Infant Food Flours Made From Local Products To Combat Acute Malnutrition In Children Under 5 Years Old In Côte D'ivoire

ABSTRACT

In Côte d'Ivoire, recurring stock shortages and difficulties in accessing specialized food products compromise nutritional treatment. This study proposes food formulas of flours composed of locally available products capable of meeting the protein-energy needs of children aged 6 to 59 months diagnosed with moderate acute malnutrition.

The methodological approach consists of formulating and determining the physicochemical, nutrient, and functional characteristics of four new formulations (1F, 2F, 3F, 4F, and 5F).

The results indicate that the formulated foods have high levels of calcium (215.60-252,29 mg/100g MS), potassium (555,70-789,29 mg/100g MS), magnesium (261,26-200,63 mg/100g MS), iron (4,86-7,03 mg/100g MS)and phosphorus (392,36 -469,36mg/100g MS). The fat content varies from 9.66% to 23.86%. The energy value determined for all flours corresponds well to the Codex.The food formulas developed would also be able to meet more than 100% of the daily requirement of vitamins E and B1. The phytate (180.26 - 227.05 mg/100 g) and oxalate (66.00 - 88.00 mg/100 g) contents are low. The presence of phenolic compounds, including flavonoids (7.78-15.44 mg/100 g) and antioxidant activity (31.09-32.84%) would be a significant asset. The levels of deoxynivalenol (62 µg/kg) recorded in flours are below 200µg/kg recommended for infants and young children.

The proposed formulations have high-water absorption capacity (136.15 -252.94%) and high solubility index (56.84 -59.2%). The wettability time ranges from 3.66 ± 0.16 s to 33.71 ± 0.23 s. Flours (1F, 2F, 3F, 5F) have a better absorption capacity for refined palm oil (132 %, 139 %, 121 % ;115 %).

The proposed new formulations have nutritional characteristics close to standard data and could therefore be recommended for children aged 6 to 59 months for complementary feeding in the context of the fight against moderate acute malnutrition.

Keywords*:Nutritional value of local flours,nutritional needs of childrenaged 6 to 59 months,moderate acute malnutrition*

INTRODUCTION

According to [1], undernutrition plays a role in approximately 45% of deaths in children under 5 years of age. These deaths occur mainly in low- and middle-income countries. Previous studies have noted that in Côte d'Ivoire, undernutrition is the underlying cause of approximately 45% of annual deaths in children under 5 years of age with 42,000 deaths per year, or 115 deaths per day [2] (André et al., 2013). More recent results from the Demographic and Health Survey indicate a prevalence of 23% of children under 5 years of age suffering from stunting, of which 8% are severely stunted, while 8% suffer from acute malnutrition with 2% in the severe form. The results also show that 14% are underweight, including 4% in the severe form. For anemia, 26% of children have the mild form, 39% the moderate form and 3% the severe form[1].

Acute malnutrition is one of the leading causes of morbidity and mortality in children under 5 years of age because it is the most severe degree of malnutrition [3]. Children suffering from acute malnutrition have a weakened immune system and are more likely to die from common childhood diseases. Those who survive may face growth and development problems throughout their lives [4].

Thus, for the reduction of acute malnutrition and its corollaries which constitute a priority for the WHO, specialized food products have been developed. Developed by public research (IRD, Research Institute for Development) and the agri-food industry, these foods have enabled strong management of acute malnutrition, which has been largely demedicalized and pharmaceuticalized ([5,6]. However, in some countries and their contexts, specialized food products in which therapeutic and supplementary foods are found are still not fully accepted by community members, while other countries face problems of supply, storage and supply chain management, which has repercussions on the availability and use of these foods [7]. The alternative to these situations for some developing countries is the formulation of traditional complementary foods or porridges made from simple, fermented or enriched local cereal flours and manufactured in a traditional way [8]. This alternative has the advantage of easier production of complementary foods thanks to the availability and use of local foods as well as the reduced cost of production conditions.

In Côte d'Ivoire, several interventions to combat malnutrition have been undertaken. Some of these interventions are systematized in intervention packages such as outpatient nutritional care for people living with HIV, the adoption of a national nutrition policy in June 2015 and the establishment of a national multisectoral nutrition plan in May 2016 [9]. This plan consists of the distribution of specialized food products. However, although the National Nutrition Program (PNN) has some funding for the supply of specialized food products, it is currently not possible to meet all demands. Indeed, recurring stockouts and difficulties in accessing services providing specialized food products compromise nutritional treatment and significantly increase dropout rates [10].

To remedy this situation, this study was initiated to propose food formulas of flours composed of local products capable of meeting the protein-energy needs of children aged 6 to 59 months diagnosed with moderate acute malnutrition.

2 MATERIAL AND METHODS

The food material consists of flours produced at the Biotechnology Laboratory of the UFR Biosciences of the Félix Houphouët-Boigny University (Abidjan, Côte d'Ivoire). from millet grains (*Panicum miliaceum*), soybeans (*Glycine max*), corn (*Zea mays*), rice (*Oriza sativa*) and peanuts (*Arachis hypogea L*) purchased from wholesalers at the "Marché forum" in Adjamé and fresh fish of the genus *Clupea harengus*, purchased from a fishmonger at the autonomous port of Abidjan (Côte d'Ivoire). The manufactured material consists of brown sugar, refined edible palm oil enriched with vitamin A, crude palm oil, sunflower oil, olive oil, whole milk powder purchased from a shopping center in the Abidjan district.

