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Optimisation of the Techno-Functional Properties of a Weaning Composite Flour Based on a Mixture Design of Millet, Soybean and Coconut

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ABSTRACT

The development of nutritionally appropriate complementary foods requires cereal-based formulations with desirable techno-functional and sensory properties. This study aimed to optimize the techno-functional properties of composite flour formulated from pearl millet *(Pennisetum glaucum*), soybean (*Glycine max*), and coconut (*Cocos nucifera*) using a simplex-lattice mixture design. Seven formulations were prepared with varying proportions of millet (65–70%), soybean (15–20%), and coconut (10–15%). Their techno-functional properties were evaluated using standard analytical methods, and the experimental data were analysed using Design-Expert software (version 13). Sensory acceptability was assessed by a panel of evaluators using a nine-point hedonic scale. Quadratic mixture models were fitted to describe the effects of the ingredient proportions on the measured responses, while a desirability function was used for multi-response optimization. The results revealed significant differences ($P < 0.05$) among formulations for several techno-functional properties, highlighting the influence of ingredient proportions on flour performance. Sensory evaluation indicated that formulation F2 (70:20:10) obtained the highest overall acceptability score (7.45). Multi-response optimization identified an optimal formulation consisting of 65% millet, 20% soybean, and 15% coconut, with an overall desirability value of 0.775. Experimental validation demonstrated good agreement between predicted and observed values, with relative prediction errors below 6.3% for the validated responses. These findings demonstrate the potential of simplex-lattice mixture design as an effective approach for optimizing the formulation of millet–soybean–coconut composite flour. The optimized formulation provides a promising technological basis for developing complementary foods with improved functional characteristics.

Keywords: Techno-functional, Composite flours, Mixture design, millet–soybean–coconut

INTRODUCTION

Adequate nutrition during the first years of life is fundamental to ensuring optimal growth, development, and long-term health. The period from 6 to 23 months is particularly critical because it coincides with the progressive introduction and diversification of complementary foods, while energy and nutrient requirements increase substantially and breast milk alone is no longer sufficient to meet all nutritional needs [1]. During this period, the quality, diversity, nutrient density, and technological characteristics of complementary foods are important determinants of dietary adequacy. However, in many low- and middle-income countries, access to nutritionally adequate and affordable complementary foods remains constrained by food availability, household purchasing power, limited dietary diversity, and inadequate knowledge of appropriate infant feeding practices. These factors may contribute to inadequate nutrient intake and increase the risk of growth faltering and micronutrient deficiencies among young children [2]. The development of affordable complementary foods based on locally available plant resources therefore represents an important strategy for improving the nutritional quality and accessibility of infant diets. Cereal–legume composite flours have attracted considerable interest for complementary feeding because combining ingredients with complementary nutritional profiles can improve the overall nutritional value of the resulting food matrix. However, nutritional composition alone does not determine the suitability of a flour for infant feeding. The technological behavior of the flour during processing, storage, reconstitution, and porridge preparation must also be considered. Techno-functional properties such as water absorption capacity, swelling capacity, solubility, dispersibility, bulk density, and oil absorption capacity influence the amount of water required for preparation, the consistency and viscosity of the resulting porridge, handling characteristics, and ultimately the practical suitability of the product for complementary feeding. Consequently, the development of composite infant flours requires an integrated approach that considers both nutritional and techno-functional attributes [3]. Millet (*Pennisetum glaucum*) is a particularly relevant cereal for the development of complementary foods in many African countries, including Côte d'Ivoire. Its agronomic adaptability, availability, and nutritional composition make it a promising raw material for locally produced infant foods. Millet provides substantial amounts of carbohydrates as well as proteins, dietary fiber, minerals, and B-group vitamins. Nevertheless, as with many cereal-based foods, the protein content and amino acid profile of millet may be insufficient to meet all nutritional requirements when it constitutes the main ingredient of a complementary food. The incorporation of a protein-rich legume can therefore provide a means of improving the nutritional balance of the cereal-based matrix. Soybean (*Glycine max*) is particularly attractive for this purpose because of its high protein content and favorable amino acid composition. Its incorporation into cereal-based formulations can increase protein density and contribute to improving the nutritional quality of complementary foods. However, soybean addition does not merely modify the nutritional composition of the flour; it can also substantially affect its physicochemical and functional characteristics. Previous research has shown that soybean incorporation into millet flour can modify water absorption capacity, oil absorption capacity, solubility, and swelling properties [4]. These characteristics are of particular importance for infant flours because excessive water absorption or swelling may increase porridge viscosity and reduce the amount of dry matter that can be provided in a given serving volume, whereas inadequate hydration and dispersibility may negatively affect preparation and consumption. In addition to cereal and legume components,

dietary fiber-rich ingredients have increasingly been considered in the formulation of functional foods. Coconut (*Cocos nucifera*) represents a potentially valuable source of dietary fiber and other nutritional components that can be incorporated into cereal–legume food matrices. Coconut-derived fiber contains soluble and insoluble fractions that can influence water binding, swelling, hydration, and other functional properties of food systems [5]. The incorporation of coconut can thus modify the interactions between the water, lipids, proteins, fibers and starch present in the formulation and, consequently, influence its technological behavior. The combination of millet, soybean and coconut can therefore be considered as a formulation strategy that combines complementary sources of carbohydrates, proteins, lipids and dietary fiber. However, only the determination of the nutritional composition of a composite flour does not in itself make it possible to conclude from its technological suitability for use as a supplementary food. Thus, technofunctional characterization is an essential tool for evaluating the technological suitability of infant flour and guiding the optimization of its formulation. Ateye & Hassan [3] highlight in particular the importance of assessing functional properties in the development of composite flours for infant foods. In this context, the techno-functional characterization of the millet–soybean–coconut flours have a dual scientific and technological interest. Despite the work devoted to the development of infant flours based on cereals and legumes, data on the specific influence of the millet–soybean–coconut flours combination on the techno-functional properties of a flour intended for complementary feeding remain limited. This lack of data justifies a systematic characterization of this composite matrix in order to determine the influence of the proportions of the various constituents on its physical and functional properties. The objective of this study is therefore to characterize the techno-functional properties of an infant flour formulated with millet–soybean–coconut flours, in order to have an optimal flour with characteristics favorable to its potential use as a weaning food.

MATERIALS & METHODS

Flour formulation

The plant material consisted of millet (*Pennisetum glaucum*), soybean *(Glycine Max*) and coconut (*Cocos nucifera*), all purchased on the local market and used as basic ingredients for flours. The preparations and formulations of flour were carried out according to the method described previously in Soro al. [6], previous study. The millet grains were sorted, washed by hand and then soaked in water for 24 hours. They were rinsed and dried in a ventilated oven at 45° C. until a constant dry mass was obtained. The dried grains were ground to obtain millet flour. As for the soybeans, they were sorted and then soaked in distilled water for 10 hours. After soaking, the grains were dehulled and then dried in a ventilated oven at 45° C. until a constant dry mass was obtained, followed by grinding. Regarding coconuts, they were broken using a stainless steel knife to extract water. Then the fresh white core was removed with a stainless steel knife followed by the removal of the brown testa that coats the almond. The coconut kernels thus obtained were washed to remove the remaining impurities. The almonds were grated using a manual grater and then dried in a ventilated oven at 60° C. until a constant dry mass was obtained. After drying, the grated grains were ground. Finally, all these flours obtained were sieved using a 300 µm sieve to obtain fine flours of uniform particle size, packaged in airtight plastic containers to prevent the absorption of moisture and marked individually. The portions of flour mixture for the preparation of the formulations were determined using a simplex lattice experimental design using the Design-Expert version 13 software (Stat-Ease Inc., Minneapolis, MN, USA). Accordingly, the

formulations for millet-soybean-coconut based flours were developed taking into account the constraints (Table 1).

