



Research Article

Formulation of a Rice-Based (*Oryza sativa*), Spinach-Based (*Spinacia oleracea*), and Peanut-Based (*Arachis hypogaea*) Complementary Food for Children Aged 6 to 24 Months

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Abstract

Child malnutrition is a serious concern that requires special attention from public authorities. It is essential to emphasize the importance of the quality of infant cereals used during the complementary feeding period. The objective of the present work was to develop an infant cereal made from parboiled rice, peanut paste, and spinach powder that meets the standards recommended by the World Health Organization. To achieve this, an extreme vertices mixture design was used to determine the ideal proportions of each ingredient in order to achieve sufficient energy content and a good balance of macronutrients and micronutrients. The ingredients selected for the blend were parboiled rice flour (65-85 g), peanut paste (10-25 g), and spinach powder (5-10 g). To produce an infant cereal with good nutritional value, parboiled rice flour, peanut paste, and spinach powder must be blended in the following proportions: 82.50% parboiled rice, 10% peanut paste, and 7.50% spinach powder. Analysis of the formulated infant cereal revealed the following nutrient content: protein (12.06%); fat (8.56%); carbohydrates (67.03%); ash (3.65%); fiber (3.06%); reducing sugars (2.84%); iron (8.18 mg); calcium (960 mg); zinc (4.97 mg); potassium (850 mg); sodium (120.37 mg); magnesium (75.18 mg); phosphorus (245.24 mg); carotenoids (19.12 mg); and a total energy value of 402 kilocalories. The optimal flour had a viscosity of 1,725 mPa/s, which demonstrates the formulated flour's ability to meet the nutritional needs of infants in fewer meals, thereby helping to combat childhood malnutrition. Analysis of the physicochemical and functional properties shows that the formulated flour contributes, in terms of quality, to the minimum dietary diversity recommended for children aged 6 to 24 months and, at the same time, helps to promote local food resources.

Keywords

Infant Cereal Formulation, Peanut Paste, Parboiled Rice, Spinach Leaves, Mixing Plan, Children Aged 6 to 24 Months

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1. Introduction

Caring about infant health also means caring about the health of the next generation of adults, and the challenge is to help these children transition to adulthood under the best possible conditions [1]. This requires adequate nutrition for children, as nutritional problems are responsible for the deaths of most of them, a drastic reduction in intellectual potential, and enormous economic losses [2]. It has been estimated that, 8.2% of the world's population, or 673 million people experienced hunger in 2024, down from 8.5% in 2023 and 8.7% in 2022. However, this improvement is not uniform, as hunger continued to gain ground in most sub-regions of Africa and West Asia, as revealed in the 2025 edition of "The State of Food Security and Nutrition in the World" [3]. This threatens the achievement by 2030 of targets 2.1 and 2.2 of the Sustainable Development Goal (SDG), which aim to end hunger and all forms of malnutrition, respectively. The situation is even more alarming in most regions of Africa. In Chad in the year of 2022, 28% or over 1/4 of children under five suffer from chronic malnutrition. Lake Chad (35.7%), Kanem (36.9%), Lamis (37.9%), Tandjilé (33.9%), Silas (33.7%) and Batha (32.7%) are the most affected regions [4]. Kone *et al.* [5] reported deficiencies in energy, protein, zinc, iron, calcium, and beta-carotene, which regulate a range of human metabolic processes are the main causes of this malnutrition. In Cameroon, the 2018 Demographic and Health Survey highlighted the prevalence and management of non-communicable diseases (NCDs). These NCDs account for a significant portion of the health burden in Cameroon, being responsible for 43% of deaths. Furthermore, deficiency-related diseases are also on the rise. More than one million children under the age of five suffer from stunted growth. The prevalence of vitamin A deficiency among children under five is 39%, and 18% among pregnant women [6].

Known in the literature by various names, such as "complementary cereal," "weaning cereal," or "infant cereal," this is a complementary food in the form of flour that is given to young children starting at six months of age either cooked or uncooked, as a porridge to supplement breast milk. It must be specially formulated to meet their nutritional needs, taking into account the contributions of breast milk and the daily frequency of meals consumed [7]. In fact, the CODEX ALIMENTARIUS/FAO/WHO recommends that infant cereal intended for infants and young children consist of at least 20% of energy derived from fat is desirable, the energy density should be at least 4 kcal per gram on dry weight basis, the dietary fibre content should be reduced to a level not exceeding 5 g/100 g. Also the amounts of vitamins and minerals to be added should be as the following: 400 µg retinol equivalent of vitamin A, 5 µg of vitamin D, 5 mg of vitamin E, 30 mg of vitamin C, 0.5 mg of thiamine and riboflavin, 6 mg of niacin,

0.5 mg of vitamin B6, 150 µg of folate, 0.9 µg of vitamin B12, 8 µg of biotin, 2 mg of pantothenic acid, 15 µg of vitamin K, 500 mg of calcium, 2.4 to 8.3 mg of zinc, 460 mg of phosphorus, 3.9-11.6 mg of iron, 90 µg of iodine, 1.2 mg of manganese, 60 mg of magnesium, 17 mg of selenium, and 0.34 mg of copper [8]. Given that childhood malnutrition worldwide is a major problem of concern to the scientific community, the formulation of infant flours based on cereals, tubers, and legumes with high protein and mineral content is proving to be a promising solution. Soro *et al.* [9] showed that an infant cereal whose characteristics met the standards could be formulated using 60% yam and 40% soy. However, a formulation containing 25% soy combined with yam flour did not meet the standards and therefore could not meet all of a child's nutritional needs. Furthermore, this yam-based formulation whether or not enriched with soy was deficient in calcium, zinc, and iron. Klang *et al.* [10] studied the effect of incorporating flours and amylase extracts from the ATP variety of corn on the nutritional value, energy density, and flow rate of porridges made from cassava, soybean, and moringa flours. They showed that adding soybean flour (25%) and moringa flour (5%) significantly increased the protein, energy, and mineral content of cassava. Tambo *et al.* [11] evaluated the technological and functional suitability of corn malt, cassava flour (sweet and bitter cultivars), corn flour (Kassai and Atp), and potato flour (local and 1112 varieties) for use in the preparation of infant porridges. The results showed that the use of amylase sources at concentrations of 1 to 3% in the porridges reduced their consistency, with this effect being most pronounced with the Atp and Kassai varieties of corn malt. Furthermore, they also demonstrated that the reduction in consistency and the increase in energy density of infant porridges depended on the variety, the type of amylase-treated flour, and the application matrix. The work of Klang *et al.* [12] on optimizing germinated paddy rice flour to improve the flowability of cassava flour-based porridges showed that the combination of optimized germinated rice flour and dry matter reduced the consistency, thereby increasing the flow rate and energy density of the porridges.

