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Original Research Article

Nutritional Qualities and Vitamin Content of Local Flours Used in Nutritional Rehabilitation Centers in Côte d'Ivoire

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Abstract: The goal of this study was to confirm that the protein, micronutrient content, and energy value of specialized food products made from local foods meet international quality criteria for the management of mild acute malnutrition. These local specialized food products are already consumed in nutritional rehabilitation facilities in Côte d'Ivoire under the supervision of the NNP (National Nutrition Program). The NNP-recommended procedures were used to manufacture the replacement flour formulations. These flours' physicochemical and nutritional properties were assessed using established procedures. Protein levels ranged from 11.19 to 18.12 % in 100 g of dry matter, carbohydrates from 51.5 to 73.9 %, lipids from 9.66 to 23.86%, and energy value ranged from 427.36 to 493.33 Kcal/100g. These flours fulfill macronutrient content quality criteria and may thus cover the protein and energy demands of children aged 6 to 59 months with mild acute malnutrition. They are, however, deficient in calcium, sodium, zinc, vitamin A, and vitamin D, with calcium contents ranging from 27.38 to 70.58 mg/100g, sodium contents ranging from 4.6 to 28.13 mg/100g, zinc contents ranging from 0.76 to 1.13 mg/100g, vitamin A contents ranging from 11.07 to 78.63 mg/100g, and vitamin D contents ranging from 0.11 to 0.48 mg/100g.

Keywords: PASLoc composite flour, local foods, nutritional value, mild acute malnutrition.

1. INTRODUCTION

Undernourishment is a serious public health issue worldwide (Kouanda *et al.*, 2008). According to FAO (Food and Agriculture Organization), IFAD (International Fund for Agricultural Development), WHO (World Health Organization), WFP (World Food Program) and UNICEF (United Nations Children's Fund) projections, there were 768 million undernourished individuals in the globe in 2020 (FAO, FIDA, OMS, PAM and UNICEF, 2021). Stunted children under the age of five are affected at a rate of 22% (149.2 million) and wasting at a rate of 6.7% (45.4 million), with nearly a quarter of them living in Sub-Saharan Africa and more than half in South Asia, the sub region with the highest prevalence of wasting at more than 14%. Actual figures, notably for stunting and wasting, are projected to be higher because to the pandemic - COVID-19 (FAO, FIDA, OMS, PAM and UNICEF, 2021).

The Multiple Indicator Cluster Survey (MICS) results in Côte d'Ivoire show a prevalence of 6% acute malnutrition (wasting), of which 1.2 % is severe, and 21.6% chronic malnutrition (stunting) for the 0-59 month age group, with regional disparities exceeding WHO emergency thresholds (MICS, 2016). In 2016, the proportion of newborns birth weighing less than 2500 g was expected to be 12.8%.

The management of these groups in developing countries, some of which are extremely vulnerable, such as children under the age of five, pregnant or nursing mothers, and persons living with HIV, necessitates the provision of Specialized Food Products (SFPs). However, according to Ivorian National Nutrition Program (NNP), these products: F-75, F-100, Plumpy'nut, Plumpy'sup, and CSB provided by WFP (World Food Program) are no longer available, compromising nutritional treatment and significantly increasing dropout rates (GNR, 2017). According to Oumarou *et al.*, (2012), the alternative is the production

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of traditional supplementary foods or porridges from fermented, or fortified local grain flours. In addition, the National Nutrition Program has recommended food formulations known as specialized local food products (PASLoc) in order to coordinate management measures, assure service quality, and contribute to the development of Côte d'Ivoire's nutritional condition. However, no scientific investigation has been conducted on the nutritional properties of these flours. The question therefore becomes whether these substitution goods utilized in rehabilitation centers are appropriate for treating mild acute malnutrition. As a result, the goal of this research is to confirm that the protein-energy values and micronutrient contents of these products exceed international quality standards for the treatment of moderate acute malnutrition.

2. MATERIALS

The flours were made from millet (*Panicum miliaceum*), soybean (*Glycine max*), maize (*Zea mays*), rice (*Oriza sativa*), and groundnut (*Arachis hypogea L*) grains acquired from wholesalers at Adjamé's "FORUM market". Brown sugar and refined palm oil fortified with vitamin A were acquired from an Abidjan shopping area. The fish meal comes from the species *Clupea harengus* and was obtained from a fish wholesaler's shop in the autonomous port of Abidjan (Côte d'Ivoire).

3. METHODOLOGY

The several flours used in the PASLoc formulation were manufactured using PNN (2015) upgraded processes.