Table 1: Design constraints

Low Limit		Constraint		High Limit
0.650	≤	X1: Millet flour	≤	0.700
0.150	≤	X2: Soybean flour	≤	0.200
0.100	≤	X3: Coconut flour	≤	0.150
		$X_1+ X_2+ X_3$	=	**1.000**

According to the compositional criteria adopted in this study for complementary flours intended for children under two years of age, the recommended maximum levels were set at 70% for carbohydrates, 15% for protein, 10% for fat, and 5% for dietary fibre, based on the cited FAO/WHO and Codex Alimentarius recommendations [7]. The implicit relational constraint was to set the sum of the mixtures to 100 % (X1 % + X2 % + X3 % = 100 %) (Table 2). The postulated model can be either linear or polynomial of second-degree where the responses are coded by Y. The fundamental constraint of the mixtures makes the constant disappear, and the second-degree terms reduce to rectangles. The second-degree polynomial mathematical model was as follows:

$$Y = \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_{12} X_1X_2 + \beta_{13} X_1X_3 + \beta_{23} X_2X_3$$

where Y is the expected response, β1, β2, and β3 are linear coefficients, β12, β13, and β23 are interaction coefficients

The validation and strength of an experimental mathematical model require the determination of a number of parameters such as the determination coefficient (R^2) which must be above 75% [8].

Table 2: Experimental matrix.

		Pseudo component			Real proportions (g)		
Run		**X_1**	**X_2**	**X_3**	**X_1**	**X_2**	**X_3**
4 C (1)	**F1**	0.700	0.175	0.125	70	17.5	12.5
1 S	**F2**	0.700	0.200	0.100	70	20	10
5 C (1)	**F3**	0.675	0.200	0.125	67.5	20	13
6 C (1)	**F4**	0.675	0.175	0.150	67.5	17.5	15
2 S	**F5**	0.700	0.150	0.150	70	15	15
7 C (2)	**F6**	0.683	0.183	0.133	68.3	18.3	13.3
3 S	**F7**	0.650	0.200	0.150	65	20	15

C: center point, S: vertex point

Optimisation procedure

A graphical optimization method was used to determine the optimal combination of the proportions of the mixture. The contour diagrams of the various attributes have been superimposed in order to obtain a superposition diagram. This superimposed graph was used to find the optimal region according to the optimization criteria. The desirability function as reported by Montgomery and Cahyono [9], was used to numerically optimize the proportions of the mixture.

Determination of techno-functional properties

The techno-functional properties of the formulated flours were evaluated by determining their bulk and tapped densities, water and oil absorption capacities, hydrophilic–lipophilic ratio, water solubility index, Carr compressibility index, Hausner ratio, porosity, light transmittance,

emulsifying and foaming properties, swelling capacity, wettability, dispersibility, gelling properties, and viscosity. The tapped density of the flour samples was determined after the bottom of the cylinder had settled completely. This allowed for the calculation of the Carr index, Hausner ratio and porosity. Light transmittance was determined by heating an aqueous flour dispersion until the starch granules were fully gelatinised and then measuring it at 650 nm with a UV-Vis spectrophotometer. The emulsion, foam, swelling, foaming, wettability, dispersibility and gelling properties of the flours were evaluated as described in a previous study by Soro et al. [6]. Viscosity was analysed as follows: 10 g of sample were mixed with 90 ml of distilled water at 30°C, then left to hydrate for 30 minutes, stirring occasionally. Viscosity was measured using a Brookfield viscometer (model RV, Brookfield Engineering Inc., Stoughton, USA). The suspension was then brought to the boil in a water bath for 20 minutes, cooled to 30°C, and the viscosity of the cooked paste was measured.

Porridge preparation

The preparation was carried out after a preliminary study on the habit of mothers to prepare infant porridges. One hundred (100) grams of commercial control flours and formulated complementary flours were mixed with 750 mL of boiling tap water and cooked at 90°C for 20 minutes. During cooking, the mixture continuous stirring to prevent lumps from forming until it reached the desired consistency. After preparation, the porridges were allowed to cool to 30 °C before sensory evaluation.

Sensory evaluation

Sensory evaluation was conducted by 55 untrained assessors aged 22 to 45 years. Some were mothers with children aged 6 to 24 months and experience in infant food preparation. The panellists were informed before the process began to obtain their consent. Approximately 50 g of the porridge samples were served in plastic containers covered with aluminum foil and labeled with randomized three-digit codes to maintain anonymity and prevent bias. The samples were coded with random numbers and presented in a random order to minimise bias. A 9-point quantitative line scale ranging from 1 (lowest intensity) to 9 (highest intensity) for each attribute was used for the seven (7) sensory attributes, such as taste, aroma, colour, appearance, texture, mouth sensation, consistency and general acceptability of the porridges. Panellists were given disposable cups and portable drinking water to rinse their mouths between samples to avoid sensory bias from one sample to another [10].

Statistical Analysis

All experimental data were subjected to statistical analysis using Design-Expert software (version 13, Stat-Ease Inc., Minneapolis, MN, USA). Results were expressed as mean ± standard deviation (n = 3). Differences among the seven composite flour formulations were evaluated using analysis of variance (ANOVA), and differences were considered statistically significant at $p < 0.05$ using Tukey's HSD test.

RESULTS

Foaming, emulsifying and swelling properties of flours

The results presented in Table 2 indicate that there is a significant difference ($p < 0.05$) in the foaming, emulsifying and swelling capacities of the flours formulated from millet–soybean–coconut flour formulations (F1–F7). The foaming capacity of the flours (8.25 – 12.35 %) was high for formulation F1. Foam stability (86.71 – 95.63 %) was high for formulation F4. The emulsifying capacity (21.06 – 22.46 %) was high for formulation F5 compared with the other flours. Emulsion stability (67.20 – 76.25 %) was high for formulation F2. Swelling capacity (6.30 – 13.92 %) was high for formulation F5. Finally, the swelling index (10.61 – 18.59 %) was higher for formulation F1.

Table 3: Foaming, emulsifying and swelling properties of the composite flour formulations

Run	Foaming capacity (%)	Foam stability (%)	Emulsifying capacity (%)	Emulsion stability (%)	Swelling capacity (%)	Swelling index
F1	12.35 ± 0.88^{a}	86.80 ± 0.05^{c}	21.76 ±1.01^{ab}	67.20 ± 0.05^{d}	7.58 ± 0.88^{c}	18.59 ± 1.21^{a}
F2	8.33 ± 0.32^{d}	94.00 ± 0.03^{b}	22.41 ± 0.99^{a}	76.25 ± 0.11^{b}	9.98 ± 0.76^{b}	15.73 ± 0.95^{b}
F3	8.55 ± 0.15^{d}	86.71 ± 0.01^{c}	21.06 ± 0.85^{b}	67.33 ± 0.03^{d}	8.05 ± 0.25^{c}	14.61 ± 1.33^{bc}
F4	10.44 ± 0.21^{bc}	95.63 ± 0.02^{a}	22.17 ± 1.30^{a}	74.21 ± 0.11^{a}	7.66 ± 0.34^{c}	15.71 ± 0.65^{b}
F5	8.25 ± 0.33^{d}	94.20 ± 0.08^{b}	22.46 ± 1.46^{a}	74.20 ±0.45^{ab}	13.92 ± 0.48^{a}	10.61 ± 0.42^{e}
F6	11.66 ± 1.01^{ab}	93.00 ± 0.01^{b}	22.44 ± 1.00^{a}	73.45 ± 0.12^{b}	7.57 ± 0.91^{c}	14.12 ± 1.15^{bc}
F7	10.61 ± 1.02^{c}	94.30 ± 0.03^{b}	21.83 ±1.15^{ab}	70.38 ± 0.09^{c}	6.30 ± 0.15^{cd}	13.10 ± 1.26^{c}

F: Formulation. Means in the same column with different superscript letters differ significantly (P<0.05)