Although these authors have produced foods with specific proportions of each ingredient, very few studies have focused on formulating an infant cereal based on parboiled rice, spinach, and peanuts, hence the importance of this study. The aim of this study was to utilize other available foods accessible to local populations and, in certain regions of Africa, harvested locally whose use could help combat protein-energy malnutrition. Therefore, it was necessary to develop an infant cereal made from parboiled rice, peanut paste, and spinach powder that can cover the nutritional requirements of infants aged 6-24 months.

2. Materials and Methods

2.1. Plant Materials

The plant raw materials used to formulate the infant cereal consisted of paddy rice (*Oryza sativa*) purchased at the central market in Moundou, Chad; spinach leaves (*Spinacia oleracea*)

harvested in the city of Dschang; and peanut seeds (*Arachis hypogaea*) purchased at the Dschang market. Once the raw materials were obtained, they were transported to the Research Unit of Biochemistry, Medicinal Plants, Food Science and Nutrition (URBPMSAN) in the Department of Biochemistry at the Faculty of Sciences of the University of Dschang to be processed into rice flour, peanut paste, and spinach powder, and finally to formulate the final infant cereal.

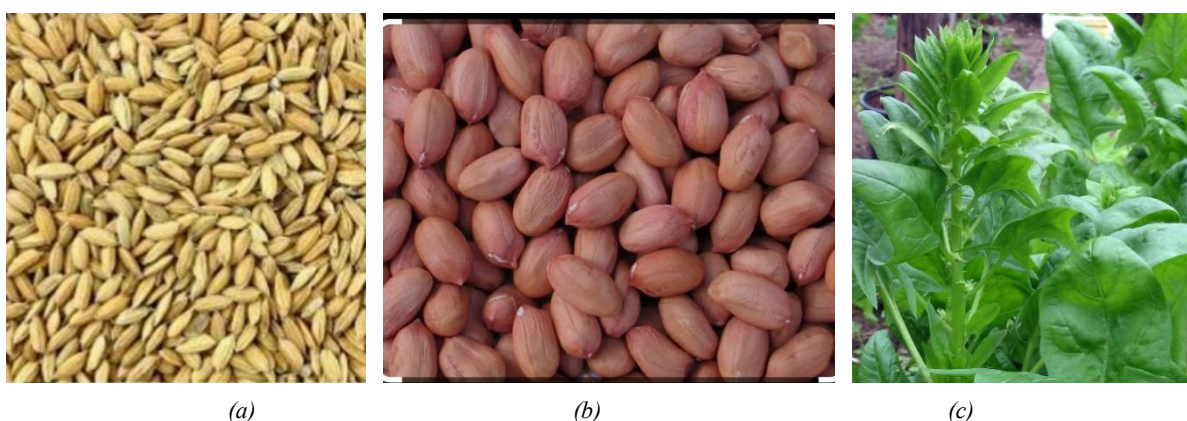


Figure 1. Ingredients used in the development of cereal complementary food based on paddy rice (a), peanuts (b), and spinach leaves (c).

2.2. Methods

2.2.1. Sample Preparation

The paddy rice was first winnowed, sorted, and then washed. It was soaked for 6 hours in hot water at 65°C, and then drained. It was then steamed for 40 minutes, dried in the shade for one hour, and dried in an oven for 18 hours at 45°C. Once the paddy rice was parboiled, it was hulled and separated from its chaff, winnowed, and then ground to produce a flour, which was sieved using a 300 µm sieve [13, 14]. The peanut seeds were sorted, roasted at a temperature of 100°C for 15 minutes, then cooled, hulled, winnowed, and ground into a paste. The spinach leaves were sorted, washed, and blanched; they were then oven-dried for 48 hours at 45°C, ground, and sieved (300 µm) to obtain a powder.

2.2.2. Experimental Design for the Formulation of the Supplementary Food

The extreme vertices mixture design was applied to the blending of the different flours. The following three factors were identified: the amounts of parboiled rice flour (FRE), peanut paste (PA), and spinach powder (PE). The responses of interest were the levels of protein, fat, carbohydrates, fiber, crude ash, minerals (iron, calcium, phosphorus, potassium, sodium, magnesium, and zinc), and carotenoids. The experimental ranges were selected based on data from the literature review, FAO/WHO and Codex Alimentarius standards, and

the individual chemical composition of each matrix. Thus, after evaluating the ranges of the various factors, we determined the number of experiments to be conducted and performed calculations that allowed us to identify coded variables according to a three-factor mixed design using Minitab software. 18 The experimental matrix, consisting of coded and actual values, is shown in Table 1

Table 1. Blending Experiment Matrix.

Trials	FRE	PA	PE
1	80.0	13.75	6.25
2	75.0	17.50	7.50
3	70.0	21.25	8.75
4	80.0	10.00	10.00
5	65.0	25.00	10.00
6	85.0	10.00	5.00
7	70.00	25.00	5.00
8	72.50	21.25	6.25
9	77.50	13.75	8.75

FRE= parboiled rice flour. PA = peanut paste. PE = spinach powder.

2.2.3. Mathematical Model and Validation Criteria

The proposed model was capable of accurately representing the experimental responses studied within the experimental range of interest and, as a result, provided estimates of the values of the studied responses that were of acceptable quality. The proposed model can be either linear or a second-degree polynomial, where the responses are denoted by (*y*). The fundamental constraint of mixtures eliminates the constant term, and the second-degree terms reduce to rectangles. The linear mathematical model for the formulated flour was as follows:

$$Y = B_1\text{FRE} + B_2\text{PA} + B_3\text{PE}$$

The second-degree polynomial mathematical model was as follows:

$$Y = B_1\text{FRE} + B_2\text{PA} + B_3\text{PE} + B_{12}\text{FRE*PA} + B_{13}\text{FRE*PE} + B_{23}\text{PA*PE}$$

where *Y* is the predicted response; *B*₁, *B*₂, and *B*₃ are the linear coefficients; *B*₁₂ is the interaction coefficient.

In order to express the observed phenomenon as an equation and predict responses within the domain defined for the study, it was important to validate the empirical models obtained so as to compare the experimental response values obtained during the experiments with those calculated using the models' mathematical equations. In addition to the coefficient of determination, which must be greater than 75%, the AADM (Absolute Average Deviation of the Mean) must be close to zero (0), and the bias factor (*Bf*) must be between [0.75–1.25].

