this particular diet (PRD_1) may be suitable as a potential complementary food, especially to support growth, cognitive development, and managing acute malnutrition among under-five aged children. The nutritional rehabilitative potential of experimental complementary foods in this present study was in line with the findings of Adejuwon *et al*. (2020) and Ijarotimi (2022), who reported that complementary foods produced from locally available food materials are adequate in nutrient-density, and suitable for infant diets.

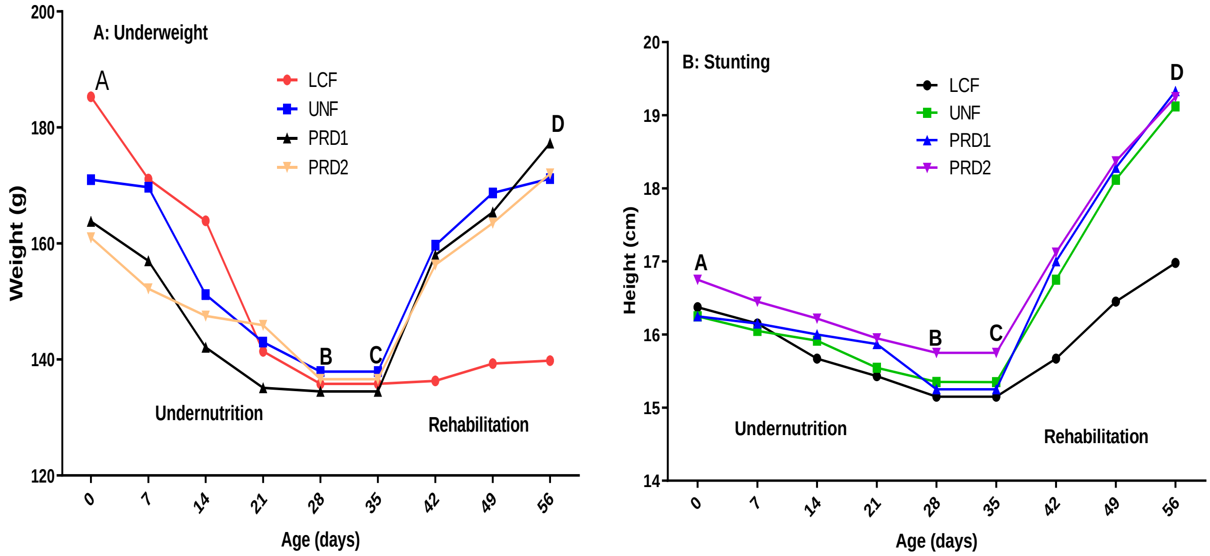

Figure 1a-b: Nutritional status [(weight-for-age index (wasting) and height-for-age index (stunting)] of Acute-Malnutrition (SAM) rats fed on therapeutic complementary foods
(Sample size 'n'= 42)
Key:
LCF: Local food (100% yellow maize), UNF: 30% Full fat milk, 25% defatted peanut, 15% Soy oil, 28% sugar and 2% mineral mix, PRD1: 30% Egg powder, 15% soy oil, 10% carrot flour, 20% banana flour, and 25% yellow maize, PRD2: 30% Crayfish powder, 15% soy oil, 10% carrot flour, 20% banana flour, and 25% yellow maize

Organoleptic property of therapeutic complementary foods for Acute-Malnutrition (SAM) management

The organoleptic property of formulated complementary foods was presented in Table 9. The appearance, aroma, texture, taste and overall acceptability of experimental complementary foods ranged from 5.73 to 7.02, 5.42 to 6.87, 5.31 to 7.07, 5.27 to 7.07 and 5.83 to 7.40 for PRD_1 and PRD_2, respectively. The organoleptic properties of diet PRD_2 were significantly ($p<0.05$) rated higher than PRD_1 and LCF, but insignificantly ($p>0.05$) lower than that of UNF (a control sample). The variation between the rating of sensory attributes of experimental complementary foods and that of control sample could be attributed to the familiarity of the panelists to the control samples or variation in food compositions; whereas, among the experimental complementary foods, PRD_2 was the most preferred. This could be ascribed to differences in food composition, which might have influenced sensorial attributes of the food products. Interestingly, there was no significant (p>0.05) different between the appearance, texture, taste and overall acceptability of PRD_2 and that of UNF (a therapeutic ready-to-eat complementary food developed by UNICEF). This finding further established nutritional quality and acceptability of the present study products as a possible substitute for the Ready-to use therapeutic food (RUTF), which is not always available at the Nutrition Rehabilitation units of the Community Health Centers. Therefore, this study agreed with the recent report on the economical, effectiveness and sustainability of homemade complementary foods for the management of severe acute malnutrition in developing countries (Roy *et al*., 2022).

Table 9: Organoleptic property of therapeutic complementary foods for Acute malnutrition management

Parameters	LCF	UNF	PRD_1	PRD_2
Appearance	6.63 ± 0.66^{b}	7.43 ± 0.77^{a}	5.73 ± 1.11^{c}	7.02 ± 0.94^{ab}
Flavour	6.37 ± 0.76^{b}	7.57 ± 0.71^{a}	5.42 ± 0.93^{c}	6.87 ± 0.87^{b}
Texture	6.17 ± 0.79^{b}	7.37 ± 0.99^{a}	5.31 ± 0.65^{c}	7.07 ± 0.54^{a}
Taste	5.91 ± 0.99^{c}	7.32 ± 0.98^{a}	5.27 ± 0.77^{b}	7.07 ± 0.98^{a}
Overall Acceptability	6.53 ± 0.71^{b}	7.70 ± 0.88^{a}	5.83 ± 0.91^{c}	7.40 ± 0.63^{a}

Mean ± standard deviation. Values with different superscript in the same row are significantly different at p<0.05. (Sample size 'n'= 30)
LCF: Local food (100% yellow maize),
UNF: 30% Full fat milk, 25% defatted peanut, 15% Soy oil, 28% sugar and 2% mineral mix
PRD_1: 30% Egg powder, 15% soy oil, 10% carrot flour, 20% banana flour, and 25% yellow maize
PRD_2: 30% Crayfish powder, 15% soy oil, 10% carrot flour, 20% banana flour, and 25% yellow maize

5. Conclusion

The study established that PRD_1 exhibited good nutritional quality, and ability to support growth and rehabilitate malnourished rats. In this regard, PRD_1 may be suitable as a replacement for milk-based ready-to-use therapeutic foods (RTUF) to manage lactose-intolerance in malnourished children. However, further clinical study is required to establish nutritional potential and acceptability of this complementary food in severely acute malnourished children.

Consent for Publication: Not Applicable

Availability of data and materials: Data are available upon request by contacting the authors.

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