3.1. Producing flour using local ingredients

3.1.1. Maize flour processing

Two (02) kg of winnowed and cleaned maize kernels were steeped in tap water for 18 hours at room temperature (30 °C). After soaking, the grains were rinsed and drained with tap water before being moved and dispersed in clean basins. They germinated for 48 hours at 30 °C in a closet away from light and any external pollutant. Following germination, the grains were rinsed again with tap water, drained, and evenly spread out on grids coated with cooking paper before being dried at 50 °C for 24 hours in a Venticell oven. The dry grains were softly crushed before being processed with a Moulinex electric mill. After sieving with a fine mesh screen (200 µm), the flour was roasted on a hot plate fitted with a probe at 70 °C for 30 minutes with continual stirring and stored in sealed glass jars at room temperature (28 ±2 °C).

3.1.2. Millet flour processing

Two (02) kg of millet grains were winnowed, then washed and drained with tap water. After that, they were decanted and dispersed in clean basins. The entire set was left to germinate for 72 hours at 30 °C in a cabinet sheltered from light and external contaminants. Following germination, the grains were rinsed again with tap water, drained, and evenly spread out on grids coated with cooking paper before being dried at 50 °C for 24 hours in a Venticell oven. The dry grains were softly crushed in a clean artisanal mortar before being processed using a Moulinex brand electric mill. The flour was sieved using a fine mesh sieve (200 µm), then roasted at 70°C for 30 minutes with steady agitation on a hot plate fitted with a probe, and stored after cooling in airtight glass jars at room temperature (28 ±2 °C).

3.1.3. Soybean flour processing

Two (02) kg of soybeans were sorted, washed with water and soaked in tap water for 24 hours at room temperature (30 °C) in a clean basin covered with a cloth (tulle). After 24 hours, the soaked grains were washed again with tap water and drained then dried at 50 °C for 24 hours in a Venticell oven. The dried grains were then lightly crushed in a mortar, winnowed and ground with a Moulinex electric mill. The flour obtained was also sieved with a fine mesh sieve (200 µm) then roasted on a hot plate at 70 °C for 30 min under constant stirring and kept after cooling in airtight glass jars at room temperature (28 ±2°C).

3.1.4. Rice flour processing

Two (02) kg of dehulled rice grains were winnowed, rinsed with tap water, and dried in a Venticell oven at 50°C for 24 hours. The dried grains were then processed in an electric mill by Moulinex. The flour was also sieved using a fine mesh sieve (200 m) before being roasted on a hot plate at 70°C for 30 minutes with continual stirring and stored in sealed glass jars at room temperature (28 ±2°C).

3.1.5. Fish flour processing

After being eviscerated and rinsed with tap water, the fresh fish (*Clupea harengus*) was dried on charcoal coals before being dried at 50°C for 24 hours in a Venticell oven. The dried fish was then pulverized in a Moulinex electric mill. The finished meal was sieved through a fine mesh sieve (200 m) and kept in sealed glass jars at room temperature (28 ±2 °C).

3.1.6. Groundnut dough processing

Half (1/2) kg of dried shelled peanut seeds were roasted for 40-60 minutes at low heat. After cooling, the seeds were rubbed to remove the shells and then winnowed to remove the skin. The peanuts were ground into a paste in two stages: coarsely in an MOULINEX electric mill and then crushed on a flat surface of handcrafted stone.

3.2. PASLoc composite flour formulations from local ingredients

The composite PASLoc flours were formulated in compliance with the recommendations included in the PNN's Local Food Nutritional Rehabilitation Guidance. According to this guidance, four (04) PASLoc flour were formulated: PASLoc 1A, PASLoc 1B, PASLoc 2A, and PASLoc 2B. The technical formulation and theoretical content of each PASLoc diet are shown in Tables 1 and 2.

Table 1: Formulation model of the different PALoc diets

Ingredients (per 100 g of food)	**PASLoc 1A**	**PASLoc 1B**	**PASLoc 2A**	**PASLoc 2B**
Maize (g)	10	20	30	
Millet (g)	15	---	---	30
Rice (g)	15	10	---	
Soybean (g)	20	15	20	
Peanut paste (g)	---	25	25	25
Fish (g)			5	10
Oil (g)	25	20	10	25
Sugar (g)	15	10		
Fruit (g)	---		10	10

Table 2: Theoretical composition of PASLoc 1A, 1B, 2A and 2B in g/100 g of dry matter

PASLoc flours / **Parameters**	**PASLoc 1A**	**PASLoc 1B**	**PASLoc 2A**	**PASLoc 2B**
Energy value in kcal	480.9	497.3	407	477.8
Protein (g)	10	13	16.3	10.6
Fat (g)	30.8	34.8	27.5	38.6
Carbohydrates (g)	40.1	32.6	22.4	21.8
Calcium (mg)	51.2	52.8	67.5	20.6
Magnesium (mg)	71.7	96	118.5	76.4
Phosphorus (mg)	168.1	210.1	272.3	174.3
Potassium (mg)	428.7	477.3	633.3	347.6
Sodium (mg)	5	6.9	12.6	18.2
Zinc (mg)	1.5	1.4	1.7	1.3
Copper (mg)	0.3	0.3	0.4	0.2
Iron (mg)	3.4	3.0	3.7	3.1
Folic Acid (µg)	32.1	48.8	58.6	35.4
Vitamin A (µg)	11.3	8.6	10.7	3.1
Vitamin D (µg)	0	0	0.1	0.3