2.1Preparation of the different ingredients used in the preparation of food formulas

Two (02) kg of millet grains were winnowed, washed with tap water and drained. They were then spread in clean basins and then germinated in a cupboard protected from light for 72 hours at room temperature (28 ± 2 °C).
Two (2) kg of dried corn grains were sorted, washed with tap water and then soaked for 18 hours at room temperature (28 ± 2 °C). After soaking, the grains were washed with tap water and drained and then spread in clean basins. They were germinated in a cupboard protected from light and any external contaminants for 48 hours at room temperature (28 ± 2 °C).
Two (2) kg of soybeans were sorted, washed with water and soaked in tap water for 24 h at room temperature (28 ± 2 °C) in a clean container covered with a cloth (tulle).
After germination, the grains and fish were washed with tap water, drained and then spread evenly on grids covered with baking paper before being dried at 50 °C for 24 h in a Venticell oven (MMM Medcenter, Germany). The dried grains and fish were lightly pounded in a clean artisanal mortar, then

ground using a Moulinex electric mill (France). The flours obtained were sieved using a fine mesh sieve (200 µm) and then roasted on a hotplate equipped with a probe at 70 °C for 30 min with constant stirring, stored after cooling in sterile glass jars labeled at room temperature (28 °C ± 2 °C). The jars were stored in a clean and non-humid place, away from any external contaminants.

2.2 Formulation of food formulas

Different formulations were made using the matrix method [11] (Table I).

Table I: Food formulas

Ingredients	**Food formulas**				
(For 100g of food)	**1F**	**2F**	**3F**	**4F**	**5F**
Corn (g)	---	20	25	20	---
Millet (g)	30	10	---	---	25
Soybeans(g)	30	30	30	30	30
Peanuts paste (g)	---	---	--	15	10
Whole milk powder(g)	15	15	15	15	15
RPO (g)	18	15	20	---	---
UPO (g)	---	---	---	10	10
Sugar (g)	7	10	10	10	10

RPO: refined edible palm oil enriched with vitamin A; UPO: unrefined palm oil

2.3 Physicochemical, biochemical, nutritious, and functional characteristics of infant food formulas

2.3.1 Determination of physicochemical characteristics

The water content of the food flourswas determined by using the oven drying methoddescribed in [12]. Food flours samples (10.00 g) were weighed out (W1)in porcelain dishes and were kept for drying at80 °C for 3 to 6 hours. Then, the sample wasremoved from the oven, cooled in a desiccatorfor 30 to 45 minutes and weighed again (W2).The moisture contents of the samples wereobtained from the weight difference (W1 – W2),and the percent weight losses were calculated,accordingly

Titratable acidity consisted of measuring the amount of acid present in the different flours using a sodium hydroxide solution (0.1 N) in the presence of phenolphthalein as a colored indicator. 10 grams of each sample were diluted in 90 mL of distilled water. The solution obtained was then filtered on filter paper (Whatman). Then, 10 mL of the filtrate was titrated with NaOH solution (0.1 N) in the presence of two (2) drops of phenolphthalein to the turn to pink [12].

2.3.3 Determination of the biochemical and nutritional properties of food formulas

2.3.3.1Crude proteins

The crude proteins of the spent brewer's yeast samples were calculated by the Kjeldahl method[13]. Nitrogen from nitrates and nitrites was not considered by using this dosing principle. Thedried sample (0.50 g) was first digested by heating in strong sulfuric acid (15.00 ml) in thepresence of a catalyst (1.00 g) which helps in the conversion of the amine nitrogen to ammoniumions. This digestion step

ended in 30 min with the appearance of green coloration. After digestion,the ammonium ions were dissolved in distilled water (250.00 ml) containing 5 drops ofphenolphthalein and 1 M sodium hydroxide (75.00 ml). The contents were heated anddistilled. The liberated ammonia gas was led into a trapping solution, (10 g/l) Boric acid (10.00 ml)mixed with a few drops of a mixed indicator dye (methyl red + bromocresol green), where itdissolved and became an ammonium ion once again. Finally, the amount of the ammonia thathad been trapped was determined by titration with a 0.1 N hydrochloric acid.

2.3.3.2 Fat extraction

The samples were minced, homogenized, and weighed. Then, the extraction of total fat was carried out on 2 g of sample using a liquid extraction based on the Folch method (chloroform/methanol 2/1 v/v) [14].

2.3.3.3 Carbohydrates

The beer lees carbohydrates were quantified by using the standard method of [15] AOAC 938.02 (1938). To 3 mL of the sample, add 2 mL of acetonitrile and 0.1 g of NaCl and the mixture was vortexed and centrifuged at 5,000 rpm for 10 min. 100 µL was withdrawn from the supernatant layer and evaporated to dryness under vacuum. Add 100 µL of dichloromethane (DCM) to the dried sample and repeat the evaporation process. Again add 100 µL of bis (trimethylsilyl) trifluoroacetamide (BSTFA). Finally, the whole mixture was dried in an oven at 80°C for 30 min and the resulted solution made up to 1.5 mL with acetonitrile then put in a vial for chromatographic analysis.

2.3.3.4 Energy Value

The energy value of the meal samples was calculated based on the energy coefficients defined by [16].

2.3.3.5Mineral contents

Mineral contents (Ca, K, Mg, Na, Fe, and Zn) were determined by atomic absorption spectrophotometry, using the digestion method described in [12]. A sample of ash (0.5 g) from each pre-dried meal sample was dissolved in 30 mL of a mixture of perchloric acid (11.80 mol/L), nitric acid (14.44 mol/L) and sulphuric acid (18.01 mol/L). The mixture, stirred under the hood, was heated on a hot plate until thick white smoke appeared. After this heat treatment, the mixture was cooled to room temperature (28 ± 2 °C) for 15 minutes and then 50 mL of distilled water was added. The mixture thus obtained was brought to a boil again for 30 minutes on a hot plate and then cooled under the same conditions as before. It was then filtered through Whatman No. 4 filter paper in a 50 mL vial. The filtrate obtained was completed with the gauge line of the flask with distilled water. The content of each mineral was determined by atomic absorption spectrophotometer at a specific wavelength corresponding to each mineral in comparison with standard solutions.

For the determination of phosphorus, to two (2) (mL) of previously prepared sample, five (5) mL of distilled water, 1 mL of molybdic reagent and 1 mL of sodium sulphate were successively added. Then, the whole thing was incubated in the dark for 30 min and the optical density was read with a spectrophotometer at 700 nm against the control.