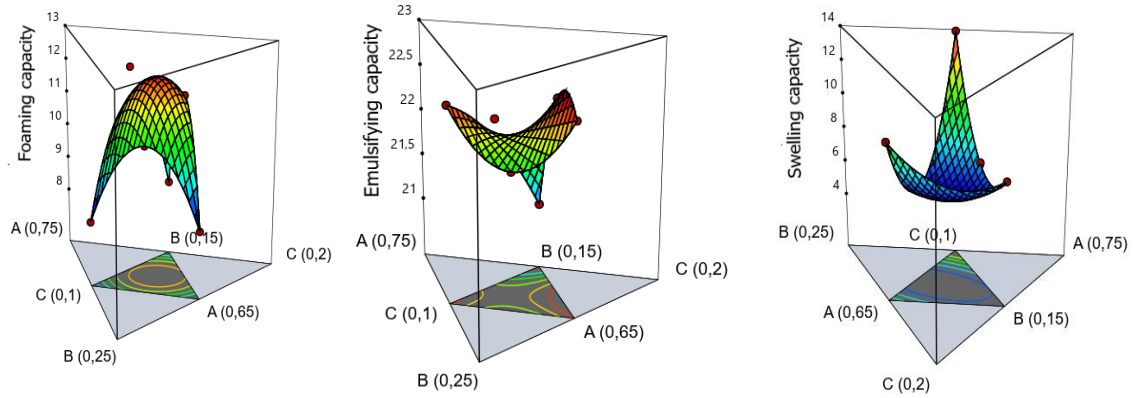

Figure 1: 3D surface plot effect of millet, soya and coconut mixture on foaming, emulsifying and swelling capacity

The equations below for the quadratic predictive models relating to the flour's foaming, emulsifying and swelling capacities were all significant ($p < 0.05$) with non-significant errors of fit ($p > 0.05$), with adjusted R^2 values ranging from 0.89 to 0.99, and adequate precision (5.21 – 145.49) > 4 indicating better predictive ability.

$$\textbf{\textit{Foaming}} = -1.71X_1 - 7.55X_2 - 0.25X_3 + 51.52X_1X_2 + 37.12X_1X_3 + 47.92X_2X_3 \ (R^2 = 0.89)$$
$$\textbf{\textit{Emulsifying}} = 21.53X_1 + 17.75X_2 + 25.43X_3 + 11.28X_1X_2 - 9.68X_1X_3 + 3.28X_2X_3 \ (R^2 = 0.96)$$
$$\textbf{\textit{Swelling}} = 26.91X_1 + 12.49X_2 + 34.39X_3 - 23.12X_1X_2 - 90.40X_1X_3 - 53.84X_2X_3 \ (R^2 = 0.99)$$

Physical properties of flours

The results presented in Table 3 indicate that there is a significant difference ($p < 0.05$) between the physical properties of the flours formulated from millet–soybean–coconut flour formulations (F1–F7), such as bulk density, tapped density and hydrated density. The bulk density (0.51 – 0.55 g/mL) was high for formulation F7. The tapped density (0.58 – 0.62 g/mL) was high for formulation F7. The hydrated density (0.75 – 0.87 g/mL) was found to be high for formulation F1. The Hausner ratio (1.11 – 1.17) was highest for formulation F6. Porosity, which varied between 10.00 and 14.75 per cent, was high for formulation F6. The equations below, corresponding to the quadratic predictive models for the bulk density of the flour, the Hausner ratio and porosity, were all found to be significant (p

< 0.05) with non-significant errors of fit (p > 0.05), adjusted R^2 values ranging from 0.90 to 0.94 and adequate precision (4.58 – 6.11) > 4, indicating better predictive ability.

Table 4: Physical properties of the composite flour formulations

Run	Bulk D. (g/mL)	Packed D. (g/mL)	Hydrated D. (g/mL)	Hausner Ratio	Porosity (%)
F1	0.53 ± 0.00^{a}	0.61 ± 0.01^{a}	0.87 ± 0.03	1.15 ± 0.00^{b}	13.11 ± 0.67^{b}
F2	0.54 ± 0.01^{a}	0.60 ± 0.03^{a}	0.81 ± 0.05	1.11 ± 0.01^{d}	10.00 ± 0.56^{c}
F3	0.52 ± 0.05^{bc}	0.60 ± 0.01^{a}	0.80 ± 0.01	1.15 ± 0.06^{b}	13.33 ± 0.44^{b}
F4	0.53 ± 0.01^{a}	0.60 ± 0.03^{a}	0.86 ± 0.03	1.13 ± 0.01^{c}	11.67 ± 0.25^{c}
F5	0.51 ± 0.02^{bc}	0.58 ± 0.01^{b}	0.75 ± 0.02	1.14 ± 0.05^{bc}	12.07 ± 0.99^{bc}
F6	0.52 ± 0.02^{b}	0.61 ± 0.03^{a}	0.82 ± 0.03	1.17 ± 0.33^{a}	14.75 ± 1.00^{a}
F7	0.55 ± 0.01^{a}	0.62 ± 0.01^{a}	0.83 ± 0.02	1.15 ± 0.01^{b}	12.90 ± 0.95^{b}

F: Formulation, D.: Density. Means in the same column with different superscript letters differ significantly (P<0.05)

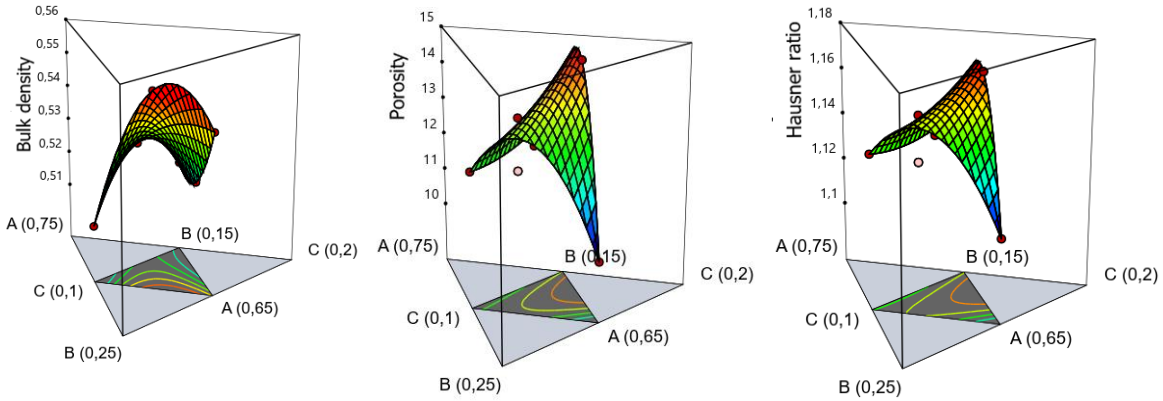

Figure 2: 3D surface plot effect of millet, soya and coconut mixture on bulk density, Hausner ratio and porosity

$$\textbf{\textit{Bulk density}} = 0.48X_1 + 0.6X_2 + 0.48X_3 + 0.16X_1X_2 + 0.48X_1X_3 + 0.24X_2X_3 \ (R^2 = 0.94)$$

$$\textbf{\textit{Porosity}} = -5.64X_1 + 5.10X_2 + 17.38X_3 + 49.36X_1X_2 + 29.84X_1X_3 - 4.96X_2X_3 \ (R^2 = 0.92)$$

$$\textbf{\textit{Hausner ratio}} = 0.90X_1 + 1.06X_2 + 1.20X_3 + 0.64X_1X_2 + 0.40X_1X_3 - 0.08X_2X_3 \ (R^2 = 0.90)$$

Flow properties of flours

The results in Table 4 indicate that there is a significant difference (p < 0.05) in the flow properties of the formulations based on millet–soybean–coconut flour formulations (F1–F7). The wettability time measured (5.24 – 6.47 s) was found to be high for formulation F7. The gel consistency (50.19–66.16 mm) was also found to be high for formulation F7. The paste clarity (39 – 55 %) was found to be higher for formulation F2. As regards the dispersibility of the flours measured (225.00 – 253.33 %), it was high for formulation F2. As for hygroscopicity (8.00 – 10.11 %), formulation F2 had the highest value. The viscosity (987.58 –1,625.33 cP) was found to be high for formulation F1. The equations below, corresponding to the quadratic predictive models for the wettability, gel consistency and viscosity of the formulated flours, were all significant (p < 0.05) with non-significant errors of fit (p > 0.05), adjusted R^2 values ranging from 0.96 to 0.99, and adequate precision (6.72 – 54.52) > 4, indicating better predictive ability.