3.3. Determination of physicochemical and biochemical property of PASLoc composite flours

3.3.1. Determination of dry matter and moisture content

According to the AOAC method (2000), the samples were weighed (P_0) using a precision balance of type SARTORUIS BP 310S, Gottingen, West Germany. They were dried in a brand oven (MEMERT, Schwabach, West Germany) at 105 °C for 24 h. At the end of the drying process, the samples were cooled in a desiccator and weighed (P_1).The percentage of dry matter was determined by calculation according to the formula:

$DM(\%) = ((P_0 - P_1) / P_0) \times 100$

The percentage of moisture content is calculated from following formula:

$M (\%) = 100 – M (\%)$

3.3.2. Determination of titratable acidity

According to the AOAC (2000) method, this assay consists of measuring the titratable acidity of a product with a sodium hydroxide (NaOH) solution, of normality 0.1N, in the presence of phenolphthalein. For this purpose, a mass P of 10 g of each PASLoc flour is diluted in 75 mL of distilled water, allowed to macerate. The supernatant is filtered and 3 drops of phenolphthalein are added to a volume V_1 = 10 mL of this filtrate. The determination is carried out by pouring in the NaOH solution of normality N_2 (0.1N) until a pink color appears. If V_2 is the volume of NaOH solution poured, the normality N_1 of the filtrate taken is obtained by the formula:

$N_1 = (N_2 \times V_2)/V_1$

This normality was converted into milliequivalents per 100 g of sample (meq/100g) using the formula:

$\text{Acidity (meq/100g)} = (N_1 \times 10^5)/P$

3.3.3. Determination of pH

The determination of pH was carried out according to the method described by AOAC (2000). It consisted of immersing the glass electrode of the pre-calibrated pH meter in 10 mL of supernatant obtained after maceration of 10 g of sample in 75 mL of distilled water. The pH value displayed on the pH meter screen is read.

3.3.4. Determination of ash content

According to the AOAC method (2000), this determination was done by mineralization of a 5 g sample (P_0) at 550 °C for 6 h in a muffle furnace (NABERTERM, Gmbh LT9/11/B180, Germany), until the destruction of all organic matter contained in the sample. The weighing (P_1) after cooling in a desiccator of the obtained ash allowed the determination of the ash content according to the formula:

$\% \text{ Ash} = ((P_0 - P_1) / P_0) \times 100$

3.3.5. Determination of the fat content

This determination is based on the fact that fat is soluble in organic solvents such as petroleum ether and hexane. The determination was made according to the method of BIPEA (1976), consisting of extracting the fat with hexane, which was then evaporated and the residue dried and weighed.

3.3.6. Determination of crude protein

The determination of proteins was carried out according to the AOAC method (2000) using a Kjeldahl distiller. This method is based on the determination of total nitrogen, which is then converted to protein, taking into account the conversion factor (6.25) of nitrogen to protein. The mineralization of 1 g of each PASLoc flour sample was carried out in the presence of a catalyst consisting of copper sulfate (CuSO4) and selenium in a Buchi 430 digester (Digestor Germany), for 3 h. Then, a distillation is performed in a Buchi 320 type distiller, Germany, after the addition of 10 mL of 40% soda solution (NaOH) to the mineralizate. The distillate was collected in a boric acid buffer solution prepared by dissolving 10 g of boric acid in 1000 mL of distilled water and 11 mL of a color indicator mixture consisting of bromocresol green and methyl red. Titration of the distillate was performed with 0.1 N hydrochloric acid (HCl). The total nitrogen and crude protein rates are obtained with the following formulas:

Total nitrogen rate = (V (HCl) x N (HCl) x 0.014 x 100) / P

Crude protein rate = Total nitrogen rate x 6.25

$V_{(HCl)}$ = HCl volume of the burette drop; $N_{(HCl)}$ = HCl normality; 0.014 =coefficient assigned to the concentration of the normal nitrogen solution (14/1000); P = sample weight

3.3.7. Determination of carbohydrate content

The total carbohydrate content were determined according to the formulas described by Bertrand and Thomas (1910):

Carbohydrate (%) =100- (% Moisture + % Protein + % Fat + % Ash)

3.3.8. Determination of the energy value

The energy value was determined by calculation, according to the formula of FAO (2002) using the coefficients of Atwater and Rosa (1899).