2.2.4. Physicochemical and Nutritional Properties of the Formulations

i. Determination of Macronutrient Content

AOAC method was used for macronutrient composition [15]. Concerning water content, a small amount of each sample was placed in porcelain crucibles and dried at 105°C in a Venticell (MM-group) ventilated oven. Protein content was determined using Kjeldahl method while lipid was determined by solubilization in a nonpolar organic solvent. The crude fiber content was determined using Scharrer's reagent, and in a muffle furnace, the sample was calcined at 450°C for 3 hours, and the fiber content was calculated by mass difference. Total digestible carbohydrate content was calculated by difference following the method of Zubair *et al.* [17] using equation 1. Reducing sugar content was determined via the AACC method using 3,5-dinitrosalicylic acid (DNSA) after water extraction and precipitation with 2% zinc acetate and 10.6% ferrocyanide [16].

$$\% \text{ Carbohydrates} = 100 - (\% \text{ Proteins} + \% \text{ Lipids} + \% \text{ Ash} + \% \text{ Fiber} + \% \text{ Moisture}) \quad (1)$$

Energy was calculated using the formula in equation 2 as described by WHO/FAO [18].

$$\text{Energy (kcal/100g)} = 4 \times \% \text{ total carbohydrates} + 4 \times \% \text{ crude proteins} + 9 \times \% \text{ lipids} \quad (2)$$

The total starch, amylose, and amylopectin contents of the various flours were determined using the method described by Jarvis and Walker [19]. Iodine (I₂) reacts with amylose and amylopectin to produce blue and brown colors, respectively. The spectra of the L2-amylose and L2-amylopectin complexes are different. Consequently, these complexes have different maximum wavelengths: $\mu_{\text{max}} = 720 \text{ nm}$ for amylose and $\mu_{\text{max}} = 548 \text{ nm}$ for amylopectin. Furthermore, amylose absorbs in the near-visible region, whereas amylopectin does not. This spectral difference has been used to simultaneously quantify total starch, amylose, and amylopectin in a biological sample. In this experiment, it was assumed that the absorbance at 580 nm is attributable to both amylose and amylopectin, whereas the absorbance at 720 nm is primarily attributable to amylose.

ii. Determination of Mineral Content

After sample ashing and digestion with an HNO₃/HCl mixture, each mineral was quantified using specific standard solutions. Absorbance was measured using a Perkin Elmer HGA 700 flame spectrophotometer (USA) at the following wavelengths: 420 nm for phosphorus, 510 nm for iron, 768 nm for potassium, and 589 nm for sodium. Calcium and magnesium contents were determined by complexometry using the calcium plus magnesium mixture on the one hand and Ca on the other. Mineral content (sodium, calcium, potassium, magnesium, iron, phosphorus, and zinc) was measured according to the method described by Pauwels and collaborators [20].

iii. Determination of the Functional Properties of Flours

The method of Okezie and Bello [21] was used for the determination of the swelling rate (SR), water absorption capacity (WAC), and oil absorption capacity (OAC). 10% (w/v) flour dispersions (in oil or water) were prepared and heated to 30°C in a calibrated water bath. The mixtures were stirred at 80 rpm for 30 minutes, then centrifuged at 4500 rpm for 15 minutes. The supernatant from each tube was removed and its volume recorded (*V*₂), while the resulting paste was weighed. Equations 3 and 4 were used to calculate the SR, WAC, and OAC respectively

$$\text{Swelling rate (\%)} = \frac{M_1 - M_0}{M_1} \times 100 \quad (3)$$

$$\text{WAC / OAC (\%)} = \frac{(V_0 - V_1)}{V_0} \times 100 \quad (4)$$

where *M*₁ is the mass of the base or mass after water absorption (g); *M*₀ is the mass of the test sample (g); *V*₀ is the initial volume (mL) and *V*₁ is the volume after absorption of oil or water (mL); WAC/OAC=water or oil absorption capacity.

The measurement of viscosity then followed according to the method described by Tsopbeng and collaborators at a shear rate of 600s allowing a stable readability, using a NDJ-8S

Brookfield rotary viscometer, and a 3# spindle rotating at 12 rpm [22]. This rotor was adjusted to match the consistency of the samples. Measurements (mPa. s) were taken immediately after removal from the water-bath, at room temperature.

iv. Determination of the Physical Properties of Flours

The pH was measured according to the AOAC method [15]. A 10% (w/v) suspension prepared with distilled water was stirred using a Barnstead/Thermolyne vortex mixer (model LS3, Chennai, India) for 30 min and then centrifuged at 4500 rpm for 15 min using a Heraeus refrigerated centrifuge. The pH of the supernatant was measured using a calibrated pH meter at $25.03 \pm 0.22^\circ\text{C}$.

Concerning titratable acidity, aliquots were prepared from the flour and distilled water (1:10, w/v). 10 mL of each mixture was titrated with a 0.1 N (2 g/L) solution in the presence of 0.1 mL of 0.1% phenolphthalein. The volume of NaOH (mL) read on the burette for each sample was recorded at the point where the initial white color changed to pink and remained so for 30 seconds. The titratable acidity (TA) for each sample was expressed in milliequivalents per 100 grams of sample.

Using the formula of equation 5, the bulk density was calculated based on the method described described by Okaka *et al.* [23].

$$\text{Bulk density (g/mL)} = \frac{M_1 - M_0}{V} \quad (5)$$

where M_0 is the mass of empty crucible, V the volume of flour, and M_1 the mass of crucible filled with flour.

v. Carotenoid Content Determination

The carotenoid content was determined using the method described by Tambo and collaborators [11]. Accordingly, 1 g of finely ground sample was weighed and placed in a 15-mL centrifuge tube. 10 mL of an acetone/water mixture in a 4:1 (v/v) ratio was added, vortexed, and allowed to macerate for 60 min. The mixture was then centrifuged (5,000 rpm) for 20 min. The recovered supernatant was used to determine the concentrations of carotenoids and chlorophyll a and b. The values were calculated using Equation 6.

$$\text{Caroténoides } (\mu\text{g}/100\text{g}) = \frac{(\text{Absorbance} \times \text{Volume} \times 100)}{m \times 0.16} \quad (6)$$

vi. Determination of Antinutritional Content (Phytates, Oxalates, Tannins)

Concerning phytate concentration, briefly, erlenmeyer flask (250 mL) was used to mix 2.0 g of sample and 100 mL of HCl (2%) during 12 h. Fine-mesh filter was used for the filtration of the solution. Subsequently, 50 mL of the filtrate, 107 mL of distilled water, and 10 mL of 0.3% ammonium thiocyanate

were mixed. The resulting solution was titrated with a standard solution $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$ (containing 0.00195 g iron per mL) until a persistent yellow-orange endpoint was reached and maintained for 5 min. Phytate content was determined using the AOAC method as showing in equation 7 [15].

$$\text{Phytate} = \frac{x \times 1.19}{0.00195} * 100 \quad (7)$$

with X , the descent of the burette

The method of Day and Underwood [24] was used for oxalate content. 01 g of each sample was weighed and added to 75 mL of 1.5 M. After 8 hours of extraction, the mixture was filtered, and a 25 mL aliquot of the filtrate was titrated at 90°C with 0.1 M KMnO_4 solution until a persistent pink color was maintained for 30 s. The oxalate content was expressed in mg/100 g and calculated using the following equation: $0.1 \text{ mL } \text{KMnO}_4 = 0.00450 \text{ g Oxalate}$.