A standard range was established from a phosphorus solution (25 ppm) and prepared under the same conditions as the samples. The calibration line was used to determine the phosphorus content of the samples analyzed.

2.3.3.6Vitamin dosage

The vitamin B1 content of the samples was determined by high performance liquid chromatography technique using the method described by European pharmacopoeia book [17].1 g of each sample was weighed and dissolved in 100 mL of the mixture containing water (94 mL v/v), acetonitrile (5 mL v/v) and acetic acid (1 mL, v/v). The mixture obtained was heated in a water bath to 65 °C under stirring until completely dissolved. The resulting solution was then filtered on whatman filter paper and 20 µL of the filtrate was injected at 1.0 mL/min as a flow rate in a C18 column for detection at 272 nm against the standard solution. It should be noted that the chromatographic chain used is of the Shimadzu SPD 20A type.

The extraction of fat-soluble vitamins A, D, E was carried out according to the method described by [18].

To 1 g of each sample were added 10 mL of a 10% solution of KOH prepared in methanol-water (1:1, v/v). To avoid the oxidation process during saponification, 0.025 g of ascorbic acid was added. The mixture was then refluxed in a water bath at 70 °C for 30 min and then cooled and extracted with 3 x 5 mL of hexane. The hexanic phases were gathered and dried on anhydrous sodium sulphate and then evaporated dry. The resulting residue (approx. 0.3 g) was included in methanol (10 mL) for analysis. 20 µL of each solution was injected at 1.0 mL/min as a flow rate.
The evaluation of the fat-soluble vitamin contents was carried out by HPLC coupled with a fluorimetric detector at 455 nm for vitamin A, 245 nm for vitamin D and 295 nm for vitamin E. The analysis was performed in isocratic mode on a Hypersil ODS column.
The standards were prepared by dilution series (1/10th then 1/2):α-tocophérol (E) :3,4µg/100 mL;Meadow (A): 11,3 µg/100 mL;Ergocalciférol (D2) : 8,6µg/100 ml. All calculations were based on the 100% control.

2.3.3.7 Carotenoids assay
The carotenoids in formulations were extracted with hexane after saponification, as described by [19].
One (1 g) of each food formula weighed in a test tube was solubilized in 5 mL of ethanol containing 0.1% (w/v) butylated hydroxytoluene (BHT) and the mixture was subsequently heated in a water bath at 85°C for 5 min. Then, 400 µL of 80% KOH solution (w/v) was added to the test tube and the suspension was saponified at 85 °C for 5 min in a water bath. After saponification, the tubes were cooled in an ice bath and then 3 mL of distilled water and 4 mL of n-hexane were successively added. The tubes were centrifuged at 1700 rpm for 3 min using a centrifuge and the supernatant containing the carotenoids was removed. Two successive extractions were performed with 2 x 4 mL of n-hexane and all supernatants were removed and mixed to form the final extract.
The carotenoids contained in the final extract were quantified by reading the optical density with a spectrophotometer at 450 nm against hexane. A standard range was established from a stock solution of β-carotene (1 mg/mL) under the same conditions as the test.

2.3.3.8Assay of total polyphenols
The method used to assay the total polyphenols was that proposed by the reagent of [20].
One (01) gram of dried yeast sample is homogenized in 10 mL of 70% (v/v) methanol. The mixture obtained was centrifuged at 1000 rpm for 10 min. The pellet was recovered in 10 mL of 70% (v/v) methanol and centrifuged again. The supernatants were pooled in a Falcon tube.

Two hundred (200) µL of methanolic extract was introduced into a test tube and added with two hundred (200) µL of Folin-Ciocalteu reagent. The tube was left to stand for 3 min, then 200 µL of 20% (w/v) sodium carbonate solution was added. To the contents of the tube was added 1.4 mL with distilled water and the whole was placed in the dark for 30 min. The absorbance reading was taken with a spectrophotometer at 760 nm against a blank. A standard range established from a stock solution of gallic acid (0.1mg/mL) under the same conditions as the test makes it possible to determine the quantity of polyphenols in the sample.

Tannin: The tannin content was determined by the method of [21]. One (1) mL of methanolic extract from each flour was collected, to which was added 5 mL of vanillin reagent (0.1 mg/mL vanillin in 70% sulphuric acid; v/v). The solution obtained was left to rest for 20 min in the dark and the absorbance was read with a spectrophotometer at 500 nm against a control.
A standard range is established from a stock solution of tannic acid (2 mg/mL) under the same conditions as the test for the determination of the amount of tannins in the sample.

Flavonoid: The method used is the one described by [22].
A volume of 0.5 mL of the methanolic extract of each flour was collected, to which were successively added five (5) mL of distilled water, 0.5 mL of aluminum chloride (10%; w/v), 0.5 mL of sodium acetate (1M) and two (2) mL of distilled water. The mixture was left to rest for 30 min at room temperature (28 ± 2°C). The absorbance was read with a spectrophotometer at 415 nm against a control.
A standard range was established from a quercetin stock solution (1 mg/mL) under the same conditions as the test for the determination of the amount of flavonoids in the sample.

*Antioxidant activity***:** This was performed according to the method described by [23]. To a volume of 1.5 mL of methanolic extract from each flour, one (1) mL of DPPH solution (3 mM in methanol) was added. The tube was left to rest for 30 minutes in the dark. The absorbance was read with a spectrophotometer at 415 nm against a blank.

2.3.4 Determination of anti-nutritional properties

The method used to determine oxalate levels is described by [24]**.** It is based on the solubilization of oxalates in an acidic medium and hot, then their dosage by potassium permanganate.
Phytates were determined according to the method described by [25]. The principle of this method is based on the modification of the color of the Iron-sulfosalicylic acid complex in the presence of phytates.
The determination of deoxynivalenol was carried out using the method described in [26]. Deoxynivalenol is removed from the sample by water. The aqueous extract is purified on an immunoaffinity column to remove any impurities from the sample. Deoxynivalenol is then quantitatively ascertained by HPLC and UV detection (220 nm).

