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PHYSICOCHEMICAL AND BIOCHEMICAL CHARACTERIZATION OF INSTANT FLOURS ENRICHED WITH SENESCENT PLANTAIN BANANAS FOR INFANT FEEDING

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ABSTRACT

The study assessed the nutritional quality of instant flours formulated from senescent plantain banana, soybean, shea caterpillars and palm oil for complementary feeding of children aged 6–36 months. Three formulations (F4BS, F5BS and F6BS) were prepared using a matrix formulation method. Their physicochemical, biochemical and mineral characteristics were determined using standard analytical methods. The flours had pH values of 5.10–5.18 and moisture contents of 3.00–4.47%. Protein, lipid and total carbohydrate contents ranged from 16.41–16.64%, 12.27–13.53% and 64.59–65.40%, respectively. Ash and fibre contents were 1.93–2.20% and 0.59–2.13%, respectively. Energy values ranged from 435.73 to 445.80 kcal/100 g. The flours also contained magnesium (55.15–73.80 mg/100 g), iron (8.08–9.39 mg/100 g) and zinc (3.00–5.29 mg/100 g). Their Na/K ratios were below 1. Overall, the measured energy and nutrient contents indicate that the formulations may be suitable as local complementary food ingredients. These findings support the valorization of senescent plantain banana and other locally available resources in the development of infant and young child foods.

Keywords: Instant Flour; Senescent Plantain Banana; Shea Caterpillar; Soybean; Infant and Young Child Feeding

1 INTRODUCTION

Malnutrition is a major public health problem and remains one of the leading causes of infant morbidity and mortality in developing countries [1]. In Côte d'Ivoire, approximately 1.4 million children are reportedly affected by various forms of malnutrition [2]. From the age of 6 months, breast milk alone is no longer sufficient to meet all of a child's increasing nutritional requirements. Adequate complementary feeding must therefore be introduced, particularly in the form of

porridges prepared from infant flours [3]. However, imported infant flours are generally more expensive and remain difficult for low-income households to access [4]. In addition, flours available on local markets often have nutritional shortcomings, particularly in terms of energy density and essential nutrient content [5]. In this context, formulating complementary foods from accessible local raw materials with high nutritional value is a relevant approach to improving young children's diets while promoting the use of locally available food resources.

Among these resources, plantain banana is of particular interest because of its high carbohydrate and mineral contents and its availability almost throughout the year in Côte d'Ivoire [6,7]. However, a significant proportion of production may be lost at the senescence stage, when the fruit is poorly valorized [8]. Its low protein content nevertheless requires it to be combined with other raw materials with better protein and lipid profiles. In this respect, soybean and shea caterpillar (Cirina butyrospermi) are interesting local sources of protein and lipids [9,10]. The addition of palm oil may also increase the energy density of the formulations [11]. Furthermore, processing these raw materials into instant flour makes porridge preparation easier, particularly by simply adding hot or boiling water [12].

Thus, the combined valorization of senescent plantain banana, soybean, shea caterpillar and palm oil could make it possible to develop local infant flours with improved nutrient density while reducing post-harvest losses of plantain banana.

The aim of this study was therefore to assess the physicochemical, biochemical and mineral characteristics of instant flours formulated from senescent plantain banana, soybean, shea caterpillar and palm oil, in order to evaluate their ability to meet the nutritional recommendations applicable to complementary foods intended for children aged 6–36 months.

2 MATERIALS AND METHODS

2.1 Plant and animal materials

The plant material consisted of flours produced at the Laboratory of Biotechnology, Agriculture and Valorization of Biological Resources of Félix Houphouët-Boigny University from senescent plantain banana fruits (*Musa paradisiaca*), soybean seeds (*Glycine max*) and palm oil (*Elaeis guineensis*). The animal material consisted of dried shea caterpillars (*Cirina butyrospermi*). All raw materials were purchased at the Gouro market in Adjamé (Abidjan, Côte d'Ivoire).

2.2 Preparation of flours and other ingredients

Senescent plantain banana flour: Five kilograms (5 kg) of senescent plantain bananas were washed and blanched for 15 min. They were then peeled and cut into thin slices. The slices were spread on baking paper and dried in an oven at 50 °C for 72 h. After cooling, they were ground. The resulting flour was sieved and stored in a dry, airtight container.

