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FORMULATION AND BIOCHEMICAL CHARACTERIZATION OF INFANT FLOUR FROM MILLET PEARL, SOYBEAN AND COCONUT PREBIOTIC FIBER, USING SIMPLEX LATTICE DESIGN

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ABSTRACT

Malnutrition is a major global public health challenge, particularly affecting the African continent. This persistent problem holds critical importance, particularly in Africa, where nutritional challenges worsen. The quality of the flours used during infant weaning plays a decisive role in the nutritional development of infants. This study examined the nutritional quality of composite flours made from a mixture of millet, soybean and coconut kernel, intended to be used as food supplements in accordance with FAO and WHO standards. The formulation of the flours was carried out according to an experimental plan of the lattice simplex type using the Design-Expert version 13 software. Composite flours were extensively analyzed for macronutrient composition and bioactive compounds using standard analytical methods followed by principal component analysis (PCA) to assess nutritional similarities between different flour formulations. The results indicated that the millet-soybean-coconut kernel blend offers flours with biochemical characteristics ideal for children of weaning age. An optimal formulation was obtained with a composition of 70% millet flour, 18.6% soybean flour and 11.4% coconut kernel flour, resulting in a nutritional composition of 15.12% protein, 8.79% fat, 5.19% fiber, 68.92% carbohydrates, and 1.98% ash, for an energy value of 415.27 kcal/100 g. These parameters meet WHO recommendations for dietary supplements for breastfed children aged 6 to 24 months. This formulation could be recommended for young children, thus contributing to the fight against child malnutrition. However, further evaluation of the functional and sensory quality of this formulation would be necessary to ensure its acceptance and effectiveness.

Keywords: Malnutrition, Formulation, Infant Flour, Nutritive, Simplex Lattice Design

1 INTRODUCTION

Malnutrition is a global crisis and a leading cause of infant mortality in children under the age of five across the globe. This issue arises from nutritional deficiencies, which remain significant medical and public health challenges worldwide. Among the prevalent deficiencies are protein-energy malnutrition (PEM) and various micronutrient deficits, including iodine, vitamin A, iron, zinc, and folate [1]. In Côte d'Ivoire, child malnutrition is a major obstacle to the country's economic and social development with a prevalence that has stagnated for the past ten years at around 8%. Severe acute malnutrition is the deadliest form of malnutrition and is one of the main threats to child survival in some regions [2]. The most affected are infants aged 6 to 23 months, as this period is crucial for the onset of dizzying growth, micronutrient deficiencies and infectious diseases. At this period, the nutrient deficiency in breast milk should normally be filled with complementary foods, which are usually flours prepared in the form of porridge [3]. In addition, at this stage, food allergies, especially to eggs, crustaceans and nuts, develop in some children, leading to the introduction of complementary foods (CF) in the diet [4]. According to WHO and UNICEF, food diversification should start at 6 months, with a gradual incorporation of foods rich in proteins, energy and micronutrients [5]. CF are all other foods than breast milk given to children in the liquid or semi-liquid form to increase their nutrient intake. It's vital for providing essential nutrients like iron, zinc, and vitamin A, with early inclusion of foods like meat, eggs, and liver being beneficial to address common deficiencies [4,6]. In developing countries such as Côte d'Ivoire in particular, the fact is that industrial food supplements offered on the local market are very often imported flours and remain expensive for most populations. This is how they turn to the use of traditional local flours, much more adapted and accessible according to the purchasing power. This is why the World Health Organization has recommended the use of local raw materials such as cereals and tubers available in the formulation with or without sugar and the use of high nutritional value FCs to promote and improve the technological knowledge of local populations in the formulation and to have cheaper infant meals for low-income households [7]. While cereals and tubers are abundant in carbohydrates, they tend to lack sufficient proteins and some micronutrients. However, apart from these starch-rich sources, many other foods in Côte d'Ivoire are high in proteins and lipids, as well as essential minerals and vitamins. These include coconut, which is available and less expensive. Singh et al., in a previous review study, reported that coconut kernel is a white edible endosperm widely consumed in fresh form and utilised in the preparation of cakes, ice creams, curries, and various traditional foods. It is a rich source of essential minerals such as magnesium, calcium, and potassium, which play important roles in bone health and muscle function. One fresh coconut kernel provides approximately 48% of the recommended daily allowance (RDA) for copper, 65% for manganese, and 24% for dietary fiber, along with several other essential vitamins and minerals. Coconut consumption has also been associated with various health benefits, including support for metabolic functions, antioxidant defence and overall well-being [8]. According to Gbogouri et al., the development of local flours would be an alternative insofar as they come directly from locally accessible raw materials. This alternative has the advantage of easier production due to the availability and use of local food, as well as reduced production costs [9]. The World Health Organization (WHO) and FAO (through the Codex Alimentarius Guidelines for Processed Food Supplements) recommend that infant meal and food supplements for children aged 6 to 24 months meet specific nutritional and moisture criteria with a minimum of 400 kcal per 100 g of dry flour representing about 60 to 70% of carbohydrates, 12 to 15% of protein (with a minimum of 7% digestibility) and about 8 to 10% of fat. It should also contain 5% fiber, 7 mg iron and 350 µg vitamin A, all in 100 g flours [10]. It is therefore appropriate to produce flours from local cereals rich in macronutrients and micronutrients essential for optimal health and good development in children. This approach aims to facilitate children's nutrition and promote local products. It is in this context that interest has focused on the development of a composite flour based on local products to contribute to the fight against child malnutrition, meeting the nutritional needs of children from 6 to 24 months.