2.3.5 Determination of functional properties

The water absorption capacity and water solubility indices of the meals were determined respectively according to the methods of [27] and [28]. A homogeneous aqueous suspension of each flour prepared at 10% (w/v) was incubated in a water bath at 37 °C for 30 min. It was then centrifuged at 5000 rpm for 15 min. The resulting pellet was weighed using a precision scale and then dried at 105 °C in an oven until a constant mass was obtained.

The method described by [29] was used to determine the oil absorption capacities of formulated flours. The oils used were refined palm oil, unrefined (crude) palm oil, sunflower oil and olive oil. One (1) g of each flour was dissolved in 10 mL of oil, the mixture obtained was stirred for 30 min at room temperature (28 ± 2°C) using a mechanical stirrer, then centrifuged at 4500 rpm for 10 min. The recovered base was weighed using a precision scale.

The method adopted for the determination of dispersibility is that described by [30]. Ten (10) mL of distilled water was added to one gram of flour contained in a 50 mL graduated cylinder. The mixture was stirred carefully by hand for two (2) min (avoid losing some of the solution). The dispersibility of each flour was defined as the difference between the total volume of particles just after manual stirring (V0) and the volume (Vt) of deposited particles recorded at time (t) min.
The hydrated densities of the flours were determined according to the method proposed by. A mass of 0.5 g of each flour was added to 5 mL of distilled water contained in a 10 mL graduated cylinder. The difference between the volume of water before and after the sample was added was marked as the volume of water moved in milliliter. The hydrated density of each flour was expressed in grams of flour per mL of distilled water displaced.

The method of [32] was used to determine the bulk densities of formulated flours. Fifty (50) g of flour was introduced into a 100 mL graduated cylinder. The volume was noted after a good difference in level with a spatula (without tapping the specimen on the bench), then the specimen was gently tapped on the bench until a constant volume was obtained. The bulk density was calculated from the following formula:

Wettability is the ability of a powder to submerge after being deposited on the surface of the water [33], it reflects the ability of the powder to absorb water at the surface [34]. In this study, it was determined using the technique of [35]. One gram of each flour was placed in a 25 mL graduated cylinder with a diameter of 1 cm. The sample is then poured into a 600 mL beaker containing 500 mL of distilled water. Wettability was determined to be the time required for the sample to become completely wet.

3. RESULTS AND DISCUSSION

3.1 RESULTS

3.1.1 Physicochemical properties of the feed formulas

Table II presents the physicochemical properties of the flours. Statistical analysis reveals a significant difference in pH (1F: 6.30 ± 0.06;2F and 3F:6.4 ± 0.00 for), titratable acidity (7 ± 1.0 meq/100g for 3F

and 16.66 ± 0.57 meq/100g for 5F) and ash content (2.2 ± 0.2% and 3.0 ± 0.00%, respectively 2F and 1F) of the different formulations (P<0.05).
No significant differences (P>0.05) were revealed for humidity values (3.37 ± 0.16% for 4F and 4.6 ± 0.00% for 1F) and for dry matter rate, (95.40 ± 0.0% for 1F to 96.63 ± 0.44% for 5F).

Table II: Physicochemical properties of food formulas

Physicochemical properties	**Foodformulas**				
	1F	**2F**	**3F**	**4F**	**5F**
pH	6.30 ±0.06[a]	6.40 ±0.00[c]	6.40 ±0.00[c]	6.30 ±0.00[b]	6.20 ±0.06[a]
Humidity (%)	4.60 ±0.00[a]	3.47 ±0.30[a]	3.76 ±0.72[a]	3.37 ±0.16[a]	3.69 ±0.44[a]
Dry Matter (%)	95.40 ±0.00[a]	96.53 ±0.30[a]	96.23 ±0.72[a]	96.63 ±0.16[a]	96.63 ±0.44[a]
TitratableAcidity(meq/100g)	15.33 ±0.57[c]	14.33 ±0.57[b,c]	7 ±1.00[a]	13.66 ±0.57[b]	16.66 ±0.57[d]
Ash (%)	3.00 ±0.00[c]	2.20 ±0.20[a]	2.30 ±0.10[a,b]	2.50 ±0.10[b]	2.3 ±0.10[a,b]

The values given in the table are the means ± standard deviations of tests carried out in triplicate. Within the same row, values with the same exponent do not differ significantly (p > 0.05).1F: 1 food formulas; 2F: 2 food formulas; 3F: 3F food formula; 4F: 4 food formula; 5F: 5 food formula

3.1.2 Biochemical properties of food formulas

The 4F food formulation is the richest in protein (23.43 ± 0.30%), fat (22.40 ± 0.00%) and a higher energy value (488.50 ±0.62) but with a low carbohydrate content (48.29 ± 0.35%) compared to the other food formulations (P<0.05) (**Table III)**

Table IIII : Biochemical properties of feed formulas

Biochemicalparameters	**Food formula**				
	1F	**2F**	**3F**	**4F**	**5F**
Fat (%)	12.63 ±0.40[a]	13.53 ±0.80[b]	13,33 ±0,57[a,b]	22.40 ±0.00[d]	20.07 ±0.23[c]
Protein (%)	17,90 ±0,20[a]	21.73 ±0.30[c]	18.00 ±0.20[a]	23.43 ±0.30[d]	20,20 ±0,20[b]
Carbohydrates (%)	61.86 ±0.20[d]	59.06 ±1.54[c]	62.60 ±0.86[d]	48.29 ±0.35[a]	54.06 ±0.30[b]

Energy Value (kcal/100g)	432.76 ±2.02[a]	444.97 ±2.75[b]	442.40 ±4.9[b]	488.50 ±0.62[d]	477.66 ±2.34[c]

The values given in the table are the means ± standard deviations of tests carried out in triplicate. Within the same row, values with the same exponent do not differ significantly (p > 0.05).1F: 1 food formulas; 2F: 2 food formulas; 3F: 3F food formula; 4F: 4 food formula; 5F: 5 food formula

3.1.3 Mineral content of food formulas

The results indicate that F5 contains more calcium (252.29 ±0.01 mg/100g DM), magnesium (261.26 ±0.05 mg/100g) and phosphorus (469.36 ± 0.00 mg/100g) and zinc (2.13 ± 0.00 mg/100g), F4 has a higher level of potassium (789.29 ± 0.06 mg/100g DM) and sodium (33.83 ± 0.00 mg/100g DM), F1 contains more iron (7.03 ±0.00 mg/100g DM) and less zinc (1.90 ± 0.00 mg/100g DM) per other food formulas (P<0.05) (Table IV).