Concerning tannin content, briefly, 1 mL of each extract (2% in MeOH/HCl 1%) was mixed with 5 mL of a reagent solution consisting of 0.5 g of vanillin and 8 mL of hydrochloric acid in 100 mL of distilled water. The mixture was incubated at 30°C for 20 min, and the absorbance was read at 500 nm against a blank. This was done using the method described by Luzardo-Ocampo *et al.* [25].

2.2.5. Statistical Analysis of the Data

Minitab version 18 was used to analyze the experimental data and to plot the isoresponse curves of the proposed models. The data were processed and analyzed using Excel 2016, and statistical analyses were performed using SPSS version 22.0. The comparison of means was conducted using an ANOVA test to rank the treatments in cases where a significant difference existed. A difference between two data points is considered significant when the actual significance level is less than 5%.

3. Results

3.1. Characterization of the Different Formulations

3.1.1. Macronutrient Content of the Different Formulated Infant Cereal Samples

Table 2 presents the nutritional values for macronutrients in the different formulations. This table shows that Sample 4 had the highest protein and carbohydrate content and the lowest fat content. Sample 1 had the highest dietary fiber content.

Table 2. Macronutrient composition of the nine formulated mixtures.

Trials	Proteins (%)	Lipids (%)	Carbohydrates (%)	Ash (%)	Fiber (%)
1	10.30±0.18c	5.82±0.57c	66.33±0.03bc	7.85±0.21a	3.85±0.17a
2	5.88±0.14 ^e	4.1±0.33 ^c	70.43±0.9 ^{ab}	6.80±0.28 ^a	2.94±0.17 ^c
3	9.41±0.55 ^{cd}	11.65±1.29 ^{ab}	63.81±1.58 ^{bcd}	6±00 ^a	3.77±0.13 ^{ab}
4	12.57±0.18 ^a	4.09±0.3 ^c	72.65±0.05 ^a	2.5±0.71 ^b	3.35±0.15 ^{abc}
5	12.52±0.54 ^a	11.56±2.01 ^{ab}	68.73±2.13 ^{ab}	3.65±0.49 ^b	3.17±0.18 ^{bc}
6	10.41±0.16 ^{bc}	13.93±2.37 ^a	61.22±2.19 ^{de}	2.63±0.53 ^b	3.01±0.20 ^c
7	11.71±0.04 ^{ab}	13.77±1.12 ^a	59.23±0.67 ^c	3.52±0.68 ^b	3.08±0.14 ^c
8	12.48±0.59 ^a	11.46±0.19 ^{ab}	65.90±0.39 ^{bc}	2.63±0.53 ^b	3.2±0.17 ^{bc}
9	8.27±0.12d	8.85±0.73bc	66.40±0.60bc	3.68±0.45b	3±0.15c

Means ± standard deviations followed by the same letter in the same column indicate that the differences are not statistically significant at the 5% probability level.

3.1.2. Micronutrient Content of the Various Formulated Infant Cereal Samples

Table 3 presents the micronutrient levels in the various formulations. The table shows that the high micronutrient levels

are primarily influenced by the amount of spinach powder incorporated into the parboiled rice flour. Sample 4 had the highest levels of iron, sodium, magnesium, potassium, and vitamin C. Sample 2 had the highest level of carotenoids.

Table 3. Micronutrient composition of the various formulations.

Trials	Fe	Ca	Na	Mg	K	P	Carotenoids
1	8.30±0.00 ^b	1220±2.83 ^a	140.93±1.56 ^c	75.23±0.89 ^e	744.28±1.61 ^g	814.43±0.11 ^f	6.83±00 ^h
2	6.24±0.00 ^b	886±5.66 ^f	38.93±0.87 ^f	96.1±1.56 ^c	1387.01±1.6 ^c	976.65±0.2 ^b	23.39±0.07 ^a
3	5.92±0.08 ^a	1072±5.66 ^c	162.88±1.57 ^b	128.92±0.51 ^b	2884.5±1.68 ^b	1349.68±0.13 ^a	17.57±0.04 ^d
4	3.81±0.10 ^a	1120±8.49 ^b	796.12±1.58 ^a	142.22±0.93 ^a	3739.27±1.4 ^a	352.21±00 ⁱ	20.37±0.04 ^b
5	4.19±0.06 ^b	1043±1.41 ^d	120.38±1.55 ^d	75.19±0.89 ^{ef}	1387.01±1.6 ^c	825.24±0.18 ^e	19.13±0.34 ^c
6	6.17±0.07 ^b	934±2.83 ^e	67.07±1.52 ^e	71.35±0.81 ^f	1056.81±1.61 ^f	535.96±0.12 ^h	12.09±0.04 ^g
7	5.29±0.03 ^b	855±7.07 ^g	120.36±1.5 ^d	87.03±1.09 ^d	1735.12±1.9 ^d	687.54±0.42 ^g	11.88±00 ^g
8	4.21±0.05 ^b	880.5±6.36 ^f	162.88±1.58 ^b	61.6±0.86 ^g	2100.41±1.6 ^c	919.86±0.11 ^c	13.44±0.08 ^f
9	3.29±0.05 ^b	1027.5±2.12 ^d	120.36±1.57 ^d	41.18±0.87 ^h	1734.66±1.9 ^d	833.33±0.14 ^d	16.91±0.04 ^e

Means ± standard deviations followed by the same letter in the same column indicate that the differences are not statistically significant at the 5% probability level. P = phosphorus, Mg = magnesium, K = potassium, Na = sodium, Ca = calcium, Fe = iron.

3.1.3. Antinutrient Levels in the Various Test Samples of the Formulated Infant Cereal

Table 4 presents the antinutrient content of the different formulations of our infant cereal. This table shows that sample 6 had the lowest phytate content. Sample 7 had the lowest oxalate content, and sample 8 had the lowest tannins content.

Table 4. Chemical composition in antinutrients.

Trials	Phytates (mg/100g)	Oxalates (mg/100g)	Tannins (mg/100g)
1	65.07±79.98 ^a	6.75±9.55 ^a	29.71±11.42 ^{bc}
2	71.11±88.28 ^a	18.47±21.61 ^a	43.11±1.6 ^{ab}
3	48.49±68.48 ^a	9±12.73 ^a	58.12±00 ^a
4	91.24±123.16 ^a	7.22±5.7 ^a	17.11±0.46 ^{cd}
5	61.54±75.08 ^a	11.72±12.07 ^a	18.24±2.51 ^{cd}
6	48.21±68.07 ^a	6.75±9.55 ^a	6.62±2.51 ^d
7	63.77±84.04 ^a	4.50±6.36 ^a	53.92±6.85 ^a
8	51.02±72.05 ^a	6.75±9.55 ^a	5.65±0.68 ^d
9	48.48±62.66 ^a	11.72±12.07 ^a	29.06±4.57 ^{bc}

Means ± standard deviations followed by the same letter in the same column indicate that the differences are not statistically significant at the 5% probability level.