2 MATERIALS AND METHODS

2.1 Plant Material

The millet (*Pennisetum glaucum*) and soybean (*Glycine Max*) were purchased from a market in Abidjan, the coconut (*Cocos nucifera*) was collected in an experimental plot. The samples thus collected were forwarded to the laboratory and proceeded into flour and powders for weaning food production.

2.2 Flours production

The millet pearl was sorted and washed by hand and then soaked in water for 24 hours. It was then rinsed and dried in a ventilated oven at 45°C until a constant dry mass was obtained. The dried grains were ground to obtain the millet flour using a grinder. As for the soybeans, they were sorted and then soaked in distilled water for 10 hours. After soaking, the grains were dried in a ventilated oven at 45°C until a constant dry mass was obtained. After drying, the grains were shelled and ground. Regarding coconuts, they were broken using a stainless-steel knife to extract water. Then the fresh white kernel was removed with a stainless-steel knife, and the brown testa pellicle was removed from the kernel with the knife. The coconut kernels thus obtained were washed to remove the remaining impurities. The kernels 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 kernels were ground using a kneader. Finally, all these powders 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 labelled individually.

2.3 Flours mixing procedure

The study evaluated the effect of a ternary flour mixture from three formulation variables: millet flour (*MilF*) [X1], soybean flour (*SoyF*) [X2] and coconut flour (*CoCF*) [X3], as individual and interdependent factors, on the biochemical characteristics of flours, using a simplex lattice experimental design. The proportions of the formulation variables were chosen taking into account the implicit individual and relational constraints. The implicit individual constraints were imposed such that the target carbohydrate content of the flour is less than or equal to 70%, protein is less than or equal to 20% and fat is less than or equal to 10% in the mixture. They were selected on the basis of a literature review, FAO/WHO standards and Codex Alimentarius guidelines. The implicit relational constraint was to set the sum of the mixtures at 100% ($X1\% + X2\% + X3\% = 100\%$) (Table 1).

Table 1: Design constraints

Low Limit		Constraint		High Limit
0.650	≤	A: Millet flour	≤	0.700
0.150	≤	B: Soybean flour	≤	0.200
0.100	≤	C: Coconut flour	≤	0.150
		A+B+C	=	1.000

These constraints made it possible to define an experimental domain in the form of a simplex consisting of seven formulations developed using the Design-Expert version 13 software (Stat-Ease Inc., Minneapolis, MN, USA) (Table 2).

Table 2: Experimental matrix

		Pseudo-component			Real variables		
Run		MilF	SoyF	CoCF	MilF (g)	SoyF (g)	CoCF (g)
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

MilF: millet flour; SoyF: soybean flour; CoCF: coconut flour. C : center point, S : vertex point

2.4 Mathematical modeling of responses

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 linear mathematical model of the formulated flour was as follows:

$$Y = \beta_1 \text{MilF} + \beta_2 \text{SoyF} + \beta_3 \text{CoCF}$$

The second-degree polynomial mathematical model was as follows:

$$Y = \beta_1 \text{MilF} + \beta_2 \text{SoyF} + \beta_3 \text{CoCF} + \beta_{12} \text{MilF} \times \text{SoyF} + \beta_{13} \text{MilF} \times \text{CoCF} + \beta_{23} \text{SoyF} \times \text{CoCF}$$

where Y is the expected response, β_1 , β_2 , and β_3 are linear coefficients, β_{12} , β_{13} , and β_{23} are interaction coefficients

2.5 Models' Validation

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%, the Absolute Mean Deviation Analysis (AMDA) which must be equal to 0 [11].

2.6 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 [12], was used to numerically optimize the proportions of the mixture.

2.7 Composite flours nutritive determination

The nutritional composition of the flours was determined using standard methods as reported by Kouadio et al. [13]. Briefly, moisture content was determined by drying samples in a hot air circulating oven (Eagle, WI, USA) at $105 \pm 2^\circ\text{C}$ until a constant weight was obtained. Total nitrogen was determined by the Kjeldahl method using a digestion and distillation apparatus, and the nitrogen-to-protein content was calculated using a conversion factor of 6.25. Total fat content was determined by continuous extraction in a Soxhlet apparatus for 8 h using hexane as a solvent. Crude ash content was determined by burning powder in a muffle furnace at 550°C until the sample was free of carbon, cooling in a desiccator and calculating the amount of ash. Crude fiber was determined after digestion of a known weight of fat-free sample in refluxing 1.25% sulphuric acid and 1.25% sodium hydroxide. The amount of total soluble sugars was estimated using the phenol-sulphuric acid reagent method and reducing sugars using 3,5-dinitro-salicylic acid. The available carbohydrate was calculated by difference. Energy value was calculated using the conversion factors. Vitamin C content of the samples was determined according to method described by Pongracz [14]. Polyphenol, flavonoid and gallic tannin contents were determined according to method described by [15–17].