Table IV: Mineral content of feed formulae

Mineral(mg/100g MS)	**Feed Formulas**				
	1F	**2F**	**3F**	**4F**	**5F**
Calcium	245.59 ±0.01[d]	220.60 ±0.00[b]	215.60 ±0.01[a]	235.60 ±0.01[c]	252.29 ±0.01[e]
Potassium	665.40 ±0.00[c]	604.58 ±0.02[b]	555.70 ±0.00[a]	789.29 ±0.06[e]	756.29 ±0.01[d]
Magnesium	206.18 ±0.02[d]	200.63 ±0.11[a]	202.30 ±0.00[b]	205.5 ±0.00[c]	261.26 ±0.05[e]
Sodium	5.06 ±0.00[a]	4.56 ±0.00[a]	6.93 ±0.00[b]	33.83 ±0.00d	32.36 ±0.00c
Iron	7.03 ±0.00[e]	6.16 ±0.00[c]	4.86 ±0.00[a]	5.23 ±0.00[b]	6.60 ±0.00[d]
Zinc	1.90 ±0.00[a]	1.93 ±0.00[a]	2.06 ±0.00[a]	2.03 ±0.00[a]	2.13 ±0.00[a]
Phosphorus	426.56 ±0.00[d]	405.5 ±0.00[b]	392.36 ±0.00[a]	414.06 ±0.00[c]	469.36 ±0.00[e]

The values given in the table are the means ± standard deviations of tests carried out in triplicate. Within the same row, values with the same exponent do not differ significantly (p > 0.05).1F: 1 food formulas; 2F: 2 food formulas; 3F: 3F food formula; 4F: 4 food formula; 5F: 5 food formula

3.1.4 Vitamin content of flours

The 3F feed formulation is rich in vitamins A (250.4 ± 0.46 µg/100 g), E (33.60 ± 0.46 mg/100 g) and vitamin D (1.06 ± 0.06 µg/100 g) while the vitamin is predominant in the F5 food formula (0.85 ± 0.06 mg/100 g) (Table V).

Table VII : Vitamin content of food formulas

Vitamins	food formulas				
	1F	2F	3F	4F	5F
Vitamin A (µg/100g)	243.77 ±0.70^{d}	201.57 ±0.51^{c}	250.40 ±0.46^{e}	50.73 ±0.25^{a}	79.93 ±0.15^{b}
Vitamin E (mg/100 g)	28.80 ±0.40b	30.36 ±0.90c	33,60 ±0,46^{d}	26,56 ±0,57^{a}	27,00 ±0,30a
Vitamin D (µg/100g)	0.93 ±0.11$^{a, b}$	0.86 ± 0.11^{a}	1.06 ± 0.06^{b}	0.86 ± 0.00^{a}	0.80 ± 0.00^{a}
Vitamin B1 (mg/100 g)	0.79 ± 0.01^{d}	0.67 ± 0.01^{c}	0.61 ± 0.01^{b}	0.58 ± 0.00^{a}	0.85 ± 0.06^{e}

The values given in the table are the means ± standard deviations of tests carried out in triplicate. Within the same row, values with the same exponent do not differ significantly (p > 0.05).1F: 1 food formulas; 2F: 2 food formulas; 3F: 3F food formula; 4F: 4 food formula; 5F: 5 food formula

3.1.5 Phenolic compound content and antioxidant activity of food formulas

The total phenol (94.29 ± 1.16 mg/100 g) and tannin (6.56 ± 0.11 mg/100 g) contents were higher in the 5F feed formula, while the flavonoid content (15.44 ± 0.55 mg/100) and antioxidant activity (32.84 ±0.36 mg/100), the highest were recorded with the 3F and 1F formulas, respectively.

Table VI: Phenolic compound content and antioxidant activity of flours

Nutritional Constituent	Feed Formulas				
	1F	2F	3F	4F	5F
Total phenols(mg/100 g)	76.15 ±3.68^{a}	86.95 ±1.3^{b}	88.14 ±1.41^{b}	92.89 ±2.94^{c}	94.29 ±1.16^{c}
Tannins (mg/100 g)	4.27 ± 0.12^{a}	5.43 ± 0.08^{b}	5.58 ±0.07^{b,c}	5.64 ± 0.06^{c}	6.56 ± 0.11^{d}
Flavonoids (mg/100 g)	8.51 ± 0.21^{a}	7.78 ± 0.55^{a}	15.44 ±0.55^{d}	13.01 ±0.75^{c}	11.79 ±0.91^{b}
Antioxidantactivity%	32.84 ±0.36^{d}	31.09 ±0.55^{b}	32.36 ±0.20^{c}	32.06 ±0.27^{c,d}	30.42 ±0.10^{a}

The values given in the table are the means ± standard deviations of tests carried out in triplicate. Within the same row, values with the same exponent do not differ significantly (p > 0.05).1F: 1 food formulas; 2F: 2 food formulas; 3F: 3F food formula; 4F: 4 food formula; 5F: 5 food formula

3.1.6 Anti-nutritional and mycotoxin levels in feed formulas

The content of oxalates (110.00 ± 0.00mg/100 g) and phytates (191.11 ± 3.02 mg/100 g) are higher in the 5F and 4F formulas respectively, while the DON value is higher (60.00 ±1.00 µg/kg) with the 1F formula (Table VII).