Table 5 : Flow properties of the composite flour formulations

Run	Wettability (s)	Gel consistency (mm)	Paste clarity (%)	dispersibility (%)	Hygroscopicity (%)	Viscosity (cP) 30 °C
F1	6.13 ± 0.88^{ab}	54.22 ± 2.77^{c}	42 ± 1.07^{bc}	234.38 ± 1.36^{c}	8.24 ± 0.71 ^{b}	1625.33 ±11.01^{a}
F2	6.10 ± 0.25^{ab}	66.16 ± 1.25^{a}	55 ± 0.99^{a}	253.33 ± 1.05^{a}	10.11 ± 0.99 ^{a}	1261.24 ± 9.22^{c}
F3	6.39 ± 0.51^{a}	60.15 ± 2.20^{b}	44 ± 2.14^{bc}	225.00 ± 2.44^{d}	9.75 ± 0.33 ^{a}	1592.00 ± 5.41^{b}
F4	5.85 ± 0.32^{c}	55.17 ± 1.33^{c}	33 ± 0.83^{d}	248.99 ± 1.66^{b}	8.00 ± 0.15 ^{b}	1607.71 ± 8.08^{a}
F5	6.17 ± 0.41^{ab}	53.16 ± 1.19^{c}	40 ± 1.05^{c}	229.03 ± 2.11^{d}	8.16 ± 0.42 ^{b}	1307.54 ± 4.33^{c}
F6	5.24 ± 0.77^{c}	50.19 ± 2.21^{d}	48 ± 1.28^{b}	225.88 ± 2.55^{d}	9.90 ± 0.82 ^{a}	1288.29 ± 6.44^{c}
F7	6.47 ± 0.61^{a}	64.15 ± 2.15^{a}	39 ± 1.33^{c}	233.87 ± 1.33^{c}	8.15 ± 0.24 ^{b}	987.58 ± 9.33^{d}

F: Formulation. Means in the same column with different superscript letters differ significantly (P<0.05)

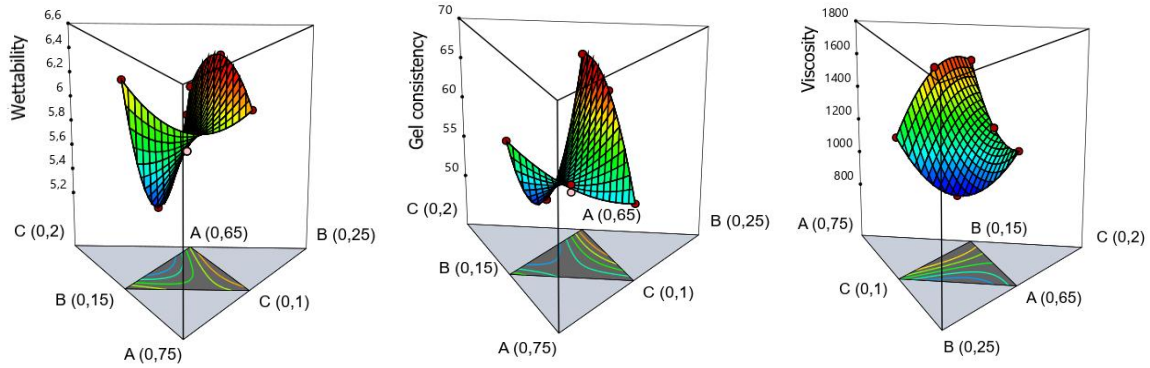

Figure 3: 3D surface plot effect of millet, soya and coconut mixture on wettability, gel consistency and viscosity

Wettability = $7.98X_1 + 12.40X_2 + 2.41X_3 - 16.08X_1X_2 + 5.36X_1X_3 - 4.64X_2X_3$ ($R^2 = 0.96$)
Gel consistency = $73.21X_1 + 136.83X_2 + 11.17X_3 - 207.44X_1X_2 + 71.84X_1X_3 - 31.36X_2X_3$ ($R^2 = 0.99$)
Viscosity = $4045.86X_1 - 324.14X_2 + 1512.62X_3 - 2213.28X_1X_2 - 4748.96X_1X_3 - 2668X_2X_3$ ($R^2 = 0.99$)

Absorption properties of flours

The results of Table 5 indicate that there is a significant difference ($p<0.05$) in the absorption properties and the hydrophilic-lipophilic ratio of the formulated flours based on millet–soybean–coconut flour formulations (F1–F7). The water absorption capacity (WAC) (180.33 – 278.42%) was high for the F2 formulation. The solubility index (0.11 - 0.18) was high for the F6 formulation. The oil absorption capacity (OAC) (73.39 – 267.07%) was high for the F2 formulation in the refined oil. The hydrophilic-lipophilic ratio (HLR) (0.34 – 2.09) was high for the F2 formulation for both refined and unrefined oil. The solubility index (0.1 – 0.18) is high for formulation F6. The equations below, corresponding to the quadratic predictive models for the WAC, OACr and solubility index of the formulated flours, were all significant ($p < 0.05$) with non-significant errors of fit ($p > 0.05$), adjusted R^2 values ranging from 0.98 to 0.99, and adequate precision (10.69 – 47.11) > 4, indicating better predictive ability.

Table 6: Absorption properties of the composite flour formulations

Run	WAC (%)	Solubilty index	OACr (%)	OACnr (%)	HLRr	HLRnr
F1	202.46 ± 1.15^{b}	0.14 ± 0.05^{c}	73.39 ± 0.88^{d}	249.51 ± 3.33^{b}	1.40 ± 0.11^{b}	0.41 ± 0.01^{b}
F2	278.42 ± 1.22^{a}	0.11 ± 0.01^{e}	86.32 ± 1.66^{a}	236.07 ± 2.78^{c}	2.09 ± 0.06^{a}	0.75 ± 0.03^{a}
F3	196.70 ± 0.99^{c}	0.16 ± 0.15^{ab}	81.65 ± 1.11^{b}	245.88 ± 1.44^{b}	1.18 ± 0.23^{bc}	0.39 ± 0.02^{b}
F4	199.28 ± 2.11^{c}	0.13 ± 0.15^{d}	74.93 ± 1.33^{d}	267.07 ± 2.29^{a}	1.33 ± 0.46^{b}	0.37 ± 0.01^{b}
F5	183.55 ± 1.03^{de}	0.13 ± 0.15^{d}	81.34 ± 0.85^{b}	236.50 ± 2.11^{c}	1.02 ± 0.33^{d}	0.35 ± 0.05^{b}
F6	180.33 ± 1.14^{e}	0.18 ± 0.15^{a}	77.48 ± 0.97^{c}	232.75 ± 1.15^{cd}	1.04 ± 0.21^{d}	0.34 ± 0.00^{b}
F7	186.517 ± 0.66^{d}	0.12 ± 0.15^{d}	78.83 ± 0.85^{c}	198.64 ± 1.78^{e}	1.10 ± 0.14^{d}	0.43 ± 0.02^{b}

F: Formulation, OAC: oil absorption capacity, nr: non-refined. Means in the same column with different superscript letters differ significantly (P<0.05)