Energy value (kcal/100g) = (4 x % Protein) + (4 x % Carbohydrates) + (9 x % Fat)

3.4. Determination of vitamins content

The determination of vitamins content was carried out using a Shimadzu SPD 20A apparatus, according to the method of Abidi (2000) with a PAD detector, a Cluzeau France brand C18 ODS column, 250 x 4.6 of isocratic mode (Acetonitrile: 55 mL); tetrahydrofuran (37 mL and water: eight (8) mL) with a mobile phase flow rate (1.5 mL) and a detection wavelength of 325 nm. A mass of one (1) g of dried boiled powder was weighed and then transferred to a 100 mL beaker containing 20 mL of methanol. The beaker was protected from light with aluminum foil. Then, the resulting solution was stirred with a bar magnet for two (2) hours 30 minutes at room temperature and then the methanol was filtered off and transferred to a 25 mL flask to form the test solutions. The standard solutions of each vitamin were immediately prepared by dilution series in methanol to constitute the control solutions.

3.5. Determination of minerals content

Mineral contents (Ca, K, Mg, Na Fe and Zn) were determined by atomic absorption spectrophotometry, using the digestion method describe by Uddin *et al.*, (2016). An ash sample (0.5 g) of previously dried PASLoc flour was dissolved in 30 mL of a mixture of perchloric acid (11.80 mol/L), nitric acid (14.44 mol/L) and sulfuric acid (18.01 mol/L). The mixture, stirred in the fume hood, was heated on a hot plate until thick white smoke appeared. After this heat treatment, the mixture was cooled to room temperature for 15 min and then 50 mL of distilled water was added. It was boiled again for 30 minutes on the same hot plate and then cooled again under the same conditions. It was then filtered on Whatman No. 4 filter paper into a 50 mL flask. The filtrate obtained was made up to the mark of the flask with distilled water. The level of each mineral was determined by atomic absorption spectrophotometer at a specific wavelength corresponding to each mineral by comparison to standard solutions. The phosphorus content was determined by the spectrophotometer method.

3.6. Statistical analysis

To investigate the degree of difference between the variables, an analysis of variance (ANOVA) was performed using XLSTAT software (version 2020, XLSTAT, USA). If there was a substantial difference between the parameters tested, Duncan's test was used to classify the means (homogeneous groups). The significance level (α) was set at 0.05. Statistical differences with a p value less than 0.05 were considered significant. Then, Principal Component Analysis (PCA) and Hierarchical Ascending Classification (HAC) were performed to find the samples with the same characteristics.

4. RESULTS AND DISCUSSION

4.1. Physicochemical and biochemical properties of PASLoc composite flours

Table 3 displays the physicochemical and biochemical parameters of the various PASLoc composite flours.

Moisture content of the PASLoc composite flours was inversely linked with the dry matter content ($\alpha = 0.05$) but did not differ significantly ($\alpha = 0.05$). It was 3.46 ±0.9 % for PASLoc 1B flour and 3.9 ±0.4 % for PASLoc 2A flour. However, the moisture levels found by Loba *et al*., (2019) for rice and maize flour are lower. The low moisture level of these flours may be advantageous in terms of microbial growth. Indeed, keeping a product at a humidity level lower than 8 %, according to Mouquet *et al*., (1998), would limit the growth of molds, the microorganisms most responsible for food spoiling. Therefore, the low water content of these flours may work to their benefit when it comes to preservation after being purchased from nutritional rehabilitation facilities.

The PASLoc flours' somewhat acidic pH is statistically distinct. For PASLoc 2B and PASLoc 1B flour, the results range from 5.83 ±0.05 to 6.20 ±0.00. Sika *et al*., (2019) obtained equivalent findings for maize and safflower-based composite flours. Because it is within the ideal pH range (4-6) for yeast and mold development, this pH level may have a detrimental influence on the shelf life of PASLoc flours. The pH values are favorably associated with the titratable acidity of the various PASLoc flours, which are 9.66 ±0.57 meq/100 g for PASLoc 2B flour and 14.33 ±2.08 meq/100 g for PASLoc 2A flour, respectively. This positive association shows that pH aids in understanding the effect of the organic acids in PASLoc flours.

With respect to ash content, statistical analysis indicates a significant difference ($\alpha < 0.05$) between PASLoc flours. This content, which is less than 3 for all PASLoc flours, meets the FAO/WHO (1991) recommendation. The contents, which range from 1.50 ±0.10 % to 2.60 ±0.00% for PASLoc 1A and PASLoc 2A, respectively, allow for coverage of 50% to 86.66% of the estimated daily needs. However, the theoretical values do not take into account the ash content of PASLoc. Ash content is a measure of the total amount of minerals present in a food product (Pomeranz and Meloan, 1994). The Pearson test shows a positive relationship between ash content and mineral content (calcium, potassium, magnesium, and sodium). This means that the consumption of PASLoc flour could meet the body's needs for these minerals.