2.8 Statistical Analysis.

All experiments in this study were performed in triplicate ($n = 3$) and results are expressed as mean $\pm$ standard deviation. Statistical differences between samples were determined by Oneway Analysis of variance (ANOVA) and Post-hoc (Tukey's Test) with a significance level of $p < 0.05$. Graphical representations of the 3 D surface of the postulated models were performed using Design-Expert version 13 software (Stat-Ease Inc., Minneapolis, MN, USA).

3 RESULTS AND DISCUSSION

3.1 Proximate composition of formulated weaning flour

The proximate composition on a dried weight basis of the developed infant formula is given in Table 3. A significant ($p < 0.05$) difference was found among the 7 formulations. Overall, the flour mixtures showed a good balance of macronutrients, in particular lipids, proteins and carbohydrates, for the complementary flours. These nutrient and energy density contents meet the standard of FAO/WHO guidelines [18]. Moisture content (5.33-6.1%) would indicate good storage stability; the lower F4 formulation suggests that it would be less conducive to microbial and fungal growth. In addition, this low humidity in the flour would limit its infestation by insects and the degradation of nutrients. This result was close to those obtained (5.85 - 7.16%) by Sanou et al. [3]. Because infants require high amounts of minerals for bone density, oxygen transport, and immune function, measuring ash helps manufacturers ensure the flour meets targeted nutritional requirements. The formulations' ash (1.84 - 2.01%) obtained were lower than those obtained (2.80 - 3.73%) by Sanou et al. [3] but values are in accordance with the recommended values. The total fiber (3 - 5.28%) was higher for F3. According to [18], dietary fiber in infant flour plays a vital balancing act: while essential for digestive health and gut development, it must be kept at low levels to prevent nutrient malabsorption and digestive discomfort. The fiber content measured by [19] was found to be low (1.54 to 3.3%) for weaning flours based on *Zea mays* (Poaceae) seeds, *Citrullus lanatus* (Cucurbitaceae) seeds and *Moringa oleifera* (Moringaceae) leaves. Contrary to our study, the incorporation of coconut flesh, a source rich in fiber, explains the richness in fiber of our formulation. Coconut kernel dietary fiber is a highly valuable, nutrient-dense becoming an increasingly popular functional ingredient in infant flour formulations (complementary weaning foods). Its incorporation drastically modifies both the nutritional matrix and physical properties of infant gruels and biscuits [20]. Infants transitioning to solid foods frequently encounter gastrointestinal irregularities. The soluble polysaccharides in the kernel act as prebiotics, stimulating the growth of beneficial gut bacteria. Concurrently, the abundant insoluble fiber adds essential bulk to the stool, supporting healthy peristalsis and preventing infant constipation [21,22]. Furthermore, [23] asserted that a low-fiber diet has an impact on children's appendicitis and constipation, and it can hinder the growth of gut bacteria during the critical first year of life. The high protein content (12.50 - 16.29%) of the formulations, in particular of the F2 formulation, indicates that its formulations are sufficiently high in protein to cover the protein needs of children.

In addition, the incorporation of soybean, which is an exceptional source of plant lysine, contributes to having a quality protein source [24] in the formulation. Protein in infant cereal-based composite flours is essential as it provides amino acids that stimulate rapid physical growth, muscle development and immune system maturation during weaning [25]. Fats and carbohydrates are the main contributors to energy value. In these formulations, lipids (6.25 – 9.66%), carbohydrates (66.61 – 71.15%) and reducing sugars (19.29 – 31.93%) were in considerable amounts in formulations F2 and F3, respectively. This could be explained by the use of millet, soybean and coconut kernel, which are known to be high in carbohydrates and fats. This is particularly beneficial for energy-intensive populations, such as children, as dietary lipids improve caloric intake, taste and absorption of fat-soluble vitamins and provide the essential fatty acids needed for growth and development [26]. In addition, adequate intake of lipids and carbohydrates which as macronutrient provides energy for infants who are very active at this stage of life. Sanou et al. [3] reported more lipids (5.85 - 7.16%) in their formulated flours. Energy density is a critical determinant of the nutritional adequacy of complementary foods because infants have high nutrient requirements but limited gastric capacity [27]. In the present study, all formulations' energy values (399.97 – 413.51 kcal/100 g) meet or exceeded the WHO minimum recommendation of 400 kcal/100 g, which is favourable for meeting the energy needs of malnourished children. Sanou et al. [3] found high energy values (408.85 – 418.54 kcal/100 g). They estimated that this energy density could cover 95 to 97% of the recommended metabolizable energy (220 kcal), similar to our formulations.