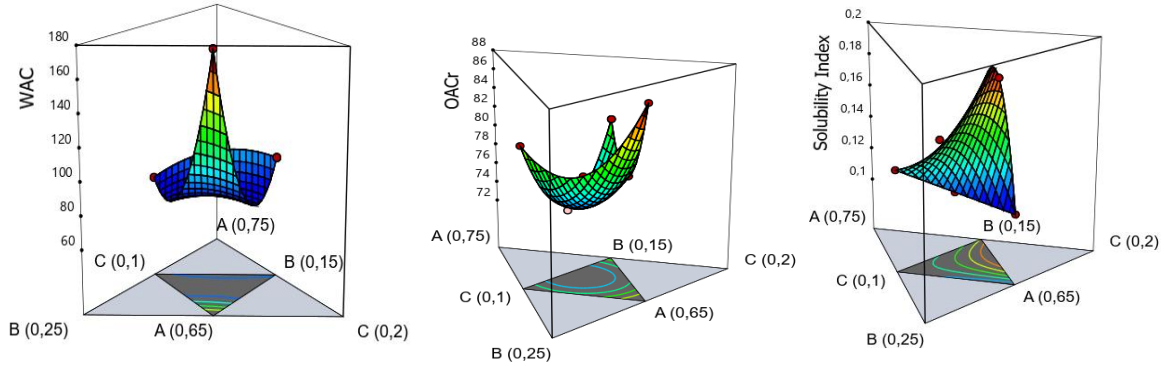

Figure 4: 3D surface plot effect of millet, soya and coconut mixture on WAC, OACr and solubility index

$$\boldsymbol{WAC} = 451.60X_1 + 173.34X_2 + 97.54X_3 - 915.68X_1X_2 - 711.49X_1X_3 + 171.92X_2X_3 \ (R^2 = 0.99)$$

$$\boldsymbol{OACr} = 93.35X_1 + 121.37X_2 + 109.95X_3 - 104.08X_1X_2 - 80X_1X_3 - 117.36X_2X_3 \ (R^2 = 0.98)$$

$$\boldsymbol{Solubility} = -0.04X_1 - 0.06X_2 + 0.36X_3 - 0.72X_1X_2 - 0.00X_1X_3 - 0.16X_2X_3 \ (R^2 = 0.98)$$

Sensory evaluation of porridges prepared from composite flour

The sensory evaluation of the millet–soybean–coconut flour formulations (F1–F7) is presented in Table 6. Significant differences ($p < 0.05$) were observed among the formulations for taste, appearance, mouthfeel, and overall acceptability, whereas colour and aroma did not differ significantly ($p > 0.05$). Formulation F5 exhibited the highest mean scores for taste (7.88) and appearance (7.34), along with a relatively high aroma score (6.50).

Table 7: Sensory evaluation of the composite flour formulations

Run	Taste	Colour	Appearance	Aroma	Mouthfeel	Overall acceptability
F1	5.24±1.22^{c}	7.02± 1.40^{a}	6.44 ± 0.88^{b}	6.51 ± 1.11^{a}	7.34 ± 1.25^{a}	7.01 ± 1.01^{a}
F2	6.55±1.09^{b}	6.87 ± 0.99^{a}	6.75 ± 1.66^{b}	6.27 ± 1.24^{a}	6.89 ± 0.77^{b}	7.45 ± 0.98^{a}
F3	7.04 ±0.93^{a}	6.78 ± 1.80^{a}	5.95 ± 1.09^{c}	6.38 ± 1.33^{a}	6.18 ± 1.35^{b}	6.39 ± 1.02^{b}
F4	6.25±1.47^{b}	7.05 ± 1.22^{a}	6.71 ± 1.51^{b}	6.19 ± 1.52^{a}	5.33 ± 1.66^{c}	6.37 ± 1.56^{b}
F5	7.88 ±0.57^{a}	6.71 ± 1.06^{a}	7.34 ± 0.55^{a}	6.50 ± 0.91^{a}	6.52 ± 1.22^{b}	6.35 ± 1.05^{b}
F6	7.54 ±1.28^{a}	6.72 ± 1.58^{a}	7.11 ± 0.44^{a}	6.25 ± 1.15^{a}	6.04 ± 1.55^{b}	6.41 ± 1.32^{b}
F7	5.71±0.90^{c}	6.83 ± 0.15^{a}	6.22 ± 0.66^{b}	6.44 ± 1.78^{a}	5.97 ± 0.74^{bc}	6.43 ± 0.84^{b}

F: Formulation. Means in the same column with different superscript letters differ significantly (P<0.05)

However, F2 recorded the highest overall acceptability score (7.45), which was not significantly different from that of F1 (7.01). Principal component analysis (PCA) further revealed distinct sensory profiles among the flour formulations (Figure 5). The first two principal components accounted for 93.09% of the total variance, with PC1 and PC2 explaining 80.38% and 12.71%, respectively. Formulations F1 and

F2 were positioned on the negative side of PC1 and were associated with mouthfeel, aroma, and overall acceptability. In contrast, formulations F4, F5, and F6 were grouped on the positive side of PC1 and were mainly associated with taste. These findings suggest that mouthfeel and aroma may contribute to the overall sensory appreciation of the composite flours, while the formulations associated with higher taste scores did not necessarily exhibit the highest overall acceptability.

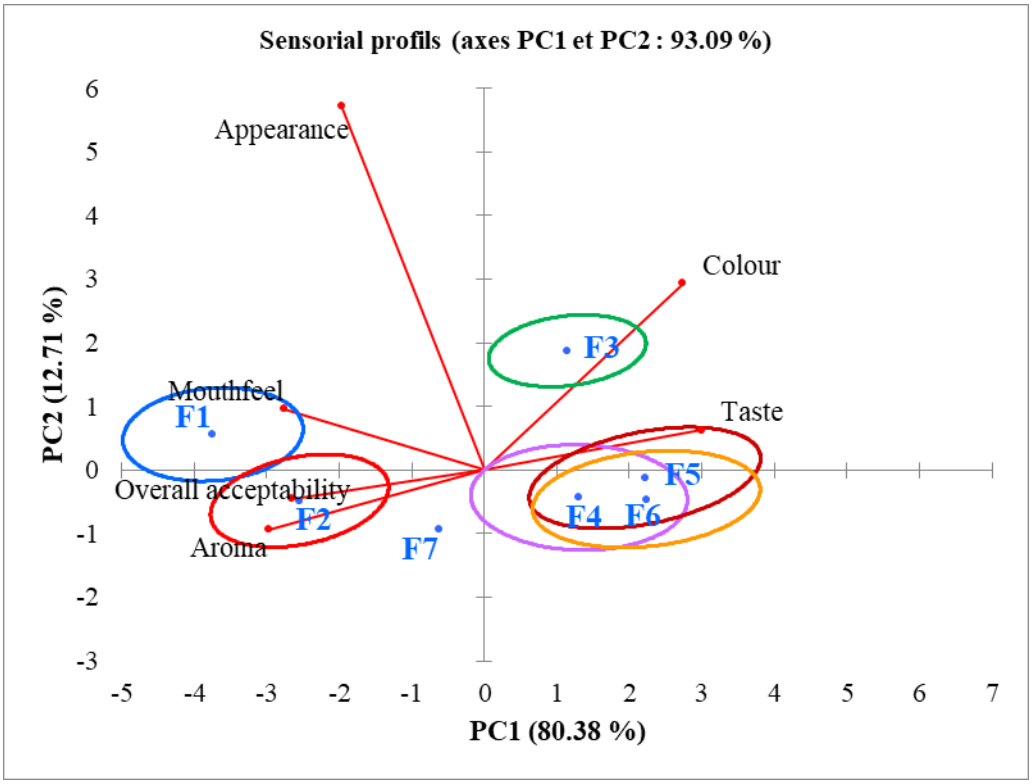

Figure 5: Biplot of formulated flour sensorial profiles according to the attributes scored

Principal Component Analysis of the Techno-Functional Properties of the Composite Flours

Principal component analysis (PCA) was performed to investigate the relationships among the techno-functional properties of the millet–soybean–coconut flour formulations (F1–F7) and to identify the main characteristics differentiating the samples. The first two principal components (PC1 and PC2) accounted for 56.33% of the total variance, with PC1 explaining 35.23% and PC2 contributing 21.10%. PC1 primarily differentiated flour formulations associated with porosity, Carr index, Hausner ratio, and solubility index, located on the positive side of the axis, from those associated with water absorption capacity, hydrophilic–lipophilic ratio, dispersibility, wettability, and gelling capacity, positioned on the negative side. PC2 was mainly associated with variations in swelling index, bulk density, hydrated density, packed density, and foaming capacity on its positive side, whereas swelling capacity, oil absorption capacity, and emulsion stability were oriented towards its negative side. The PCA biplot revealed that formulation F5 was primarily associated with swelling capacity and emulsion stability. In contrast, F6 was showing associations with solubility index, Carr index, Hausner ratio, and porosity. Formulation F7 was associated with density-related parameters and swelling index, while F3 and F4 has less distinctive profiles within the first two principal components.