3.2. Optimal Flour Formulation

3.2.1. Optimization of Flour Formulation Conditions

Table 5 summarizes the nine trials conducted according to the extreme vertices mixture design, as well as the responses obtained during the formulation of the optimal flour combining parboiled rice flour (FRE), peanut paste (PA), and spinach powder (PE).

Table 5. Factors and responses of the different formulation trials.

Trials	Factors			Responses												
	FRE	PA	PE	TP	TL	TC	Ash	Fiber	Fe	Ca	Mg	Zn	Na	P	K	Carotenoid
1	80.00	13.75	6.25	10.30	5.81	66.33	7.85	3.85	12.30	1220	75.22	10.49	140.92	814.42	744.28	6.82
2	75.00	17.50	7.50	5.87	4.09	70.42	6.80	2.93	17.24	886	96.10	4.89	38.93	976.65	1387.0	23.38
3	70.00	21.25	8.75	9.40	11.64	63.80	6.00	3.77	15.92	1072	128.91	16.70	162.87	1349.67	2884.5	17.56
4	80.00	10.00	10.00	12.57	4.09	72.62	2.5	3.34	16.80	1120	142.22	14.49	796.11	352.21	3739.2	20.36
5	65.00	25.00	10.00	12.51	11.56	68.73	3.65	3.16	14.18	1043	75.18	4.13	120.37	825.24	1387.0	19.12
6	85.00	10.00	5.00	10.41	13.93	61.22	2.62	3.00	17.16	934	71.35	0.26	67.06	535.96	1056.8	12.09
7	70.00	25.00	5.00	11.70	13.77	59.23	3.52	3.07	13.28	935	87.03	0.12	120.35	687.54	1735.1	11.87
8	72.50	21.25	6.25	12.47	11.46	65.89	2.62	3.19	10.20	880.52	61.60	0.30	162.84	919.85	2100.4	13.44
9	77.50	13.75	8.75	8.27	8.84	66.40	3.99	2.99	16.28	1027.57	41.17	1.26	120.35	833.32	1734.6	16.91

FRE = parboiled rice flour, PA = peanut paste, PE = spinach powder, TP = total proteins, TL = total lipids, TC = total carbohydrates, P = phosphorus, Mg = magnesium, K = potassium, Na = sodium, Zn = zinc, Ca = calcium, Fe = iron.

3.2.2. Analysis of Variance of the Model

Table 6 presents the p-values and R² coefficients of determination for the factors influencing the responses. This table

shows that the levels of protein, carbohydrates, fat, ash, dietary fiber, iron, calcium, sodium, potassium, phosphorus, zinc, magnesium, and carotenoids are influenced by the effects of the factors (FRE, PA, PE) at the $p \leq 0.05$ level.

Table 6. Analysis of Variance.

Equations	TP	TL	TG	Ash	Fiber	Fe	Ca	Na	Zn	P	K	Mn	Carotenoids
Regressions	0.031	0.220	0.640	0.603	0.680	0.832	0.944	0.776	0.817	0.629	0.745	0.491	0.239
Linear	0.107	0.221	0.438	0.727	0.410	0.571	0.956	0.687	0.539	0.878	0.626	0.264	0.149
Quadratic	0.101	0.270	0.425	0.723	0.429	0.560	0.958	0.671	0.555	0.804	0.574	0.286	0.138
FRE*PA	0.043	0.060	0.431	0.967	0.238	0.379	0.785	0.446	0.522	0.947	0.395	0.408	0.133
FRE*PE	0.175	0.460	0.219	0.540	0.593	0.874	0.874	0.226	0.811	0.606	0.883	0.564	0.061
R ² (%)	99.65	99.56	99.67	99.44	99.10	96.82	98.83	92.57	97.25	98.68	93.79	92.04	92.64

FRE = parboiled rice flour, PA = peanut paste, PE = spinach powder, TP = total proteins, TL = total lipids, TC = total carbohydrates, P = phosphorus, Mg = magnesium, K = potassium, Na = sodium, Zn = zinc, Ca = calcium, Fe = iron.

3.2.3. Predictions from Mathematical Models and the Contribution of Factors

The following regression equations (8-20) were obtained after analyzing the various responses (TP = total proteins, TL = total lipids, TC = total carbohydrates, Ash, Fiber, P = phosphorus, Mg = magnesium, K = potassium, Na = sodium, Zn = zinc, Ca = calcium, Fe = iron and carotenoids), with these responses (Y) as a function of parboiled rice flour (FRE), spinach powder (PE), and peanut paste (PA).

Protein: The protein content of the mixture is primarily influenced by the content of parboiled rice, spinach powder, and the parboiled rice/peanut paste interactions; however, the peanut paste content has a negative effect on the protein content.

$$Y1 = 0.02423FRE - 3.14929PA + 4.04384PE + 0.05104FRE*PA - 0.05732FRE*PE + 0.00000PA*PE \quad (8)$$

Total Carbohydrates: The proportion of parboiled rice, peanut paste, and the parboiled rice/spinach powder interaction have a positive effect on the carbohydrate content of the mixture, while the proportion of spinach powder and the parboiled rice/peanut paste interaction have a negative effect on the carbohydrate content of the mixture.

$$Y2 = 0.4724FRE + 6.2960PA - 15.8078PE - 0.0682FRE*PA + 0.2261FRE*PE + 0.00000PA*PE \quad (9)$$

Total lipids: The content of parboiled rice, spinach powder, and the parboiled rice/peanut paste interactions had the greatest influence on the fat content of the mixture, whereas the parboiled rice/spinach powder and peanut paste interactions had a negative influence on the fat content.

$$Y3 = 0.28104FRE - 1.76322PA + 7.89163PE + 0.02071FRE*PA - 0.11489FRE*PE + 0.00000PA*PE \quad (10)$$

Ash: The peanut paste content and the interactions between parboiled rice and spinach powder had a positive effect on the ash content of the mixture, whereas the parboiled rice content, spinach powder content, and the interaction effects between parboiled rice and peanut paste, as well as between parboiled rice and spinach powder, had a negative effect on the ash content of the mixture.