Table 3: Proximate composition (g/ 100 g dry matter) and energy value of the formulated weaning flour

Run	Carbohydrates (%)	Ash (%)	Moisture (%)	Protein (%)	Fat (%)	Fiber (%)	Energy (Kcal/100g)
F1	69.88±1.57 ^{ab}	1.97±0.88 ^{ab}	5.34±1.19 ^b	14.41±0.65 ^c	8.40±1.01 ^{ab}	5.18±0.45 ^a	412.76±2.54 ^{ab}
F2	66.61±1.33 ^c	1.74±0.76 ^c	5.70±1.08 ^{ab}	16.29±0.43 ^a	9.66±0.99 ^a	3.00±0.11 ^c	418.54±2.76 ^a
F3	71.15±1.05 ^a	2.01±0.25 ^a	6.09±0.82 ^a	12.50±0.61 ^d	8.25±0.85 ^{ab}	5.28±0.33 ^a	408.85±3.25 ^{bc}
F4	69.91±2.29 ^{ab}	1.97±0.34 ^a	5.33±0.71 ^b	14.39±0.72 ^c	8.40±1.30 ^{ab}	5.18±0.11 ^a	412.80±2.36 ^{ab}
F5	69.54±1.31 ^{ab}	1.92±0.48 ^{ab}	5.36±1.36 ^b	14.69±0.78 ^c	8.51±1.46 ^{ab}	5.00±0.45 ^a	413.51±2.55 ^{ab}
F6	70.08±1.68 ^a	1.90±0.91 ^{ab}	6.10±0.90 ^a	14.50±0.41 ^c	7.42±1.00 ^{bc}	4.00±0.12 ^b	405.10±1.72 ^c
F7	70.22±2.01 ^a	1.84±0.15 ^b	5.98±1.20 ^a	15.71±0.53 ^{ab}	6.25±1.05 ^d	4.45±0.19 ^b	399.97±1.49 ^d
FWS	65 – 68	> 5	5	12 – 15	7 - 10	< 5	400

F : Formulation, , FWS : FAO/WHO Standard, Means in the same column with different superscript letters differ significantly (P<0.05)

Table 4: Phytochemical content of the formulated weaning flour

Run	Total sugars (%)	Reducing sugars (%)	Polyphenols (mg GAE/g)	Flavonoids (mg QE/g)	Vitamins C (mg/g)	Tannins (mg CE/g)
F1	56.40±1.55 ^a	19.29±1.03 ^c	0.20±0.06 ^{bc}	6.34±0.24 ^{ab}	0.54±0.05 ^a	2.24±0.09 ^{ab}
F2	50.00±1.02 ^c	31.93±1.65 ^a	0.19±0.04 ^{cd}	5.42±0.55 ^{de}	0.37±0.08 ^c	2.22±0.12 ^{ab}
F3	50.51±1.68 ^c	22.12±1.56 ^b	0.20±0.00 ^b	6.05±0.45 ^{cd}	0.55±0.04 ^a	2.40±0.33 ^{ab}
F4	56.66±1.11 ^c	19.30±1.41 ^c	0.20±0.05 ^{bc}	6.33±0.11 ^{ab}	0.54±0.06 ^a	2.25±0.04 ^{ab}
F5	53.06±1.05 ^b	30.81±1.22 ^a	0.23±0.00 ^a	6.69±0.34 ^a	0.46±0.01 ^b	2.21±0.57 ^{ab}
F6	55.36±0.98 ^a	23.31±1.11 ^b	0.19±0.04 ^d	5.91±0.06 ^d	0.45±0.04 ^b	1.78±0.27 ^c
F7	49.17±1.17 ^{cd}	22.91±1.22 ^b	0.20±0.05 ^b	6.15±0.82 ^{bc}	0.44±0.03 ^b	3.08±0.00 ^a

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

The results of the polyphenol, flavonoid, tannin and vitamin C content of the different formulated weaning flours are displayed in Table 4. Polyphenols and flavonoids play a dual, highly nuanced role in infant flour. While they are highly beneficial for expanding the flour's shelf life and providing health-promoting bioactives for the infant, they also act as antinutrients that can hinder the absorption of critical minerals [23]. Tannin (1.78 - 2.40 TAE/g), polyphenol (0.19 - 0.23 mg GAE/g), flavonoids (5.42 - 6.69 mg CE/g) and vitamins C (0.37 - 0.54 mg/g) were found to be high in F5, F3 and F8 formulations. A previous study by [23] found more polyphenols (0.85 - 0.96 mg GAE/g), lower flavonoids (0.37 - 0.63

mg QE/g) and lower tannins (1.06 - 2.15 mg CE/g) for the formulated complementary foods from brown rice, chickpeas, mature pumpkin, and ripe Sabri bananas.