Table VII: Levels of anti-nutritional compounds and mycotoxins in feed formulas

Anti-nutritional compounds and mycotoxin	Feed Formulas				
	1F	2F	3F	4F	5F
Oxalates (mg/100 g)	88.00 ± 0.00^{b}	110.00 ±0.00^{c}	66.00 ± 0.00^{a}	88.00 ± 0.00^{b}	110.00 ±0.00^{c}
Phytates (mg/100 g)	227.05 ±2.81^{e}	216.52 ±1.84^{d}	205.01 ±2.1^{c}	191.11 ±3.02^{b}	180.26 ±1.6^{a}
Deoxynivalenol (µg/kg)	53.33 ±3.21^{c}	60.00 ±1.00^{d}	45.00 ±1.00^{a}	49.33 ±1.52^{b}	51.66 ±1.52^{b,c}

The values given in the table are the means ± standard deviations of tests carried out in triplicate. Within the same row, values with the same exponent do not differ significantly (p > 0.05).1F: 1 food formulas; 2F: 2 food formulas; 3F: 3F food formula; 4F: 4 food formula; 5F: 5 food formula

3.1.7 Functional properties of food formulas

The 2F food formula has a higher water absorption capacity (252.94 ± 0.01%) and solubility index (59.20 ± 0.01%) while the 5F has a high dispersibility (88.89 ± 0.00%). The highest hydration density (0.50 ± 0.10 g/mL) is recorded with the 3F and 4F food formulas. In addition to having high porosity (29 ± 0.00%), 4F has the highest bulk density (0.80 ± 0.00 g/mL) and the lowest wettability 3.66 ± 0.16%

In terms of oil absorption capacity, refined palm oil obtained the highest values for 1F, 2F, 3F and 5F flours (132 ± 1%, 139 ± 1%, 121 ± 1 and 115 ± 1%) while unrefined palm oil obtained the highest value for 4F flour (98 ± 1%)

Table VIII: Functional properties of food formulas

Functionalproperties	Food Formulas				
	1F	2F	3F	4F	5F
WAC (%)	233.33 ± 0.01^{c}	252.94 ± 0.01^{e}	236.44 ± 0.01^{d}	136,15 ± 0.01^{a}	228.7 ± 0.1^{b}
SI (%)	58.6 ± 0.01^{d}	59.2± 0.01^{e}	57.2 ± 0.1^{b}	57.4 ± 0.1^{c}	56.84 ± 0.94^{a}
DI (%)	77.77 ± 0.00 ^{a}	88.42 ± 0.79 $^{c, d}$	87.82 ± 1.82$^{c, d}$	88.89 ± 0.00^{d}	80 ± 0.00^{b}

HD (g/mL)	0.46 ± 0.05[a]	0.40 ± 0.00[a,b]	0.50 ± 0,00[a,b]	0,50 ± 0.00[a,b]	0.40 ± 0,1[a]
BD (g/mL)	0.64 ± 0.00[a]	0.65 ± 0.00[a]	0.66 ± 0.00[a]	0.80 ± 0.00[b]	0.66 ± 0.00[a]
P (%)	24.27 ± 0.00 [a]	25.96 ± 0.00 [b]	24 ± 0.00[a]	29.54 ± 0.00 [c]	24 ± 0.00 [a]
WE (s)	18.31 ± 0.29[c]	25.29 ± 0.29[d]	33.71 ± 0.23[e]	3.66 ± 0.16[a]	12.91 ± 0.07[b]
ACRPO(%)	132 ± 1[d]	139 ± 1[e]	121 ± 1[c]	93 ± 1[a]	115 ± 1[b]
OOAC (%)	59 ± 1[a]	82 ± 1[d]	69 ± 1[b]	68 ± 1[b]	79 ± 1[c]
SOAC (%)	98 ± 1[d]	95 ± 1[c]	100 ± 1[e]	80 ± 1[a]	86 ± 1[b]
ACUPO (%)	119 ± 1[d]	118 ± 1[d]	108 ± 1[c]	98 ± 1[a]	104 ± 1[b]

The values given in the table are the means ± standard deviations of tests carried out in triplicate. Within the same row, values with the same exponent do not differ significantly (p > 0.05).
WAC: water absorption capacity; SI: Solubility Index; DI: dispersibility; HD: hydrated densities; BD: bulk density; P: porosity; WE: wettability; ACRPO: Absorption capacity of refined palm oil; OOAC: Olive Oil Absorption Capacity; SOAC: sunflower oil absorption capacity; ACUPO: Absorption capacity of unrefined palm oil (red oil).1F: 1 food formulas; 2F: 2 food formulas; 3F: 3F food formula; 4F: 4 food formula; 5F: 5 food formula

3.2 DISCUSSION

The food formulas developed have high levels of calcium, potassium, magnesium, iron, zinc and phosphorus. They could be very good sources and could therefore be used as a complementary food in the fight against moderate acute malnutrition and malnutrition due to deficiency of these minerals. In fact, the calcium content obtained per 100 g of each food formula developed can cover between 43 and 50% of the reference dietary intake and more than 70% of the daily needs of infants aged 6 months and over. In terms of the average nutritional requirement, between 30 and 64% for children aged 12 to 59 months. Consuming these elaborate food formulas would therefore be more advantageous for moderate acute malnourished, especially 1F, 4F and 5F flours. Indeed, calcium plays a key role in mineralization and skeletal structure. It is required for many biological functions such as neuromuscular excitability, blood clotting, membrane permeability, hormone release, enzyme activation, and cell signaling [36]**.**