Statistical analysis reveals a significant difference ($\alpha < 0.05$) in the fat content of the different PASLoc flours. The contents ranged from 9.66 ±0.57 to 23.86 ±0.11 for PASLoc 1A and PASLoc 2A flour, respectively. These fat contents are well below the theoretical values estimated by the National Nutrition Program. However, only PASLoc 1B, PASLoc 2A and PASLoc 2B have the fat contents in accordance with the recommendation of FAO/WHO (1991), which calls for a minimum fat content of 20% in supplementary feed preparations. In view of these contents that meet the nutritional needs of children, it would be advantageous not to add oil during the preparation of these foods in the porridge. It would be more beneficial for the National Nutrition Program to consider the amount of oil added so as not to overestimate the fat content and energy value of PASLoc porridges.

The low fat content of PASLoc 1A could be explained by the fact that oil is not considered during the formulation process of this flour. However, the fat content of this flour is higher than those obtained by Zannou *et al.*, (2011) for cassava and soybean-based infant flours. In addition to contributing to the enhancement of energy value, fat from food could facilitate the transfer of essential fatty acids to target organs and facilitate the absorption of fat-soluble vitamins (A, D, E and K) (Sanders, 2016). Pearson's test reveals a positive correlation between fat content and pH and then titratable acidity. This correlation insinuates that fats could behave as important functional ingredients, acting as a flavor carrier, while providing textures and mouthfeel (Sanders, 2016).

Regarding protein contents, they vary significantly ($\alpha < 0.05$) from 11.19 ± 0.01 to 18.12 ± 0.11 for PASLoc 1A and PASLoc 2A flours respectively. However, the protein contents of PASLoc 1B, PASLoc 2A and PASLoc 2B flours are higher than the codex alimentarius (1991) recommendation of 15% and suggest that the consumption of these flours could have a positive impact in the fight against moderate childhood malnutrition. In addition to being metabolized into energy, dietary proteins perform several important functions. Indeed, they provide essential amino acids, which are used for protein synthesis in growth and tissue repair, and it is the main source of nitrogen in the body. Nitrogen is essential for the synthesis of non-essential amino acids and other nitrogenous molecules, such as nucleic acids, purines, pyrimidines and some neurotransmitter substances (Case et al., 2011). The low protein content of PASLoc 1A and 2B suggest that consumption of these flours may not effectively address the problem of moderate acute malnutrition. However, the protein contents are all above the theoretical values presented in Table 2.

In terms of carbohydrate content, the results indicate high levels with a significant difference between PASLoc flours. The contents are 73.9 ± 0.60, 57.18 ± 0.32, 51.5 ± 0.14 and 59.15 ± 0.35 for PASLoc 1A, PASLoc 1B, PASLoc 2A and PASLoc 2B flours respectively. These carbohydrate contents are in line with the daily carbohydrate requirements estimated by

ANSES (2016). In addition, these levels are significantly higher than the proposed theoretical values.

As for the energy value of PASLoc flours, it also shows a significant difference at the $\alpha < 0.05$ threshold with the highest content observed in PASLoc 2A flour (493.33 ±1.02 Kcal/100g DM) and the lowest observed in PASLoc 1A flour (427.36 ± 2.60 Kcal/100g DM). These energy values are positively correlated with fat content ($r2 = 0.658$), protein content ($r = 0.850$) and ash content ($r = 0.773$) and negatively with carbohydrate content ($r = -0.969$). This positive correlation means that these parameters contribute to the enhancement of the energy value of the different PASLoc flours.

The analysis of the physicochemical parameters reveals the overall nutritional potential of the different PASLoc flours. However, the oil should be completely removed from the preparation process to avoid the occurrence of metabolic disease in children with moderate acute malnutrition.

Table 3: Physicochemical and biochemical properties of PASLoc composite flours

PASLoc flours / Parameters	PASLoc 1A	PASLoc 1B	PASLoc 2A	PASLoc 2B	Standard (child 06-59 months)*
pH	6.06 ±0.057^{b}	6.20 ±0.00^{c}	6.10 ±0.00^{b}	5.83 ±0.05^{a}	ND
Moisture (%)	3.74 ±0.06^{a}	3.46 ±0.19^{a}	3.90 ±0.14^{a}	3.56 ±0.19^{a}	ND
Dry Matter (%)	96.26 ±0.061^{a}	96.54 ±0.19^{a}	96.10 ±0.14^{a}	96.44 ±0.19^{a}	ND
Titratable Acidity (meq/100g)	10.66 ±1.15^{b}	11.00 ±1.00^{b}	14.33 ±2.08^{c}	9.66 ±0.57^{a}	ND
Ash (%)	1.50 ±0.10^{a}	2.10 ±0.10^{c}	2.60 ±0.00^{d}	1.80 ±0.00^{b}	ND
Fats (%)	9.66 ±0.57^{a}	21.53 ±0.11^{b}	23.86 ±0.11^{c}	21.66 ±0.24^{b}	≥ 20
Proteins (%)	11.19 ±0.01^{a}	15.72 ±0.03^{c}	18.12 ±0.11^{d}	13.82 ±0.05^{b}	6-15
Carbohydrates (%)	73.9 ±0.60^{d}	57.18 ±0.32^{b}	51.5 ±0.14^{a}	59.15 ±0.35^{c}	ND
Energy Value (Kcal/100g)	427.36 ±2.60^{a}	485.42 ±0.55^{b}	493.33 ±1.02^{c}	486.86 ±1.25^{b}	≥ 400

The values shown in the table are the means ± standard deviations of trials performed in triplicate. Within a row, values with the same exponent do not differ significantly at the threshold ($\alpha > 0.05$). *Recommended dietary allowance FAO/WHO (1991).