$$Y4 = -0.02735FRE + 0.24615PA - 2.99045PE - 0.00156FRE*PA + 0.04746FRE*PE + 0.00000PA*PE \quad (11)$$

Total Fiber: It is evident that parboiled rice, spinach powder, and the parboiled rice/peanut paste interaction effects have a major and minor influence, respectively, on total fiber content, while peanut paste and the parboiled rice/spinach powder interaction effects have a minor influence.

$$Y5 = 0.013965FRE - 0.554700PA + 0.632803PE + 0.008785FRE*PA - 0.007311FRE*PE + 0.00000PA*PE \quad (12)$$

Iron: Spinach powder and the interaction effects between parboiled rice and peanut paste had the greatest influence on the mixture's iron content, whereas the interaction effects between parboiled rice and spinach powder, peanut paste, and parboiled rice had a negative effect on iron content.

$$Y6 = -0.016397FRE - 0.360678PA + 0.240939PE + 0.005689FRE*PA - 0.002112FRE*PE + 0.00000PA*PA \quad (13)$$

Calcium: The calcium content is positively influenced by parboiled rice, spinach powder, and the parboiled rice/peanut paste interaction. Conversely, peanut paste and the parboiled rice/peanut paste interaction have a negative influence.

$$Y7 = 9.55417FRE - 402,941PA + 648,392PE + 0.7958FRE*PA - 0.91958FRE*PE + 0.0000PA*PE \quad (14)$$

Zinc: Zinc is primarily influenced by the interaction effects between parboiled rice and peanut paste, and between parboiled rice and spinach powder, and is negatively influenced by spinach powder, parboiled rice, and peanut paste.

$$Y8 = -0.39521FRE - 5.33265PA - 3.44697PE + 0.09176FRE*PA + 0.06636FRE*PE + 0.0000PA*PA \quad (15)$$

Magnesium: Magnesium is positively influenced by the two interaction effects between parboiled rice and spinach powder, and between parboiled rice and peanut paste. Conversely, parboiled rice, spinach powder, and peanut paste had a minor influence on the magnesium content of the mixture.

$$Y9 = -1.9846FRE - 26.6314PA - 40.2102PE + 0.4919FRE*PA + 0.6669FRE*PE + 0.0000PA*PE \quad (16)$$

Sodium: The sodium level is positively influenced by spinach powder and the interaction between steamed rice and peanut paste. Conversely, spinach powder and parboiled rice have a negative influence.

$$Y10 = -9.908FRE - 234.656PA + 175.176PE + 3.844FRE*PA - 2.141PE + 0.0000PA*PE \quad (17)$$

Potassium: The potassium content is negatively influenced by the interaction between parboiled rice, spinach powder, and peanut paste.

$$Y11 = -55.21 FRE - 1,047.52 PA + 707.52 PE + 17.30 FRE*PA - 5.40 FRE*PE + 0.0000 PA*PE \quad (18)$$

Phosphorus: Peanut paste and the interaction between parboiled rice and spinach powder have a positive effect on the phosphorus content of the mixture, whereas parboiled rice, spinach powder, and the interaction between parboiled rice and peanut paste have a negative effect on the phosphorus content of the mixture.

$$Y12 = -5.498FRE + 49,876PA - 315.697PE - 0.360FRE*PA + 5.688FRE*PE + 0.0000PA*PE \quad (19)$$

Carotenoids: The carotenoid equation is primarily influenced by peanut paste and the interaction between parboiled rice and spinach powder, and to a lesser extent by parboiled rice, spinach powder, and the interaction effects between parboiled rice and peanut paste.

$$Y13 = -0.0609FRE + 10.1321PA - 25.2974PE - 0.1287FRE*PA + 0.3535FRE*PE + 0.0000PA*PE \quad (20)$$

The mathematical equations show that each measured response varies depending on the proportion of the different components. The levels of all minerals increase significantly with the amount of spinach powder incorporated into the parboiled rice flour.

*With RE: effect of parboiled rice on the response; PA: effect of peanut paste on the response; PE: effect of spinach powder on the response. RE*PA: interaction between parboiled rice and peanut paste on the response; RE*PE: interaction between parboiled rice and spinach powder on the response. The term PA*PE cannot be estimated and this was removed by Minitab version 18.*

3.2.4. Model Validation

Table 7 presents the values of the coefficient of determination (R^2), the AADM (Absolute Analysis of Mean Deviation), and the Bf (Bias Factor) obtained for the various responses. This table shows that the R^2 for the various responses is greater than 75%, that the AADM is equal to 0, and that the Bf ranges from 0.75 to 1.25.

Table 7. Coefficient of determination (R^2), AADM, and Bf for the various responses.

Responses	R^2 (%)	AADM	Bf
Proteinss	99.65	0	1
Lipids	99.56	0	1
Carbohydrates	99.67	0	0.9
Ash	99.44	0	0.9
Fiber	99.10	0	1
Iron	96.82	0	0.9
Calcium	98.83	0	1

Responses	R ² (%)	AADM	Bf
Sodium	92.57	0	0.8
Zinc	97.25	0	0.9
Magnesium	92.04	0	0.9
Phosphorus	99.68	0	1
Potassium	93.79	0	0.9
Carotenoids	92.64	0	1
Standard values	>75%	0	0.75<Bf<1.25

3.2.5. Validation of the Optimal Conditions for the Various Tests

Table 8 shows the response values under the various optimal conditions predicted by the model for the optimal formulation, along with the desirability coefficients.

Table 8. Optimal Conditions for the Complementary Flour.

Responses	FRE	PE	PA	Predicted Optimal Values	Desirability
Total proteins	86.22	5.00	7.78	14.00	1
Totals lipids	88.36	6.25	9.50	8.00	1
Total carbohydrates	76.44	7.50	13.52	71.02	1
Ash	81.28	5.00	8.50	3.00	1
Fiber	86.82	7.00	12.50	5.00	1
Iron	74.36	8.2	13.25	7.50	1
Calcium	87.63	6.25	10.50	425.00	1
Sodium	83.21	5.00	10.79	140.75	1
Phosphorus	82.73	6.27	10.00	281.20	1
Zinc	85.82	5.15	8.03	3.50	1
Magnesium	90	5.00	5.00	54.00	1
Potassium	81.30	5.57	12.13	450.00	1
Carotenoids	84.19	6.64	8.17	4.00	1

FRE = parboiled rice flour, PA = peanut paste, PE = spinach powder.

3.2.6. Physicochemical, Nutritional, and Techno-Functional Composition of the Optimal Flour

Table 9 presents the chemical composition of the optimal flour formulated with 82.50% parboiled rice, 7.50% spinach powder, and 10% peanut paste. The table shows that these values are close to the predicted values. The protein, fat, carbohydrate, and fiber contents were approximately 12.06 ± 0.53 , 8.56 ± 2.00 , 67.03 ± 2.12 , and $3.06 \pm 0.01\%$ DM, respectively.