Optimal flour formulation for optimal techno-functional properties

Following validation of the model, an overall formulation was defined to achieve maximum viscosity, bulk density, dispersibility and emulsifying capacity, whilst minimising wetting time, in order to ensure a high nutrient concentration, improved reconstitution and to prevent any phase separation. The optimal formulation predicted by the model comprised 65.00% millet flour, 20% soybean flour and 15.0% coconut flour to achieve optimal techno-functional properties of the flours, with an overall desirability score of 0.775, higher than the reference value of 0.5, confirming the accuracy and reliability of the model [10] (Figure 7).

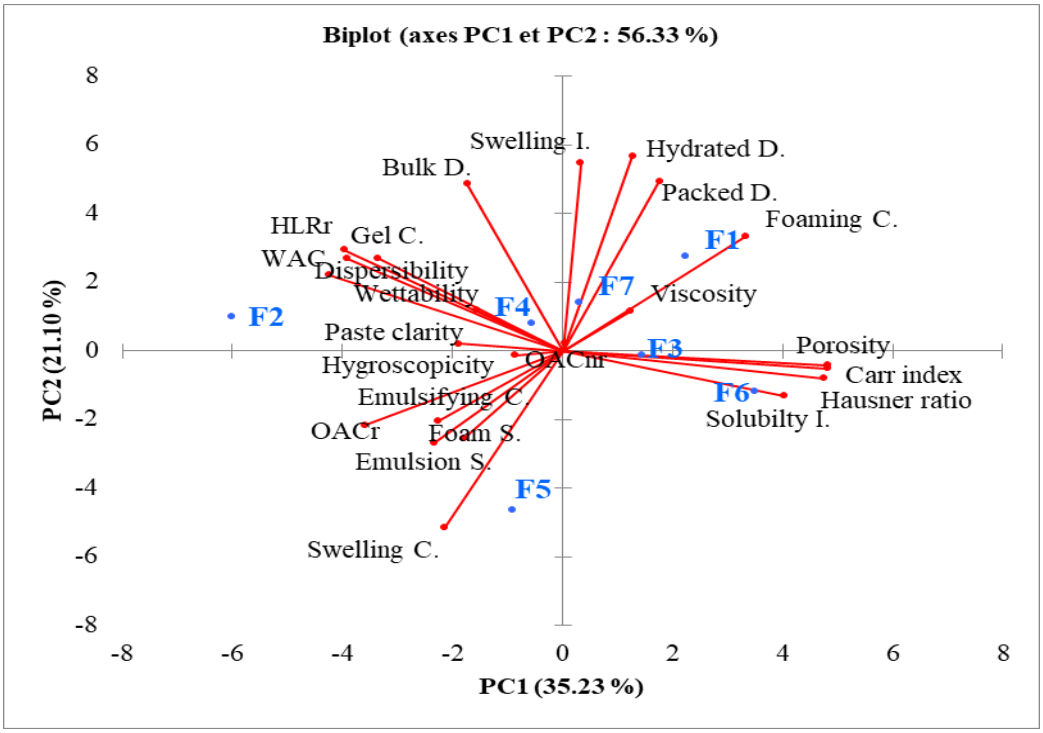

Figure 6: PCA of functional properties of the millet–soybean–coconut composite flours

Table 6 presents both the predicted values and the experimental values obtained under these conditions. No significant difference ($p < 0.05$) was observed between the model's predictions and the laboratory results.

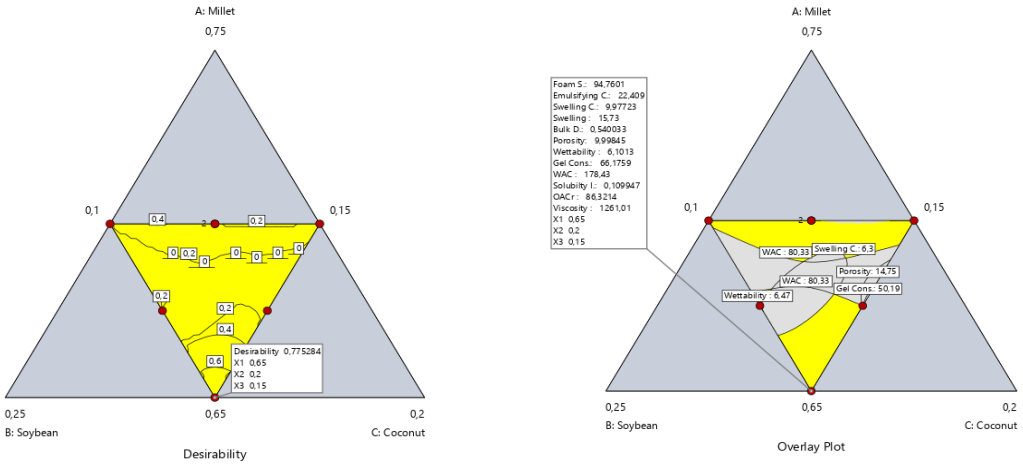

Figure 7: Global desirability and optimal flour functional

Table 8: Optimal composition of the formulated weaning flour

Responses	***Predicted Optimal Values***	***Experimental Optimal Values***
Foaming C.	8.330 [a]	8.55 ± 0.28[a]
Foam S.	94.758 [a]	93.55 ± 0.83[a]
Emulsifying C.	22.410 [a]	23.44 ± 1.23[a]
Swelling C.	9.980 [a]	10.22 ± 0.65[a]
Swelling	15.730 [a]	16.07 ± 1.55[a]
Bulk D.	0.540 [a]	0.53 ± 0.08[a]
Packed D.	0.600 [a]	0.61 ± 0.04[a]
Hausner R.	1.110 [a]	1.07 ± 0.05[a]
Porosity	10.000 [a]	9.95 ± 0.66[a]
Wettability	6.100 [a]	6.28 ± 0.25[a]
Gel Cons.	66.160 [a]	66.27 ± 1.00[a]
WAC	178.420 [a]	177.76 ± 1.76[a]
Solubilty I.	0.110 [a]	0.11 ± 0.02[a]
OACr	86.320 [a]	87.44 ± 1.24[a]
Viscosity	1261.240 [a]	1187.06 ± 2.05[a]
Global desirability score of 0.775		

Means ± standard deviations followed by the same letter in the same column indicate that the differences are not significant ($p \leq 0:05$).