4.2. Minerals content of PASLoc composite flours

Table 4 shows the mineral content of PASLoc composite flours. The mineral content of the different PASLoc flours differs statistically ($\alpha < 0.05$), with the experimental calcium, potassium, and iron contents being higher than the theoretical values. In terms of calcium requirements, the contents varied from 27.38 ± 0.01 mg to 57.68 ± 0.03 mg for PASLoc 2B and PASLoc 1B respectively. These levels correspond to a daily intake of between 9.78% and 25.20% of the calcium requirements of children aged 6 months. Calcium is a very important mineral that is involved in the formation and strength of bones and teeth (Theobald, 2005). Thus, diets containing insufficient amounts of calcium can lead to low bone mineral density, which can affect bone health in later life, including the risk of osteoporosis. Therefore, PASLoc 1B and PASLoc 2A, which provide intakes above 20% of the daily requirement, could have a positive impact on the well-being of children.

Potassium levels ranged from 387.89 ±0.01 mg to 708.59 ±0.01 mg for PASLoc 2B and PASLoc 2A, respectively. These potassium contents of PASLoc flours, which are higher than 50% of the minimum intake, are lower than the recommended daily requirement. Potassium is an essential mineral and a major electrolyte in the human body. It plays an important role in electrolyte regulation, nerve function, muscle control, and blood pressure (Bellows and Moore, 2013). A diet low in potassium and high in sodium may be one of the many factors causing high blood pressure and cardiovascular disease. The fact that these foods can provide 50% of the minimum daily intake is an advantage for children aged 6–59 months.

In terms of magnesium, only PASLoc 1B and PASLoc 2A have levels that cover the daily requirements of children. Regarding iron intake, only PASLoc 2A has levels below the recommended requirement. For zinc, the content of PASLoc flours below the recommended daily requirement is between 26.20% and 38.96%, respectively, for PASLoc 2B and PASLoc 2A. The main minerals could protect the organism against arterial hypertension, maintain osmotic balance, and intervene in the mechanism of intestinal glucose absorption and the improvement of protein retention during the growth phase (Houston *et al*., 2008). On the other hand, trace elements (iron, zinc) are beneficial for the proper functioning of the immune system, reduction of tiredness, protection of cells against oxidative stress, normal functioning of the nervous system, and normal psychological functions (Burdin, 2014). It should be noted that the zinc content of the different formulations is below the theoretical values and the standard recommended by ANSE (2021). This could constitute a deficiency in the immune system.

Overall, the different PASLoc flours have a good mineral composition. However, a low zinc content could constitute a deficiency in the immune systems of moderately acute malnourished people who need this trace element more for the activation of their immune systems.

Table 4: Mineral content of PASLoc composite flours in 100 g of dry matter

PASLoc flours / Parameters	PASLoc 1A	PASLoc 1B	PASLoc 2A	PASLoc 2B	Daily needs (child 06-59 months)*
Calcium (mg)	55.50 ±0.05^{b}	57.68 ±0.03^{c}	70.58 ±0.02^{d}	27.38 ±0.01^{a}	280-500 mg/j
Potassium (mg)	442.60 ±0.01 ^{b}	499.60 ±0.01 ^{c}	708.59 ±0.01^{d}	387.89 ±0.01^{a}	750-1100 mg/j
Magnesium (mg)	76.20 ±0.01^{a}	86.70 ±0.01^{c}	109.69 ±0.01^{d}	79.21 ±0.01^{b}	80-210 mg/j
Sodium (mg)	4.6 ±0.00^{a}	27.86 ±0.00^{c}	28.13 ±0.00^{c}	12.73 ±0.00^{b}	370-1000 mg/j
Iron (mg)	4.3 ±0.00 ^{b}	4.26 ±0.00 ^{b}	3.83 ±0.00^{a}	4.2 ±0.00 ^{b}	4-11 mg/j
Zinc (mg)	1.06 ±0.00^{b}	1.13 ±0.00^{b}	0.76 ±0.00^{a}	0.86 ±0.00 ^{a}	2.9-5.5 mg/j
Phosphorus (mg)	179.13 ±0.00^{a}	302.16 ±0.00^{d}	232.80 ±0.00 ^{c}	201.66 ±0.00^{b}	160-440 mg/j
Lead (µg/kg)	13.63 ±0.00^{c}	15.43 ±0.00^{d}	11.83 ±0.00^{a}	12.46 ± 0.00^{b}	10 µg/kg

The values shown in the table are the means ± standard deviations of trials performed in triplicate. In the same row, values with the same exponent do not differ significantly at the threshold ($\alpha > 0.05$). *Recommended Dietary Allowance for vitamins and minerals (Anses, 2021).