In this study the high flavonoids could be due to the *Pennisetum glaucum* (millet pearl) incorporation, which contains a rich and significant amount of flavonoids and other phenolic compounds compared to many other common staple cereals [28]. Concerning Vitamin C (1.78 - 3.08 mg CE/g), it was found to be high in the F7 formulation containing more soybean flour. Vitamin C in infant supplement flour crucially helps the body absorb non-heme plant iron from ingredients like soybean and legumes, while also supporting immune health [29,30].

3.2 Principal component analysis (PCA)

The PCA biplot (Figure 1) of the seven composite samples of millet-soybean-coconut flour (F1–F7) illustrates a clear nutritional differentiation, with CP1 and CP2 accounting for 35.32% and 28.99% of variability, respectively, or 64.31% of total variability (Figure 2). These flours F2 and F5 are positioned on the positive side of PC1, indicating a richness in proteins, fats, reducing sugars, titratable acidity, pH and energy. This indicates that these meals could cover the energy needs of children suffering from protein-energy malnutrition. F1 and F4 are clearly separated from the negative side of PC1, associated with a high content of bioactive compounds (flavonoids and vitamin C) and soluble sugars, which could provide soluble carbohydrates providing calories easily assimilated in children. F3, F6 and F7 are grouped on the positive side of PC2 and near the vectors of carbohydrates, fiber and moisture, showing good nutritional density and facilitation of digestion in children. This PCA result also shows that protein, fat and energy vectors are oriented in similar directions, indicating their positive correlation, while raw fiber and carbohydrates oppose these vectors, confirming their inverse relationship with macronutrients. The PCA provides information on the main compositional factors influencing the nutritional quality of maize-cotton composite flours.

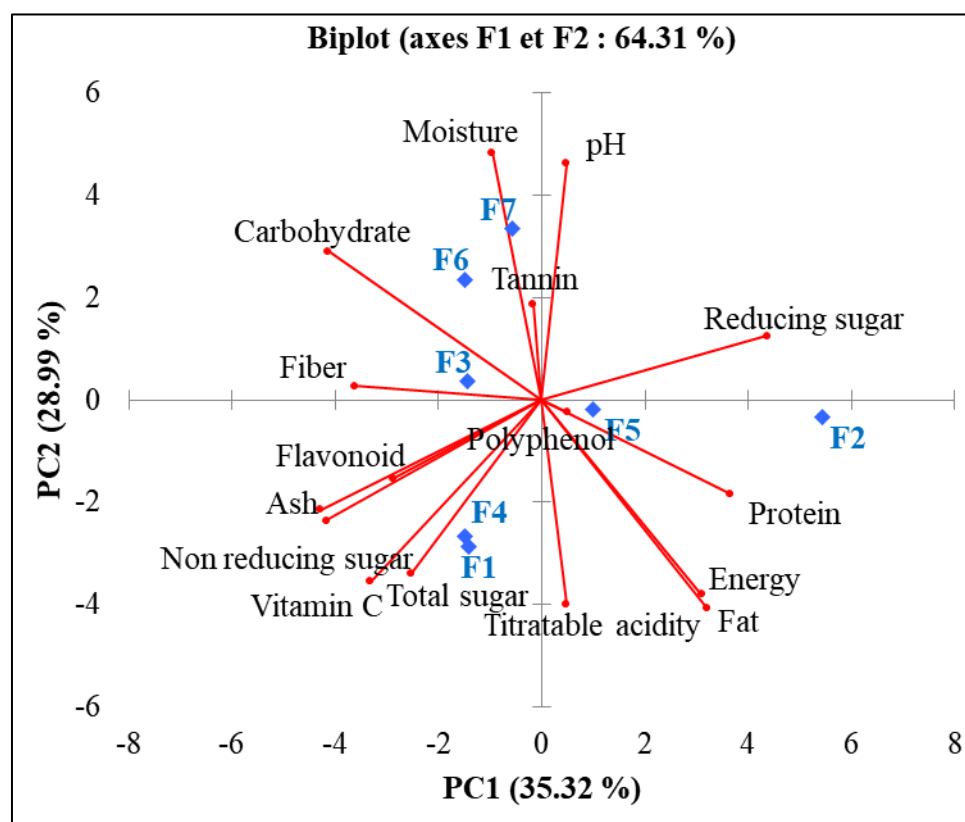


Figure 1: PCA of proximate composition of millet-soybean-coconut composite flours

3.3 Analysis of variance and model validation

Table 5 presents the p-values and the coefficients of determination of (R^2) for the factors significantly influencing the nutritional responses. The results show that the majority of the responses studied are better described by the quadratic model, as indicated by the significant values obtained for pH, humidity, proteins, carbohydrates, sugars, polyphenols, tannins and energy ($p \leq 0.05$). On the other hand, fibers, ash and flavonoids were mainly explained by the significant linear model in interactions between different raw materials showed variable effects depending on the parameters. *MilF*×*SoyF*, *MilF*×*CoCF* and *SoyF*×*CoCF* interactions significantly influenced several physicochemical and bioactive characteristics, including moisture, protein, carbohydrates, sugars, polyphenols and tannins. However, some

interactions have proved to be insignificant for parameters such as titratable acidity, lipids or vitamin C. The adjusted coefficients of determination (adjusted R^2) obtained are high and between 0.85 and 0.99 greater than 75%, reflecting a good match of the models with the experimental data.