Soybean flour: Two and a half kilograms (2.5 kg) of soybean seeds were sorted, washed and soaked in tap water for 2 h at room temperature (30 °C). The seeds were then blanched at 100 °C for 20 min and dried in an oven at 50 °C for 72 h. The dried seeds were ground. The flour was sieved and stored in airtight glass jars at room temperature.

Shea caterpillar flour: Two and a half kilograms (2.5 kg) of dried caterpillars were sorted, washed and dried in an oven at 50 °C for 24 h. They were then ground and sieved (100 µm). The resulting flour was stored in an airtight jar.

Palm oil: The palm oil was used as purchased, without any prior treatment.

2.3 Flour formulation

Formulation was performed using a calculation system developed in Microsoft Excel and based on the matrix formulation method [13,14]. Using a list of ingredients, this method determines the proportions required to meet the requirements for at least two nutrients using at least two ingredients.

Table 1: Formulation of the instant flours

	Senescent plantain flour	Soybean flour	Shea caterpillar flour	Palm oil
F4BS	70 %	15 %	15 %	1/10
F5BS	70 %	12.5 %	17.5 %	1/10
F6BS	70 %	17.5 %	12.5 %	1/10

2.4 Preparation of instant flours

The specified quantities of each ingredient were weighed and homogenized using a spatula. Distilled water was then added at a ratio of 1:2 (w/v) to obtain a homogeneous paste. The paste was spread on baking paper and baked in an oven at 150 °C for 30 min. After cooling, the cooked sheet was dried in an oven at 50 °C for 24 h, then ground and sieved. The resulting instant flours were packed in food-grade bags and stored at room temperature (28 °C) until analysis. ~~The processing flow chart is presented in Figure 1.~~

2.5 Determination of physicochemical properties

The pH was determined according to the AOAC method [15]. Ten grams (10 g) of flour were dispersed in 90 mL of distilled water, and the suspension was then filtered. The pH was measured directly in the filtrate using a previously calibrated pH meter.

Moisture and dry matter contents were determined according to the AOAC method [16] by drying 5 g of flour in an oven (MEMMERT, Germany) at 105 ± 2 °C until constant weight was reached.

Ash content was determined according to the AOAC method [17] by incinerating 5 g of sample in a muffle furnace (NABERTHERM, GmbH LT9/11/B180, Germany) at 550 °C for 24 h.

2.6 Determination of biochemical properties

Lipid content was determined using the BIPEA method [18]. Five grams (5 g) of sample were extracted with hexane in a Soxhlet apparatus for 6 h. The solvent was then evaporated using a rotary evaporator, and the residue was dried at 105 °C before weighing.

Total proteins were determined using the Kjeldahl method [16]. One gram (1 g) of sample was digested at 400 °C for 2 h in concentrated sulfuric acid in the presence of a catalyst. The digest was distilled under alkaline conditions, and the ammonia collected in boric acid was titrated with 0.1 N H_2SO_4. Protein content was obtained by multiplying the nitrogen content by a factor of 6.25.

Fibre was determined according to the Wolff method [19]. Two grams (2 g) of sample underwent two successive hydrolysis steps, first acid hydrolysis (0.25 N H_2SO_4) and then alkaline hydrolysis (0.31 N NaOH), each for 30 min at boiling temperature. The residue was dried at 105 °C for 8 h and then incinerated at 550 °C for 3 h.

- Total carbohydrates were calculated by difference [20]:
- Total carbohydrates (%) = 100 − (% moisture + % lipids + % proteins + % ash)
- Energy value was calculated using the Atwater factors [20]:
- EV (kcal/100 g) = 4 × C (%) + 9 × L (%) + 4 × P (%)
- where C, L and P represent carbohydrate, lipid and protein contents, respectively.

Minerals: Mineral contents (Mg, Fe, Zn, Al, I, Na, K, Ca and P) were determined by X-ray fluorescence spectrometry (XRF). Four grams (4 g) of sample were mixed with 1 g of binder and homogenized in a vibratory mill. The mixture was then pressed into a pellet using a hydraulic press (10 tonnes) before analysis. The Na/K and Ca/P ratios were calculated from the measured contents.