The presence of zinc at a higher level in these elaborate food formulas could make it possible to make up for the deficits and deficiencies of children in the fight against malnutrition and its consequences. Zinc is an essential micronutrient, the deficiency of which could lead to stunted growth in children and weight loss, immunosuppression associated with increased susceptibility to infections and tumours[37]**.** Similarly, magnesium deficiency is the cause of muscle contractions and hyperactivity encountered in malnourished children [38]**.**The consumption of elaborate food formulas would be more beneficial, especially since 100g of these flours are able to fully meet the daily magnesium requirement of children aged 6 to 59 months (80-210 mg/day).
The high potassium levels indicate that these elaborate food formulas can meet more than 50% of the daily requirement of children aged 6 to 59 months (750-1100 mg/day) for this mineral. Thus, the consumption of these food formulas would be beneficial for malnourished children given the fundamental role of potassium in nerve transmission, muscle contraction and heart function. It is also involved in insulin secretion, in carbohydrate and protein metabolism and in acid-base balance. Potassium deficiency mainly results in heart rhythm disorders, cramps, fatigue and polyuria [36]**.**

The phosphorus content of the food formulas developedcan meet more than 100% of the daily requirement of infants aged 6 months and more than 80% of the daily requirement of children aged 1 to 3 years and more than 50% of the daily requirement of children aged 4 to 6 years (160-440 mg/day).
For iron, the values determined for the formulated formulas are likely to meet the daily requirement of children aged 6 to 59 years (5-8 mg/day). The presence of iron in these foods could help prevent iron deficiency anemia in children and make up for the deficits of those suffering from moderate acute malnutrition. Indeed, iron is necessary for the transport and use of oxygen as well as for various oxidation-reduction reactions. Iron deficiency in infants and young children is thought to cause attention, memory and learning impairments for which iron administration has no effect. However, an *in vivo* studywill need to be conducted to determine its bioavailability.

These developed food formulas have relatively low sodium levels compared to the nutritional reference for children aged 6 to 59 months (370-1000 mg/day). However, this intake could be compensated by family foods from the local diet.

The fat content of the 1F, 2F, 3F, 4F and 5F formulas is between 9.66% and 23.86%, which corresponds to a range of 20.34% to 43.53% of total energy intake. These levels are in accordance with the recommendation of [39]Codex **CAC/GL 8-1991** for supplementary food preparations, i.e. at least 20% of the total energy intake. Indeed, the contribution of lipids to energy intake is very important in infants. In addition to their energetic roles, lipids are essential for brain development and function [40]**.** The values thus determined are greater than those determined by [41 for infant flours made from cassava and soya.
These high fat levels are thought to result from the presence of two legumes (peanut and soybean) rich in lipids [42]**.**Peanuts and soybeans are oleaginous legumes that contain 42-48% and 18-21% fat respectively with an average of 15-20% unsaturated (mainly oleic, linoleic, linolenic) [43] which are considered "good fats" for cardiovascular health (monounsaturated and polyunsaturated). These elaborate food formulas would therefore be good lipid sources that could help in the fight against moderate acute malnutrition. In addition, the relatively low-fat content of formulated 1F, 2F, 3F food formulas would be beneficial for their preservation because, according to [44]**,** a low-fat content in a dry product could reduce the risk of rancidity, thus increasing the shelf life.
The energy value determined for all flours corresponds well to the Codex recommendation which recommends a minimum energy intake of 4 Kcal/g (400 Kcal/100g) in the complementary preparations of children of weaning age and those of young age (12 to 36 months). The 4F and 5F formulations have a higher energy value that can be explained by their high lipid content.

The food formulas developed would also be able to meet more than 100% of the daily requirement of vitamins E and B1. Also, for vitamin A, the formulations 1F, 2F and 3F could be used as a complementary food, as they would be able to cover more than 60% of the daily requirement. Nutritional rehabilitation with these food formulas would therefore be more beneficial, as they could contribute to the correction of the still reversible damage caused by vitamin A deficiency, thus preventing it from reaching an irreversible level. Indeed, vitamin A deficiency could lead to intrauterine and postnatal growth retardation, as well as birth defects, loss of twilight vision and dryness of the ocular conjunctiva [36]**.** The food formulas developed are low in vitamin D, a fat-soluble vitamin that participates in the maintenance of calcium and phosphorus homeostasis, and in the mineralization of tissues (bones, cartilage and teeth), during and after growth.
The combination of soy and milk as the main sources of minerals and vitamins is a considerable asset for food formulations. Indeed, according to [45]**,** soybeans are a good source of calcium, iron, potassium, sodium, magnesium, sulphur, phosphorus, and vitamins B12 and E. Also, for the French Food Safety Agency [46]**,** a balanced intake between plant and animal proteins is more desirable than a single intake in one of these categories and makes it possible to obtain both a satisfactory intake of essential amino acids and a better ratio between essential and non-essential amino acids. Another aspect to consider is their digestibility. It is generally slightly higher for animal proteins than for vegetable proteins.
In addition, taking milk into account in the different formulations is advantageous, because for [47]serious nutritional consequences (kwashiorkor, rickets) may result from the exclusion of milk and dairy products in children under 3 years of age. This exclusion also has negative consequences on bone mineralization, with an increased risk of fracture, in older children [48]**(Goulding *et al*., 2004).**

As the 4F and 5F food formulas are deficient in vitamin A, unrefined palm oil (red oil) was also chosen as a source of fortification. Thus, their respective vitamin A contents increased from 50.73 to 449.4

µg/100g and from 79.93 to 628.00 µg/100g in their respective porridge. Indeed, like any oil, crude and refined palm oils contain almost 100% lipids in the form of triglycerides, and crude palm oil (red oil) is thought to contain the largest source of natural carotenoids (500 to 2000 mg/kg of crude oil) [49]**.** This crude oil contains 15 times more carotenoids than carrots, and 300 times more than tomatoes. Among these carotenoids is β-carotene. In the body, it is converted into vitamin A, which makes crude palm oil an excellent source of vitamin A [50]**.** According to theUnited Nations, regular consumption of crude palm oil limits blindness disorders caused by vitamin A deficiency. It is also rich in vitamin E with tocopherols (150 to 200 mg/kg of crude oil) and tocotrienols (up to 500 mg/kg of crude oil). These molecules are natural antioxidants because they limit the formation of free radicals [50]**.**