Moreover, the low coefficients of variation and the AMDA (Absolute Mean Deviation Analysis) equal to 0 observed for most of the responses indicate good adequacy between the experimental responses and the predicted responses given by the model [31].

Table 5: Analysis of variance of the model for the formulated weaning flour

	<i>linear</i>	<i>Quadratic</i>	<i>MilF×SoyF</i>	<i>MilF×CoCF</i>	<i>SoyF×CoCF</i>	<i>Lack of fit</i>	<i>R² ajus.</i>	<i>CV (%)</i>	<i>Adeq. A.</i>	<i>AMDA</i>
pH	0.60ns	0.0069*	0.0298*	0.0122*	0.0031*		0.85	0.26	7.63	00
TTA	0.70ns	0.0427*	0.0281*	0.667 ns	0.6181 ns		0.99	4.16	47.35	00
Mois.	0.39 ns	0.0065*	0.0071*	0.0051*	0.0057*		0.99	0.36	313.60	00
Prot.	0.872ns	0.0057*	0.0059*	0.0112*	0.7153*		0.99	0.14	365.84	00
Fat	0.923ns	0.049*	0.422 ns	0.012*	0.0049*		0.97	1.92	42.45	00
Fiber	0.00*	0.873 ns				0.87ns	0.98	1.20	30.99	00
Carb.	0.59ns	0.0083*	0.0053*	0.0428*	0.0066*		0.99	0.04	247.07	00
TSS	0.55ns	0.0402*	0.0281*	0.02472*	0.606 ns		0.99	0.34	43.24	00
RS	0.27ns	0.0008*	0.0015*	0.0006*	0.0007*		0.99	02.92	1930.50	00
Ash	0.003*	0.960 ns				0.96ns	0.91	1.45	14.75	00
EV	0.94ns	0.0008*	0.0008*	0.0027*	0.0004*		0.99	0.00	2836.61	00
Polyp.	0.790ns	0.0063*	0.0101*	0.0084*	0.0040*		0.99	0.65	71.37	00
Flav.	0.00*	0.1553 ns				0.15ns	0.95	1.38	21.32	00
Tan.	0.82ns	0.0085*	0.0485*	0.0084*	0.0043*		0.99	0.20	292.75	00
Vit C.	0.00*	0.0106*	0.0912 ns	0.0281*	0.0199*		0.99	0.21	193.16	00

MilF (Millet flour); SoyF (Soybean flour); CoCF (Coconut flour); Prot. (Proteins); Carb. (Carbohydrates); Mois. (Moisture); TTA (Titratable acidity); TSS (Total soluble sugars); RS (Reducing sugars); EV (Energy value); Polyp. (Polyphenols); Flav. (Flavonoids); Tan (Tannins); Vit C (Vitamins C); Adeq. A. (Adequate accuracy); AMDA (Absolute Mean Deviation Analysis) value = 0, indicates good adequacy; ns (non-significant); (*): indicates significant p-values ($p < 0.05$) at 95 % confident interval.

3.4 Analysis of variance of the weaning flour formulation model

The regression models correctly representing the relationships between the responses which are the biochemical parameters linked to the proportions of the 3 flours mixed are indicated below. In addition, the 3D surface graphs (Figure 2) show the desired response values for moisture, carbohydrates, protein, fat, ash, fiber and energy as a function of the proportion of flour mixture.