The optimally formulated flour had a high sugar content, with 43.22% starch, 21.56% amylose, and 78.43% amylopectin, and the amylose-to-amylopectin ratio was 0.28%. The bulk density, pH, and titratable acidity of the final formulated flour were 0.59 g/mL, 7.16, and 29.5 meq of NaOH/100 g, respectively. The swelling rate, water-holding capacity, and oil-holding capacity of the optimal flour were 58.22, 15.50, and 10.00, respectively.

Table 9. *Physicochemical, nutritional, and techno-functional composition of the optimal flour.*

Parameters	Optimal flour
Macronutrients (%DM)	
Moisture (%)	9.86±0.02
Proteins	12.06±0.53
Carbohydrates	67.03±2.12
Lipids	8.56±2.00
Reducing sugar	2.84±0.18
Ash	3.65±0.49
Fiber	3.06±0.01
Starch (g)	43.22±1.40
Amylose (g)	21.56±2.38
Amylopectin (g)	78.43±2.38
Amylose/amylopectin (g)	0.28±0.04
Micronutrients (mg/100g)	
Iron	8.18±0.06
Calcium	960±1.41
Zinc	4.97±0.06
Potassium	850.01±1.60
Phosphorus	245.24±0.17
Sodium	120.37±1.54
Magnesium	75.18±0.88
Carotenoids	19.12±0.33
Anti-nutrients (mg/100g)	
Phytates	45.46.19±4.34
Oxalates	21.25±3.18
Tannins	15.24±2.51
Physical properties	
Bulk density (g/ml)	0.59±0.06
pH	7.16±0.01
Titrateable acidity (meq de NaOH/100g)	29.50±0.8
Functionnal properties (%)	
Swelling rate	58.23±2.72
Water absorption capacity (WAC)	15.5±0.71
Oil absorption capacity (OAC)	10±0.00

4. Discussion

This study was conducted with the aim of contributing to the improvement of the nutritional quality of complementary foods. The goal was therefore to provide low-income households with high quality infant cereals made from locally available and accessible ingredients.

Moisture content is a very important factor in predicting the stability and shelf life of foods, as it promotes spoilage. The moisture content of the different formulations ranged from 9.80% to 9.87%, with an optimal value of 9.82%, under optimal conditions consisting of 82.50% parboiled rice flour, 10% peanut paste, and 7.50% spinach powder. This high value may have been influenced by the amount of peanut paste and spinach powder incorporated into the parboiled rice flour. However, this moisture content was higher than that specified by Liu *et al.* [26] who found that the compressive strength and solubility of the block infant formula made from milk powder with a moisture content of 4.75 was the most suitable for the preparation of block infant formula. These results were in line with those reported by Alozié *et al.* [27], who found a moisture content of 5% in Bambara infant flour, a value above which the environment becomes conducive to the growth of microorganisms. The protein content of the formulated flour ranged from 5.87% to 12.57%, with an optimal value of 12.06%. It is known that protein requirements for feeding children aged 6 to 23 months are 6 to 11 g per 100 g [29]. Therefore, the protein content of the formulation based on rice (*Oryza sativa*), spinach (*Spinacia oleracea*), and peanut (*Arachis hypogaea*) could help meet children's protein needs. These results were similar to those obtained by Nedion *et al.* [28], who found a value of 12.67% for a formulation based on *Ipomoea batatas*, *Phaseolus vulgaris*, *Pleurotus floridanus*, *Phoenix dactylifera*, *Spirulina platensis* and palm oil. The protein content of infant formula can have a positive impact on tissue repair and muscle development. It is therefore extremely important during growth and pregnancy [30]. The fat content in infant formulas intended for complementary feeding should account for approximately 20% of total energy intake, corresponding to a fat content of about 8% [8, 28]. The various formulated flours had fat contents ranging from 4.09 to 13.77%, with an optimal value of 8.18%, thus complying with the CODEX ALIMENTARIUS/FAO/WHO recommendations. This fat content appears to be positively influenced by the amount of peanut paste incorporated into the parboiled rice flour. The carbohydrate content of the various formulations ranged from 59.23% to 72.64%, with an optimal value of 67.03%. This complies with the standard recommended by CODEX ALIMENTARIUS/FAO/WHO which is up to 30% [31]. This value was lower than that reported by Klang *et al.* [10], who obtained a value of approximately 79.91% for a formulation consisting of 82.5% cassava flour, 15% soybean flour, and 2.5% moringa. Thus, this flour could serve as a source of dietary energy for infants due to the amount of readily available sugar for basic metabolic activities that support growth and development. The

ash content obtained in this study ranged from 2.5% to 7.85%, with an optimal value of 3.65%. It is an indicator of the mineral content in a food. The increase in the incorporation rate of spinach powder into parboiled rice flour is believed to be responsible for the increase in the ash content of the formulated flour. This value was higher than those obtained by Shrikiki *et al.* [32], which ranged from 1.19 to 2.60% for an optimal formula based on corn, soybean, and peanut flours enriched with *Moringa oleifera* leaves. The fiber content of infant flours must not exceed 5 g per 100 g of product on a dry matter basis. The values obtained for the composite flour were within the standard, with fiber contents ranging from 2.93 to 3.85%, and an optimal value of 3.06%. This low fiber content in the flour could reduce bulk and promote high digestibility and the absorption of nutrients such as proteins and minerals, as reported by Olorunfemi *et al.* [33]. According to the work of AFSSA [34], the presence of fiber in blended flour helps reduce postprandial blood glucose and insulin levels. The total starch content of the optimal flour in this study was 43.22 mg/100 g. This content was lower than that reported by other authors [10, 11], who showed that cassava flour contains more starch than corn flour. The reducing sugar content in the optimal flour was 2.84. This reducing sugar content is slightly higher than that reported by Fotso [35], who obtained a value of 2.25 for corn-soybean flour. Energy is one of the most critical factors in infant growth. The average energy value of the infant formula was 402 kcal per 100 g of dry matter. This value was very close to the standard of 400 kcal/100 g [8, 36].