2.7 Statistical analysis

Analyses were performed in triplicate, and results were expressed as mean ± standard deviation. Analysis of variance (ANOVA) was performed using IBM SPSS Statistics version 20.0, followed by Duncan's test at the 5% significance level. Principal component analysis (PCA), coupled with hierarchical cluster analysis (HCA), was performed using XLSTAT 2026 to establish relationships between the parameters studied and group the flours according to their profiles.

3 RESULTS

3.1 Physicochemical properties of the instant flours

The physicochemical properties of the three instant flours (F4BS, F5BS and F6BS) are presented in Table 2. The results show significant differences ($p < 0.05$) among the flours in pH, dry matter and moisture contents. In contrast, ash contents do not differ significantly ($p > 0.05$).

pH values range from 5.10 ± 0.05 for flour F4BS to 5.18 ± 0.03 for flour F6BS. Flour F6BS has the highest pH value, which differs significantly from those of flours F4BS and F5BS, whose values are statistically similar ($p > 0.05$).

Moisture contents are relatively low, ranging from 3.00 ± 0.20% for flour F5BS to 4.47 ± 0.64% for flour F6BS. The latter has a significantly higher content ($p < 0.05$) than the other two flours. Conversely, dry matter contents are high, ranging from 95.53 ± 0.64% for flour F6BS to 97.00 ± 0.20% for flour F5BS. Flours F4BS and F5BS have statistically similar dry matter contents ($p > 0.05$), but significantly higher values than flour F6BS ($p < 0.05$).

Ash contents range from 1.93 ± 0.23% for flour F6BS to 2.20 ± 0.20% for flour F5BS, with no significant difference among the three formulations ($p > 0.05$).

Table 2: Physicochemical properties of the instant flours

Parameters	F4BS	F5BS	F6BS	Reference values
pH	5.10 ± 0.05b	5.12 ± 0.02b	5.18 ± 0.03a	–
Dry matter (%)	96.53 ± 0.12a	97.00 ± 0.20a	95.53 ± 0.64b	> 95
Moisture (%)	3.47 ± 0.12b	3.00 ± 0.20b	4.47 ± 0.64a	< 8
Ash (%)	2.00 ± 0.20a	2.20 ± 0.20a	1.93 ± 0.23a	< 3

Values are expressed as means ± standard deviations of analyses performed in triplicate. Within the same row, values with different superscript letters are significantly different ($p < 0.05$).

3.2 Biochemical composition and energy value of the instant flours

The macronutrient contents and energy values of the three instant flours (F4BS, F5BS and F6BS) are presented in Table 3. Statistical analysis shows significant differences ($p < 0.05$) among the flours in lipid and fibre contents and energy values, whereas protein and total carbohydrate contents do not differ significantly ($p > 0.05$).

Lipid contents range from 12.27 ± 0.31% for flour F6BS to 13.53 ± 0.31% for flour F4BS. The latter has a significantly higher content ($p < 0.05$) than flours F5BS and F6BS, which have statistically similar values ($p > 0.05$).

Instant flours F4BS, F5BS and F6BS have protein contents ranging from 16.41 ± 0.18% for flour F4BS to 16.64 ± 0.07% for flour F6BS. Despite these variations, no significant difference is observed among the three formulations ($p > 0.05$). Similarly, total carbohydrate contents range from 64.59 ± 0.45% for flour F4BS to 65.40 ± 0.15% for flour F5BS, with no significant difference among the flours ($p > 0.05$).

In contrast, fibre contents differ significantly ($p < 0.05$), ranging from 0.59 ± 0.15% for flour F5BS to 2.13 ± 0.76% for flour F6BS. Flours F4BS and F6BS have statistically similar fibre contents ($p > 0.05$), but significantly higher values than flour F5BS ($p < 0.05$).

Regarding energy value, the values of the instant flours range from 435.73 ± 2.39 kcal/100 g for flour F6BS to 445.80 ± 1.40 kcal/100 g for flour F4BS. Flours F4BS and F5BS have statistically similar energy values ($p > 0.05$), but significantly higher values than flour F6BS ($p < 0.05$).