- $\text{pH} = -3.65\text{MilF} - 39.25\text{SoyF} - 3.65\text{CoCF} + 96\text{MilF} \times \text{SoyF} + 48\text{MilF} \times \text{CoCF} - 32\text{SoyF} \times \text{CoCF}$
- $\text{Titratable acidity} = 9\text{MilF} + 41.8\text{SoyF} - 17.4\text{CoCF} - 96\text{MilF} \times \text{SoyF} - 16\text{MilF} \times \text{CoCF} + 88\text{SoyF} \times \text{CoCF}$
- $\text{Moisture} = -48.23\text{MilF} - 62.83\text{SoyF} - 56.83\text{CoCF} + 328\text{MilF} \times \text{SoyF} + 376\text{MilF} \times \text{CoCF} - 672\text{SoyF} \times \text{CoCF}$
- $\text{Protein} = 287.29\text{MilF} - 1036.11\text{SoyF} + 3678.49\text{CoCF} + 504\text{MilF} \times \text{SoyF} - 6384\text{MilF} \times \text{CoCF} + 12.64\text{SoyF} \times \text{CoCF}$
- $\text{Lipid} = 355.29\text{MilF} + 929.89\text{SoyF} + 2380.29\text{CoCF} - 2456\text{MilF} \times \text{SoyF} - 4536\text{MilF} \times \text{CoCF} + 8\text{SoyF} \times \text{CoCF}$
- $\text{Fiber} = 23.75277\text{MilF} - 23.348\text{SoyF} - 18.869\text{CoCF}$
- $\text{Carbohydrate} = -573.01\text{MilF} - 3116.61\text{SoyF} - 2101.41\text{CoCF} + 672\text{MilF} \times \text{SoyF} + 5376\text{MilF} \times \text{CoCF} - 672\text{SoyF} \times \text{CoCF}$
- $\text{Total sugars} = -31.18\text{MilF} - 5830.58\text{SoyF} + 2099.62\text{CoCF} + 8168\text{MilF} \times \text{SoyF} - 37766\text{MilF} \times \text{CoCF} + 7592\text{SoyF} \times \text{CoCF}$
- $\text{Reducing sugars} = 610.93\text{MilF} + 3469.53\text{SoyF} + 9183.73\text{CoCF} - 594\text{MilF} \times \text{SoyF} - 135366\text{MilF} \times \text{CoCF} - 11472\text{SoyF} \times \text{CoCF}$
- $\text{Ash} = 3.30\text{MilF} - 2.09246\text{SoyF} + 0.148\text{CoCF}$
- $\text{Energy} = 2370.09\text{MilF} + 5391.09\text{SoyF} + 12590.29\text{CoCF} - 13752\text{MilF} \times \text{SoyF} - 24312\text{MilF} \times \text{CoCF} + 2680\text{SoyF} \times \text{CoCF}$
- $\text{Polyphenol} = 126.15\text{MilF} + 1207.35\text{SoyF} + 1570.15\text{CoCF} - 1744\text{MilF} \times \text{SoyF} - 2096\text{MilF} \times \text{CoCF} - 3616\text{SoyF} \times \text{CoCF}$
- $\text{Flavonoid} = 1130.42\text{MilF} - 1.018\text{SoyF} - 1226.138\text{CoCF}$

- Tannin = $-1244.31MilF + 62890.29SoyF - 92813.31CoCF - 84104 MilF \times SoyF + 1395925MilF \times CoCF - 10080SoyF \times CoCF$
- Vitamin C = $176.07MilF + 407.139SoyF - 3916.486CoCF - 1418.56MilF \times SoyF + 4640.96MilF \times CoCF + 15338.32SoyF \times CoCF$