The presence of phenolic compounds, including flavonoids, and the antioxidant activity determined in all food formulas would be a considerable asset. Indeed, according to [51], the consumption of foods rich in flavonoids is thought to protect the body against diseases associated with oxidative stress, coronary heart disease and cancer.
The low tannin content recorded for all compound meals could be attributed to the different biotechnological treatments used during the preparation of the formulations. According to [37]**,**depending on the nature of the plant material, soaking would reduce tannin content by 24 to 48%. According to the same author, germination is also responsible for significant reductions in tannins of 33 to 72%.
These low tannin levels could contribute to the bioavailability of macronutrients and minerals in different flours. Tannins have been found to have negative effects on the nutritional quality of grains [52]due to their ability to bind to both exogenous and endogenous proteins, including enzymes in the digestive tract, resulting in decreased protein utilization [53]**.**Tannins would also create complexes with certain cations, thus decreasing their bioavailability [54]**.**

The phytate levels of the formulated feed formulas are low compared to those contained in whole cereals of maize, millet and rice, at 800 mg/100 g, 200 mg/100 g and 800 mg/100 g, respectively [55]**.** Nutritionally, phytates and oxalates are considered anti-nutritional because they limit the absorption of nutrients by the body [56]**.** Oxalates chelate ions and form soluble (e.g., with K and Na) or insoluble (e.g., with Fe and Ca) precipitates [57]**.** They bind specifically to divalent ions such as iron, calcium and zinc, to form oxalate crystals (e.g. calcium oxalates). These crystals, which are then excreted in the urine, or which can create clots, make these minerals unavailable to the body. Phytates (phytic acid salts) have a strong binding capacity and can therefore form complexes with multivalent proteins and cations, thus reducing their biological availability [37]**.** According to [58, 59]phytates have a double negative effect on protein digestibility, which they reduce, first, by the presence of phytate-protein complexes that are difficult to hydrolyze and, second, by the inhibitory effect of phytates on digestive enzymes. However, the oxalate content of the meals is low and below the lethal limit value given by [60]which is 15 g of oxalates per 100 g of child food.
Mycotoxins are secondary metabolites of moulds that naturally contaminate many foodstuffs, including cereals. Deoxynivalenol is one of several mycotoxins produced by some Fusarium species that frequently infect corn, wheat, oats, barley, rice, and other cereals in the field or during storage [61]**.** Deoxynivalenol affects animal and human health by causing temporary acute nausea, vomiting, diarrhea, abdominal pain, headache, dizziness, and fever [61]**.**The limit value according to [62]standard for cereal-based foods for infants and young children is 200 µg/kg, the levels recorded in flours are well below this recommendation (≤ 62 µg/kg). Therefore, these meals would be suitable for human consumption without risk of deoxynivalenol poisoning.

The results of the functional properties reveal higher water absorption capacities than those of food powders commonly used in the food industry, which are 120% to 126% for cowpea varieties, or 105% to 110% for voandzou varieties [63]**.** These compound flours would therefore be likely to be used in the food industry, because a food powder is easily manipulated when it absorbs enough water. The water absorption capacity is related to the amorphous nature of starch [64]but also to the moisture content of the flour and its protein content [65, 66]**.** This property is an indicator of the maximum amount of water that a flour is likely to retain or absorb [67]. According to the results obtained, the flours would be able to absorb a lot of water, thus giving a dough that is easier to handle, and therefore suitable for use in the making of pastries. In addition to porridge, ready-to-eat food products can be made from these flours, which would be an advantage in the care of children suffering from moderate acute malnutrition.

The water solubility index would reflect the extent of starch degradation [68]and determine the consistency of the food [69]**.** Flours showed high values. This could be explained by the pronounced degree of degradation of starch due to the different technological treatments undergone by the flours. The flours would therefore be adapted for the manufacture of homogeneous porridges as part of the nutritional care of children suffering from moderate acute malnutrition. The 1F, 2F, 3F, 4F and 5F formulations have obtained a high-water absorption capacity and solubility index so they would be more suitable for possible handling in the food industry [63]**.**

The dispersibility offood formula is an indicator of its reconstitution in water, it is a useful functional parameter in the formulations of various food products [30]**.**The higher the percentage of dispersibility, the greater the ability of the flour to reconstitute itself in water to give a fine and coherent dough. The flours had higher dipersibility values than those reported by [70]for yam flours (66.00 to 72.50%).
Flour is considered wettable when the wettability time is less than 60 seconds and very wettable if it is less than 30 seconds [71]**.** The wettability time of flours is between 3.66 ± 0.16 s and 33.71 ± 0.23 s. These meals could therefore be considered "Very wettable". This wettability is due on the one hand to the composition of the flours and the affinity between their components and water, and on the other hand to the accessibility of water in terms of structure (porosity and capillarity) to the constituents of the flours [72, 73]**.** According to [73]**,** a food formula capable of wetting would be suitable for swelling during dough handling. These flours could therefore be used for the preparation of porridge, cakes and biscuits.
The ability of a food to trap oil is thought to be an important characteristic in fatty food formulations, as it acts as a flavour retainer, soft texture and mouthfeel enhancer [74](and is also important in food preservation by preventing the development of oxidative rancidity [75]**.**
The 1F, 2F, 3F and 5F food formulations achieved a better absorption capacity for refined palm oil (132 ± 1%, 139 ± 1%, 121 ± 1 and 115 ± 1%). This oil will therefore be better suited for their preparation because it is more absorbed, it will contribute to improving the quality and mouthfeel while enhancing the flavour of the various ingredients [76, 77]**.** For the improved 4F flour, unrefined palm oil will be the best choice.

CONCLUSION

From the analysis of the results obtained for the food products formulated during this study, it appears that these products can meet the protein-energy needs of children aged 6 to 59 months diagnosed with moderate acute malnutrition but are also able to fill the deficiencies in vitamins and minerals except for vitamin D and sodium. The functional properties of these food formulas would be more suitable for possible handling in the food industry,

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