4.3. Vitamins content of PASLoc composite flours

The vitamin content of PASLoc composite flours is shown in table 5. Statistical analysis generally reveals a significant difference ($\alpha < 0.05$) in the vitamin content of the different PASLocs flours. However, the experimental values are higher than the expected theoretical values for vitamins A and D. In terms of intake, the amounts of vitamins A and D are lower than the recommended daily requirement, while the amounts of vitamins E and B1 are sufficient to meet the daily requirement. Vitamins are organic substances that are essential for normal metabolism, growth, development, and regulation of cell function. They are molecules that are necessary for the body and cannot be synthesized by it. Thus, their intake of food allows us to consume them to maintain good health and prevent chronic diseases (Ati-Hellal & Hellal, 2021). The high levels of vitamins E and B1 suggest that daily consumption of PASLoc flour could contribute to the fight against moderate acute malnutrition. Despite their essential role, vitamins are not consumed in sufficient quantities in developing countries, where millions of children die each year from micronutrient deficiencies due to malnutrition (Ati-Hellal & Hellal, 2021). The low levels of vitamin A and D suggest that these foods should be consumed with food supplements rich in these nutrients.

Table 5: Vitamins content of PASLoc composite flours in 100 g of dry matter

PASLoc flours / Parameters	PASLoc 1A	PASLoc 1B	PASLoc 2A	PASLoc 2B	Daily needs (child 06-59 months)*
Vitamin A (µg/100g MS)	17.80 ±0.17^{c}	15.70 ±0.3^{b}	78.63 ±0.35^{d}	11.07 ±0.38^{a}	250-300 µg/j
Vitamin E (mg/100g)	15.63 ±0.41^{a}	30.36 ±0.37^{c}	28.13 ±0.15^{b}	30.46 ±0.41^{c}	5-7 mg/j
Vitamin D (µg/100g)	0.39 ±0.5$^{a.b}$	0.23 ±0.05^{ab}	0.11 ±0.02^{a}	0.48 ±0.02^{b}	10-15 µg/j
Vitamin B1 (mg/100g)	0.56 ±0.02^{c}	0.50 ±0.01^{b}	0.59 ±0.05$^{c.d}$	0.46 ±0.03^{a}	0.5 mg/j

The values shown in the table are the means ± standard deviations of trials performed in triplicate. In the same row, values with the same exponent do not differ significantly at the threshold ($\alpha > 0.05$). *Recommended Dietary Allowance for vitamins and minerals (Anses, 2021)

4.4. Relationship between different PASLoc flours and physicochemical and biochemical parameters

Principal component analysis was performed to visualize the relationships between physicochemical, biochemical and vitamins parameters with the different PASLoc composite flours. The principal component analysis (PCA) revealed a total cumulative variance of 82.65%, of which 55.62% of the variables are correlated with axis 1 (F1) and 27.03% of the variables are correlated with axis 2 (F2) (Figure 1) in terms of the variables used. In this regard, PASLoc 1B and 2A, which are positively correlated with axis 1 (F1), are located on the right side of the graph, while PASLoc 2B and 1A are located on the left side of the graph, and are negatively correlated with axis 1 (F1). On axis 2 (F2), only PASLoc 2B, located on the top, was positively correlated with it. This distribution of PASLoc flours in the factorial plane allows us to classify the different flours into three distinct groups. The first group, PASLoc flours 1B and 1A, were positively correlated with water content, protein content, ash content, fat content, vitamin A, B1, and E content, mineral content (phosphorus, sodium, magnesium, calcium, and potassium), moisture, energy value, and titratable acidity. The second group is PASLoc 2B flour, whose intrinsic correlation is positively related to pH, dry matter content, and iron content. However, protein content, ash content, fat content, vitamin E; mineral content (phosphorus, sodium, potassium) and energy value are also positively correlated with axis 2. The third group that is correlated neither with axis 1 nor with axis 2 is PASLoc 1A flour and is expressed by carbohydrate and vitamin D content.

The hierarchical clustering test (HCA) presented in Figure 2 classified the different PASLoc flours into three groups according to their degree of similarity with physicochemical and biochemical characteristics. PASLoc 2A is positively correlated with axis 1 and constitutes one group, while PASLoc 2B is positively correlated with axis 2 and constitutes one group. PASLoc 1A and PASLoc 1B, which are diametrically opposed in the correlation plane, also form a cluster. From this grouping, it appears that PASLoc 2A is the best PASLoc flour because of its interesting nutritional potential compared to the other PASLoc.