Mineral content was primarily influenced by the amount of spinach powder and peanut paste. The optimal values obtained for iron, calcium, sodium, zinc, magnesium, potassium, and phosphorus in this formulation were approximately 8.18, 960, 108.37, 4.97, 75.18, 850, and 240 mg per 100 g of dry matter, respectively. The level of phosphorus was lower than that of the standards recommendations, which are 460 mg/100 g, while the levels of calcium was higher than that of standard which is 500 mg/100 g. However, the levels of iron, zinc, manganese, and magnesium were in line with the recommended values, which should be 3.9-11.6, 2.4-8.3, 1.2, and 60 mg/100 g, respectively [8]. Nevertheless, the presence of all these minerals in these formulated flours would be beneficial, as they play a role in a child's physical development and can help prevent nutritional deficiencies, as reported in the work of Lutter *et al.* [29]. Indeed, iron is involved in the formation of hemoglobin, myoglobin, and numerous enzymes; it is also essential for a wide range of metabolic reactions. Calcium and phosphorus, for their part, ensure bone strength and support children's growth during weaning. Zinc, along with iron, is one of the minerals found in the highest concentrations in the brain. Therefore, it is essential to meet an infant's zinc needs, as brain growth is still rapid at this stage. Zinc also plays a role in immunity, as it reduces the incidence and severity of diarrhea in children. Copper, present in very small amounts in the human body, is a component of many enzymes and is also in-

involved in bone mineralization, strengthening the immune system, and in iron and glucose metabolism [37]. Magnesium, for its part, is necessary for biochemical reactions in the body, helping to maintain muscle function, improve nerve function, maintain heart rhythm, and regulate blood sugar levels [32].

Carotenoids are generally tetraterpenoid photochemical compounds that cannot be synthesized by humans; some of them, such as beta-carotene, can be metabolized into vitamin A [38]. The carotenoid content of the various formulations ranged from 6.82 to 23.38 mg/100 g, with an optimal value of 19.12 mg/100 g corresponding to 191.2 µg. This value was lower to that recommended by CODEX ALIMENTARIUS/FAO/WHO standard which is 400 µg retinol equivalent [8]. Carotenoids are an important source of provitamin A (beta-carotene, beta-cryptoxanthin, alpha-carotene), as they contribute to its intake. They also possess strong antioxidant properties; they can inhibit the spread of lipid peroxidation, reduce oxidative damage to DNA, and thus protect against cancer. They are also important as immunomodulators and in cellular communication [39].

Antinutrients are substances naturally present in plants that reduce the absorption of certain nutrients. This is why reducing these antinutrients is important. The levels of antinutrients in infant formula were 45.4 mg/100 g for phytates, 21.25 mg/100 g for oxalates, and 15.24 mg/100 g for tannins, respectively. This could be explained by the various treatments applied to the matrices, such as soaking, cooking, roasting, bleaching, and hulling [10-12]. CODEX ALIMENTARIUS/FAO/WHO standard recommends that the product should not contain contaminants or other undesirable substances such as biologically active substances in amounts which may represent a hazard to the health of older infants and young children. The maximum level for lead should not exceed 0.02 mg/kg (in the ready-to-used product) however there are not specific standard values for phytates, oxalates, and tannins evaluated in the present study [8, 31].

Mass density is the mass of a substance per unit volume, depending on the raw material used and the size of the starch granules. The bulk density of our formulated flour was 0.59 g/mL. This value was close to that reported by Klang [40], which was approximately 0.55 g/mL for corn flour. The physicochemical characteristics of the optimal flour revealed that the pH of our analyzed flour was slightly neutral (6.93 to 7.23), with an optimal value of 7.16, as this value complies with the standards recommended by the Codex Alimentarius, which stipulates that the pH of infant flour must be 7. The optimal flour had a titratable acidity of 29.50 meq·g/100 g. Flours with an acidic pH are better protected against microbial contamination. Thus, rice flour, spinach powder, and peanut paste could be stored with a reduced risk of microbial spoilage. This finding was reported in other studies in which mango mesocarp flours were used to fortify sorghum-based flours [9]. The swelling rate is a measure of a flour's ability to increase its water volume. It reflects the strength of the amorphous and crystalline regions of the granules [41]. It is noted that the

swelling ratio of infant cereal generally ranges from 54.47 to 69.02, with an optimal value of 58.23. Viscosity is the fluid's resistance to flow due to friction between its constituent molecules. It results from molecular rearrangement and the formation of amylose-lipid complexes [42]. The viscosity of the optimal formulated flour was 1,725 mPa/s, indicating a high retrogradation capacity of the flour. This viscosity could be explained by the rupture of starch granules during water absorption and the size of the starch granule residues. These results were higher than those obtained by Fotso *et al.* [35], whose values were 1,159.5 mPa/s for a rice- and soybean-based flour formulation. The final viscosity obtained complies with the recommended standards, which specify values between 1,000 and 2,000 mPa/s, highlighting the importance of this porridge in the fight against childhood malnutrition.

Although this study provides new information on the formulation of a dietary supplement made from local plants, it has certain limitations that should be acknowledged. The infant cereal must contain a variety of vitamins and minerals. However, apart from determining the carotenoid content, no vitamins were quantified in this study. Also, although we quantified the content of some minerals, others such as iodine, copper, selenium, and manganese were not quantified. It would have been necessary to assess the palatability or acceptability of the formulation among children through a sensory analysis; unfortunately, this was not done, which also constitutes a limitation of this study. The amino acid profile and the Protein Digestibility Corrected Amino Acid Score (PDCAAS) were not assessed during this study. However, these are important parameters for assessing the quality of infant formula in terms of protein content. It would therefore be advisable to evaluate this in future studies.

5. Conclusion

The objective of this study was to develop an infant cereal made from parboiled rice, peanut paste, and spinach powder that meets the recommended standards. The results show that several formulation trials led to an optimal cereal blend consisting of 82.50% parboiled rice, 7.50% spinach powder, and 10% peanut paste. Analysis of the rheological properties of the formulated cereal revealed a viscosity flow rate of 1,725 mPa·s. Analysis of the physicochemical and functional properties shows that the formulated flour contributes, in terms of quality, to the minimum dietary diversity recommended for children aged 6 to 24 months by combining at least recommended food groups. Thus, this infant formula can contribute to the fight against protein-energy malnutrition. This study, conducted with the aim of contributing to the improvement of complementary feeding for infants during the weaning period, has made it possible to utilize the local resources available in our region to develop a nutritionally beneficial formula whose ingredients are readily available, accessible, and less expensive. Future studies could focus on the production of the formulation through stability studies and preservation methods;

the acceptability of the formulation through sensory analysis of the final product in human subjects; and assessing the amino acid profile, and the Protein Digestibility Corrected Amino Acid Score (PDCAAS), and fatty acids in the optimal formula in order to see if this meets the standard recommendations.

Abbreviations

AADM	Absolute Average Deviation of the Mean
Bf	Bias Factor
DNSA	3,5-Dinitrosalicylic Acid
FRE	Parboiled Rice Flour
NCDs	Non-Communicable Diseases
OAC	Oil Absorption Capacity
PA	Peanut Paste
PDCAAS	Protein Digestibility Corrected Amino Acid Score
PE	Spinach Powder
SR	Swelling Rate
TC	Total Carbohydrates
TL	Total Lipids
TP	Total Proteins
URBPMSAN	Research Unit of Biochemistry, Medicinal Plants, Food Science and Nutrition
WAC	Water Absorption Capacity

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Data Availability Statement

The data is available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare no conflicts of interest.

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