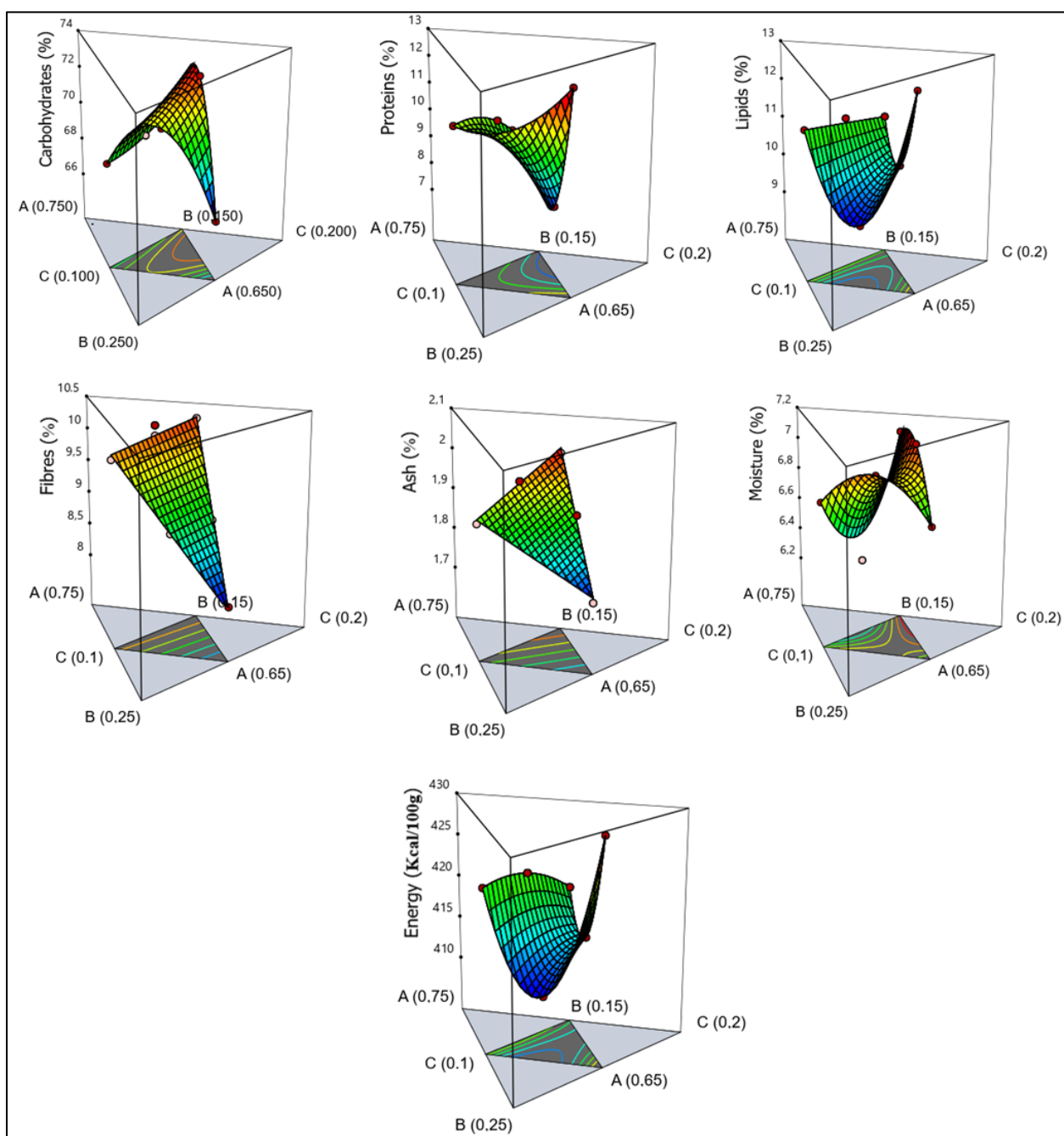


Figure 2: 3 D surface plot for moisture, carbohydrate, protein, lipid, ash, fiber and energy

3.5 Optimum formulation for optimal nutrient-dense flour

Following model validation, a global formulation was defined to minimise moisture content while maximising other nutritional parameters, in accordance with acceptable macronutrient standards for infant meal. The optimal formulation predicted by the model included 70% millet flour, 18.6% soybean flour and 11.4% coconut flour. Table 6 presents both the predicted values and the experimental values obtained under these conditions. No significant differences were observed ($p < 0.05$) between the responses given by the model and those obtained in the laboratory, with a global desirability score of 0.626 higher than the valid 0.5 value, confirming the accuracy and reliability of the model [11]. Under optimum conditions, the pH was 5.40, the titratable acidity was 0.21%, and the moisture content was 5.29 g/100 g, with 15.12 g/100 g protein, 8.79 g/100 g fat, 5.19 g/100 g fiber, 68.92 g/100 g carbohydrates, 57.82 g/100

g total sugars, 1.88 g/100 g ash, 0.22 mg/g polyphenols, 6.48 mg/g flavonoids, 2.07 mg/g tannins, and 0.51 mg/g vitamins C. A 100 g serving of flour provides 415.18 Kcal/100g of metabolisable energy. In addition, the macronutrient composition conforms to the recommended standard. Also, the optimal metabolisable energy found is in agreement with the normative value of 400.

Table 6: Optimal composition of the formulated weaning flour

Responses	Predicted Optimal Values	Experimental Optimal Values
pH	5.39 ^a	5.40 ± 0.03 ^a
Titrateable acidity	0.19 ^a	0.21 ± 0.01 ^a
Moisture	5.25 ^a	5.29 ± 0.26 ^a
Proteins	14.73 ^a	15.12 ± 0.23 ^a
Fat	8.45 ^a	8.79 ± 0.99 ^a
Fibers	5.10 ^a	5.19 ± 0.44 ^a
Carbohydrates	69.63 ^a	68.92 ± 1.38 ^a
Total sugars	56.07 ^a	57.82 ± 1.77 ^a
Ash	1.94 ^a	1.98 ± 0.05 ^a
Energy	413.49 ^a	415.27 ± 2.23 ^a
Polyphenols	0.20 ^a	0.21 ± 1.65 ^a
Flavonoids	6.51 ^a	6.48 ± 2.66 ^a
Tannins	2.21 ^a	2.27 ± 1.24 ^a
Vitamins C	0.51 ^a	0.51 ± 0.23 ^a
Composite Desirability =0.626		

Means ± standard deviations followed by the same letter in the same column indicate that the differences are not significant ($p \leq 0.05$).

4 CONCLUSION

This study provides a complete physico-chemical characterization of local infant flours enriched with coconut kernel prebiotic fibers from Ivorian food resources. The analyses carried out showed that the various samples used for the formulation by the mixing plane made it possible to find the optimal conditions. For example, to have nutritional-grade weaning flour, 70% millet flour, 18.6% soybean flour and 11.4% coconut flour are needed to meet the nutritional and energy needs of the child according to WHO standards. These results demonstrate that locally available ingredients can be successfully combined to produce nutritionally adequate weaning flours. This flour, made from millet (*Pennisetum glaucum*), soybean (*Glycine max*) and coconut (*Cocos nucifera*), would be useful in the practice of substituting imported and expensive infant flours, so as to promote the importance of processing technologies to determine the nutritional quality of food supplements and support the use of safe, affordable and locally available ingredients to strengthen the use of infant flours in Côte d'Ivoire in the fight against nutritional deficiencies in children of weaning age.

STATEMENTS ON COMPLIANCE WITH ETHICAL STANDARDS

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Disclosure of conflict of interest

The authors confirm that they have no conflicts of interest concerning the work described in this manuscript.

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