DISCUSSION

Functional properties describe how food ingredients behave during processing, preparation, and cooking, as well as their influence on the texture, appearance, and sensory characteristics of the final products [11]. Among these properties, emulsifying capacity (EC) and foaming capacity (FC) are particularly important because they reflect the ability of food constituents, especially proteins, to form oil–water and air–water interfaces, respectively. Emulsifying capacity refers to the ability of surface-active compounds to facilitate the dispersion of oil droplets in an aqueous phase, whereas foaming capacity describes their ability to incorporate air during agitation and form a foam structure. These properties are relevant to composite flours intended for complementary feeding because they may influence the physical stability, texture, consistency, and homogeneity of reconstituted porridges, particularly when oils are incorporated to improve energy density. Both properties depend on protein composition, solubility, molecular flexibility, and interactions with starch and dietary fibre [12,13]. In the present study, emulsifying capacity (21.06–22.46%) and foaming capacity (8.25–12.35%) were lower than the emulsifying capacity (35.05–50.95%) and foaming capacity (10.83–15.40%) reported by Awuchi [14]. Such differences may be attributed to variations in raw material composition, protein characteristics and processing conditions. Furthermore, Nishinari et al. [12] highlighted the influence of protein aggregation and molecular interactions on the emulsifying behaviour of soybean proteins. These mechanisms may partly explain the functional characteristics observed in the millet–soybean–coconut composite flours. Soybean proteins may contribute surface-active components capable of adsorbing at oil–water and air–water interfaces, whereas millet starch and coconut dietary fibre may modify the viscosity and structural characteristics of the surrounding aqueous phase. Notably, formulation F2 (70:20:10) exhibited the highest emulsion stability (76.21%), suggesting that its constituent macromolecules may have contributed to the formation of a more stable emulsion under the experimental conditions. However, the specific contributions of the individual ingredients and their interactions require further investigation. Swelling capacity and swelling index describe the hydration-associated expansion of flour constituents and are particularly relevant to the texture and consistency of complementary porridges [15]. Swelling is

influenced by starch granule structure, the accessibility of hydrophilic groups and the capacity of dietary fibre to retain water [16]. Interestingly, F5 (70:15:15) exhibited the highest swelling capacity but the lowest swelling index, suggesting that the two measurements captured different aspects of hydration or structural expansion. In comparison, Omah et al. [17] reported swelling capacities of 0.10–0.30 mL/g in roasted pearl millet–soybean complementary flour blends, while a study of millet–soybean–African locust bean complementary foods reported values of 0.67–2.45%. Yalegama et al. [18] demonstrated that coconut-derived dietary fibre concentrates possess appreciable water-retention and swelling properties, supporting the possibility that coconut fibre contributed to the hydration behaviour of the present composite flours. The relatively high swelling capacity of F5 may therefore reflect favourable interactions among starch, proteins and fibre, although the underlying mechanism requires further structural investigation. Wettability is an important reconstitution property that describes the ability of water to penetrate and displace air from the surface of flour particles. Rapid wetting facilitates the preparation of homogeneous porridges and may reduce the formation of dry agglomerates during mixing [19]. In the present study, wettability time (5.24–6.47 s) high for F7 (Table 4), indicating relatively rapid wetting. These values were lower than the 10.63–25.54 s reported by Akinsola et al. [20] for maize–millet–soybean complementary flours subjected to different processing treatments. The shorter wetting times observed in the present study may reflect differences in particle size distribution, surface hydrophilicity, powder structure and ingredient composition. Fournaise et al. [21] demonstrated that powder reconstitution behaviour is influenced by physicochemical characteristics, including particle size and surface composition. Thus, the relatively rapid wettability of the millet–soybean–coconut formulations may be associated with the accessibility of hydrophilic groups in starch, proteins and coconut fibre. Dispersibility, which describes the ability of wetted flour particles to distribute throughout an aqueous medium, is another important determinant of reconstitution quality. The dispersibility (225.00–253.33%) was higher for F2 compared to Akinsola et al. [20] reported dispersibility values of 63.50–70.25% for maize–millet–soybean complementary flours. In food science, particularly in the study of cereal- or tuber-based composite flours, gel consistency, viscosity, and hygroscopicity are critical functional and rheological parameters. They dictate the sensory quality, preparation efficiency, storage stability, and nutritional density of porridge [22]. In the present study, gel consistency (50.19–66.16 mm) (Table 4) suggests differences in gel structure among the millet–soybean–coconut flour formulations. Assuming that greater gel flow distance indicates a softer gel, the higher value observed in F2 suggests a comparatively softer gel structure. These variations may be associated with differences in starch gelatinisation, amylose–amylopectin interactions, protein–starch associations, and water distribution within the flour matrix. The viscosity (987.58–1625.33) at 30°C of the composite was broadly comparable to the approximately 892.5–1577.5 cP reported by Omah et al. [17] for roasted pearl millet–soybean complementary flour blends. The relatively high viscosity observed in F1 may be attributed to enhanced starch swelling, water immobilisation, and interactions among millet starch, soybean proteins, and coconut dietary fibre. Nevertheless, excessively viscous porridges may limit the amount of flour incorporated into a serving, potentially reducing the energy and nutrient intake of young children [23]. Hygroscopicity, defined as the ability of a dry powder to absorb moisture from the surrounding atmosphere, is another important parameter affecting flour handling, caking tendency, and storage stability. In the present study,

hygroscopicity (8.00–10.11%), indicating differences in the moisture-uptake behaviour of the formulations. The comparatively high hygroscopicity of F2 may reflect a greater availability of hydrophilic functional groups in starch, proteins, and dietary fibre. Overall, these findings demonstrate that the millet–soybean–coconut flour formulations exhibited distinct gel-forming, rheological, and moisture-sorption characteristics, highlighting the importance of balancing gel consistency, viscosity, and hygroscopicity to develop complementary flours with suitable preparation properties, acceptable texture, and improved storage performance. Water and oil absorption, hydrophilic–lipophilic ratio (HLR), and solubility govern how materials (such as proteins, polymers, and surfactants) interact with polar and non-polar environments. The WAC (180.33–278.42%) in F2 (Table 5), indicating substantial differences in their hydration behaviour. Dendegh et al. [24] reported high values of 2.70–2.91 g/g for pearl millet–soybean–baobab complementary flour blends. The oil absorption capacity (OAC) (73.39–267.07%) was lower compared to Dendegh et al. [24], who reported OAC values of 1.90–2.72 g/g for pearl millet–soybean–baobab flour blends. Such differences may be related to the physicochemical characteristics of the oils, including viscosity, minor constituents and interactions with the flour matrix. Protein-associated hydrophobic regions and the porous structure of dietary fibre may also contribute to lipid retention. OAC measures the ability of flour particles to retain oil through physical entrapment, surface interactions and associations with hydrophobic regions of food macromolecules. OAC is relevant to complementary food formulation because added edible oils may contribute to dietary energy density, while oil retention can influence texture and product homogeneity. The solubility index varied (0.11–0.18). Interestingly, F2 exhibited the highest WAC but the lowest solubility index. This contrasting behaviour suggests that water retention and solubilisation were governed by different physicochemical mechanisms. High WAC may result from hydration of insoluble starch, proteins and dietary fibre, whereas solubility depends on the presence and release of water-soluble constituents. Previous investigations of instant food powders have emphasised that wetting, dispersibility and solubility represent distinct stages of reconstitution [19]. The relatively high solubility index of F6 may therefore reflect greater accessibility or release of soluble compounds, although confirmation would require analysis of the soluble fraction. Sensory evaluation is essential in complementary food development because nutritional and technological suitability alone cannot ensure product acceptance. Taste, colour, appearance, aroma and mouthfeel influence the perception of prepared foods, while overall acceptability reflects the combined sensory response of the assessors [25]. The present results revealed significant differences among formulations for taste, appearance, mouthfeel and overall acceptability, whereas colour and aroma did not differ significantly (Table 6). Taste scores (5.24–7.88) in F5, and appearance scores (5.95–7.34) suggest that the variations in mixture composition affected the sensory perception of the composite flours, particularly their taste and visual appearance. Such differences may be related to the relative contributions of millet-derived compounds, soybean constituents and coconut fibre, as well as the influence of processing on flavour development, colour and texture. Mouthfeel, which describes the tactile sensations perceived during oral processing, is particularly important for complementary porridges because particle texture, thickness and smoothness can affect eating comfort. Mouthfeel scores (5.33–7.34), indicating that the formulations differed in their perceived textural characteristics. These differences may be related to variations in hydration, swelling, particle dispersion and

viscosity. Makame et al. [23] demonstrated that the viscosity and oral texture of complementary porridges are relevant to their suitability for young children, particularly when excessive thickness or graininess limits consumption. In addition, the variation in overall acceptability suggests that overall preference was influenced by the combined perception of several sensory attributes rather than taste alone. Similar formulation-dependent sensory responses have been reported in millet–soybean complementary foods. Omah et al. [17] demonstrated that processing and formulation conditions influenced the sensory characteristics of roasted millet–soybean blends. Principal component analysis further illustrated the differentiation of the sensory profiles, with the first two principal components explaining 93.09% of the total variance. Formulations F1 and F2 were positioned on the negative side of PC1 and were associated with mouthfeel, aroma and overall acceptability, whereas F4, F5 and F6 were positioned on the positive side and were more closely associated with taste. This pattern was broadly consistent with the experimental sensory scores and reinforces the distinction between taste preference and overall acceptability. Multi-response optimization is particularly relevant to complementary flour development because desirable technological properties may be interdependent or conflicting. In the present study, viscosity, bulk density, dispersibility and emulsifying capacity were maximized, whereas wettability time was minimized. The predicted optimal formulation consisted of 65.00% millet flour, 20.00% soybean flour and 15.00% coconut flour, with an overall desirability value of 0.775. This result indicates a relatively favourable compromise among the selected responses within the investigated mixture domain. For comparison, Omah et al. [17] reported an overall desirability of 0.50 when optimizing the processing conditions of roasted pearl millet–soybean complementary flour blends.