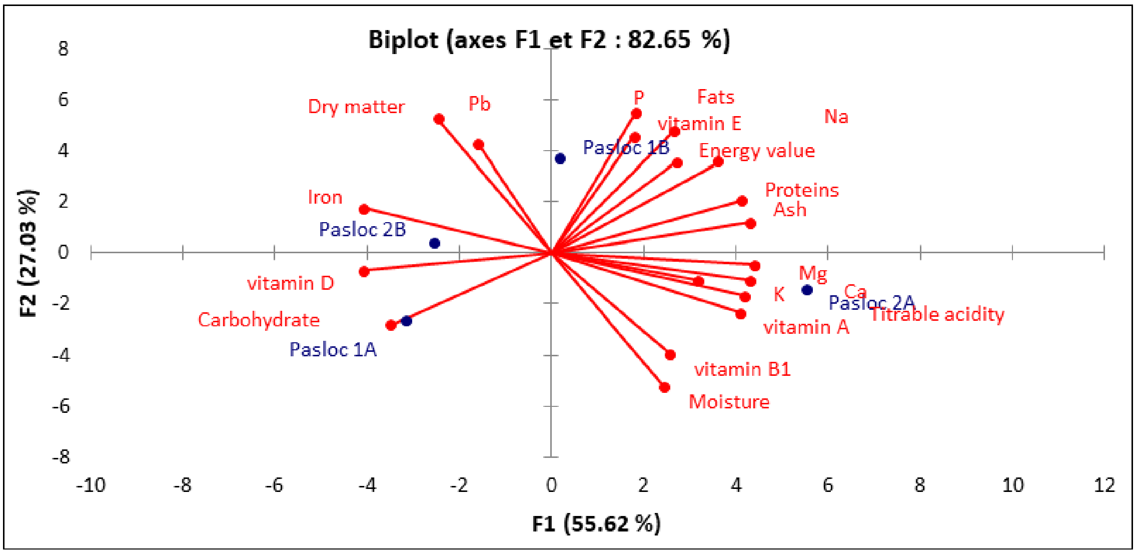

Figure 1: Factor map resulting from the superposition of the physicochemical, biochemical and vitamins content with PASLoc composites flours

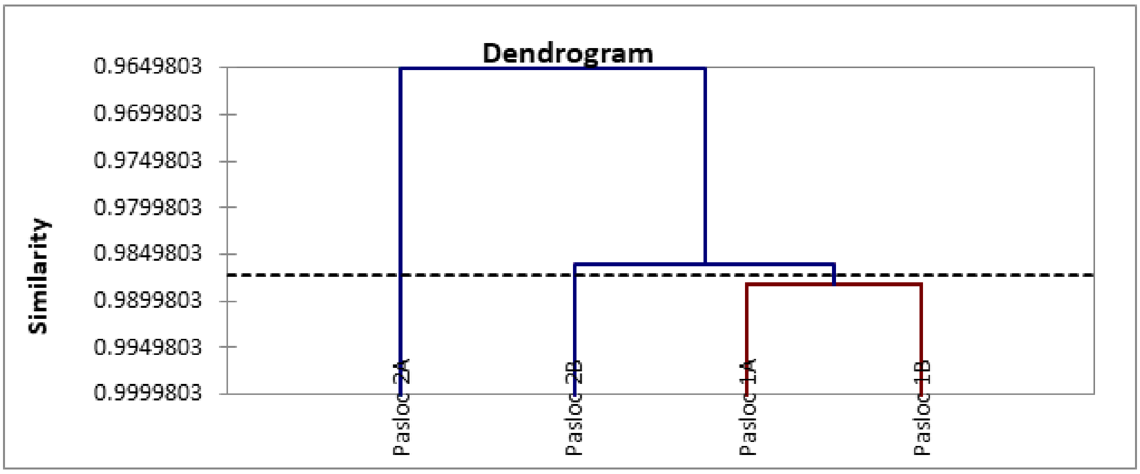

Figure 2: Classification of PASLoc flours according to their similarity with physicochemical, biochemical and vitamins characteristics

5. CONCLUSION

To combat moderate to acute malnutrition in Côte d'Ivoire, composite flours were formulated from various indigenous ingredients on the basis of their theoretical composition. The results obtained indicate the interesting nutritional potential of the different PASLoc flours's protein, fat, mineral, and vitamin content. However, it is necessary to closely monitor the fat content, which has an enormous impact on the energy value of the food. However, the Pasloc 2A and Pasloc 2B composite flours significantly stood out from the other two composite flours and displayed levels that were comparable to those for diets used to treat moderate acute malnutrition. In order to prove the nutrients' beneficial effects on consumer health, additional research is required to determine their bioavailability and real effects after digestion. By adding additional components to Pasloc 1A and Pasloc 1B flours, the quantities of protein, calcium, salt, zinc, and vitamins A and D may be significantly increased, significantly reducing moderate acute malnutrition in children aged 6 to 59 months.

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