CONCLUSION

This study demonstrated the effectiveness of simplex-lattice mixture design in optimizing the techno-functional properties of millet–soybean–coconut composite flour. The optimal formulation consisted of 65% millet, 20% soybean, and 15% coconut fibre, with an overall desirability of 0.775. Experimental validation confirmed good agreement between predicted and observed responses, supporting the predictive potential of the developed models. The findings highlight the potential of combining these ingredients to develop composite flours with desirable technological and sensory characteristics. Further investigations into nutritional composition, microbiological safety, and infant-specific acceptability are required before recommending the optimized flour for complementary feeding.

Declaration by Authors

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REFERENCES

1. World Health Organization. WHO guideline for complementary feeding of infants and young children 6–23 months of age. Geneva: World Health Organization; 2023. ISBN: 978-92-4-008186-4.
2. Hailu M, Kassahun W, Yesuf HA, et al. Serum electrolyte disturbances and treatment outcomes in hospitalized children with severe acute malnutrition in Ethiopia. Sci Rep. 2026; 16:21366. doi:10.1038/s41598-026-44123-1.

3. Ateye MD, Hassan SM. Development and evaluation of functional properties, anti-nutritional factors, and sensory profile for complementary infant food. Adv Res. 2025;26(3):253–265. doi:10.9734/air/2025/v26i31342.
4. Ali MAM, Tinay AHE, Elkhalifa AEO, Mallasy LO, Babiker EE. Effect of different supplementation levels of soybean flour on pearl millet functional properties. Food Nutr Sci. 2012;3(1):1–6. doi:10.4236/fns.2012.31001.
5. Trinidad TP, Mallillin AC, Valdez DH, Loyola AS, Askali-Mercado FC, Castillo JC, et al. Dietary fiber from coconut flour: a functional food. Innov Food Sci Emerg Technol. 2006;7(4):309–317. doi: 10.1016/j.ifset.2004.04.003.
6. Soro PL, Yao KA, Kouadio MK, et al. Comparative effect of cyanide reduction processes on the techno-functional properties of cassava flour. Am J Life Sci. 2026;14(2):30–48. doi: 10.11648/j.ajls.20261402.12.
7. FAO/WHO Codex Alimentarius Commission. Standard for processed cereal-based foods for infants and young children. CXS 74-1981. Adopted in 1981; revised in 2006; amended in 2017, 2019 and 2023.
8. Gunvig A, Andresen MS, Jacobsen T, Borggaard C. Staphtox predictor: a dynamic mathematical model to predict formation of Staphylococcus enterotoxin during heating and fermentation of meat products. Int J Food Microbiol. 2018; 285:81–91. doi: 10.1016/j.ijfoodmicro.2018.07.030.
9. Montgomery DC. Design and analysis of experiments. 9th ed. Hoboken (NJ): John Wiley & Sons; 2019.
10. Gobara Hamid M, Böhme C, Mustafa KA, Idris YMA, Hamad M, Muneer F, et al. Sensory profiling of traditional sorghum porridge (Aceda): advancing nutritious and culturally accepted biofortified products. Front Sustain Food Syst. 2025; 9:1578353. doi:10.3389/fsufs.2025.1578353.
11. Lin SD. Effects of processing and cooking on physicochemical, sensory, and functional properties of food: second edition. Foods. 2025;14(21):3601. doi:10.3390/foods14213601.
12. Nishinari K, Fang Y, Guo S, Phillips GO. Soy proteins: a review on composition, aggregation and emulsification. Food Hydrocoll. 2014; 39:301–318. doi: 10.1016/j.foodhyd.2014.01.013.
13. Tang CH. Emulsifying properties of soy proteins: a critical review with emphasis on the role of conformational flexibility. Crit Rev Food Sci Nutr. 2017;57(12):2636–2679. doi:10.1080/10408398.2015.1067594.
14. Awuchi CG. Proximate composition and functional properties of different grain flour composites for industrial applications. Int J Food Sci. 2019;2(1):43–64. doi:10.47604/ijf.1010.
15. Adebayo TK, Sobukola OP, Adeyanju AA, Bamidele OP. Nutritional composition, thermal and structural properties of extrudates from tannin sorghum, black-eyed cowpea composite flour. Appl Food Res. 2026;6(1):101690. doi: 10.1016/j.afres.2026.101690.
16. Yu Q, Qin X, Zheng B, Xie M. Dietary fiber in food industry: extraction, preparation and component interaction. Agricultural Products Processing and Storage. 2025;1(1):25. doi:10.1007/s44462-025-00029-1.
17. Omah EC, Eze CO, Eze CR, Umego EC, Anchang MM. Processing and optimisation of complementary food blends from roasted pearl millet (*Pennisetum glaucum*) and soybean (*Glycine max*) using response surface modeling. J Food Sci Technol. 2022;59(11):4273–4287. doi:10.1007/s13197-022-05494-1.
18. Yalegama LLWC, Karunaratne DN, Sivakanesan R, Jayasekara C. Chemical and functional properties of fibre concentrates obtained from by-products of coconut kernel. Food Chem. 2013;141(1):124–130. doi: 10.1016/j.foodchem.2013.02.118.
19. Jiang H, Zhang N, Xie L, Li G, Chen L, Liao Z. A comprehensive review of the rehydration of instant powders: mechanisms, influencing factors, and improvement strategies. Foods. 2025;14(16):2883. doi:10.3390/foods14162883.
20. Akinsola AO, Idowu MA, Babajide JM, Oguntona CRB, Shittu TA. Production and functional property of maize-millet based complementary food blended with soybean. Afr J Food Sci. 2018;12(12):360–366. doi:10.5897/AJFS2015.1387.
21. Fournaise T, Petit J, Gaiani C. Main powder physicochemical characteristics influencing their reconstitution behavior. Powder

Technol. 2021; 383:65–73. doi: 10.1016/j.powtec.2021.01.056.
22. Charles AN, Mburu M, Njoroge D, Jekle M, Zettel V. Functionality and appearance of sorghum-pearl millet composite flour fortified with oyster mushroom for thin porridges. Food Sci Nutr. 2026;14(3): e71630. doi:10.1002/fsn3.71630.
23. Makame J, De Kock H, Emmambux MN. Nutrient density and oral processing properties of common commercial complementary porridge samples used in southern Africa: effect on energy and protein intakes among children aged 6–24 months. J Texture Stud. 2023;54(4):481–497. doi:10.1111/jtxs.12753.
24. Dendegh TA, Ukeyima M, Dendegh RA. Proximate composition, functional and sensory properties of pearl millet, soy flour and baobab fruit pulp composite flour as a complementary food. Asian Food Sci J. 2019;8(3):1–11. doi:10.9734/afsj/2019/v8i329992.
25. Chen B, Lin X, Liang Z, Chang X, Wang Z, Huang M, et al. Advances in food flavor analysis and sensory evaluation techniques and applications: traditional vs emerging. Food Chem. 2025; 494:146235. doi: 10.1016/j.foodchem.2025.146235.

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