Table 3: Biochemical composition and energy value of the instant flours

	F4BS	F5BS	F6BS	Reference values
Lipids (%)	13.53 ± 0.31a	12.80 ± 0.20b	12.27 ± 0.31b	--
Proteins (%)	16.41 ± 0.18a	16.60 ± 0.15a	16.64 ± 0.07a	--
Total carbohydrates (%)	64.59 ± 0.45a	65.40 ± 0.15a	64.69 ± 0.69a	--
Energy value (kcal/100 g)	445.80 ± 1.40a	444.20 ± 0.92a	435.73 ± 2.39b	≥ 400
Fibre (%)	1.93 ± 0.45a	0.59 ± 0.15b	2.13 ± 0.76a	< 5

Values are expressed as means ± standard deviations of analyses performed in triplicate. Within the same row, values with different superscript letters are significantly different ($p < 0.05$).

3.3 Mineral contents of the instant flours

The mineral contents of the three instant flours (F4BS, F5BS and F6BS) are presented in Table 4. The results reveal significant variations ($p < 0.05$) among formulations for most of the minerals analyzed, with the exception of iron, whose contents do not differ significantly ($p > 0.05$).

Magnesium contents range from 55.15 ± 0.13 mg/100 g DM for flour F4BS to 73.80 ± 0.90 mg/100 g DM for flour F6BS, with significant differences ($p < 0.05$) among the three formulations. Iron concentrations range from 8.08 ± 1.31 to 9.39 ± 0.30 mg/100 g DM for flours F5BS and F6BS, respectively, with no significant difference ($p > 0.05$). Zinc contents range from 3.00 ± 0.60 mg/100 g DM for flour F4BS to 5.29 ± 0.20 mg/100 g DM for flour F6BS. The latter has a significantly higher content ($p < 0.05$) than flours F4BS and F5BS, whose values are statistically similar ($p > 0.05$).

Sodium and potassium concentrations increase significantly ($p < 0.05$) from flour F4BS to flour F6BS. Sodium contents increase from 41.30 ± 1.76 to 72.33 ± 1.53 mg/100 g DM, while potassium contents rise from 1,194 ± 3.60 to 2,031 ± 2.64 mg/100 g DM. Calcium contents range from 101.6 ± 0.60 mg/100 g DM for flour F5BS to 169.6 ± 1.73 mg/100 g DM for flour F6BS, with significant differences ($p < 0.05$) among the three flours. A similar trend is observed for phosphorus, whose concentrations range from 360.9 ± 1.40 mg/100 g DM for flour F4BS to 487.5 ± 2.18 mg/100 g DM for flour F6BS. However, flours F4BS and F5BS have statistically similar phosphorus contents ($p > 0.05$), but significantly lower values than flour F6BS ($p < 0.05$).

Furthermore, sodium/potassium (Na/K) ratios range from 3.46 ± 0.14% for flour F4BS to 3.94 ± 0.04% for flour F5BS. The latter has a significantly higher ratio ($p < 0.05$) than flours F4BS and F6BS, whose values are statistically similar ($p > 0.05$). Calcium/phosphorus (Ca/P) ratios range from 27.78 ± 0.07% for flour F5BS to 34.79 ± 0.20% for flour F6BS, with significant differences ($p < 0.05$) among the three formulations.

Table 4: Mineral contents of the different instant flours

	F4BS	F5BS	F6BS	Reference values (mg/day)
Magnesium (mg/100 g DM)	55.15 ± 0.13c	63.83 ± 0.87b	73.80 ± 0.90a	80-180
Iron (mg/100 g DM)	8.96 ± 0.10a	8.08 ± 1.31a	9.39 ± 0.30a	3-8
Zinc (mg/100 g DM)	3.00 ± 0.60b	3.46 ± 0.40b	5.29 ± 0.20a	2.9-3.6
Sodium (mg/100 g DM)	41.30 ± 1.76c	55.56 ± 0.57b	72.33 ± 1.53a	370-800
Potassium (mg/100 g DM)	1194 ± 3.60c	1412 ± 1.73b	2031 ± 2.64a	750-800
Calcium (mg/100 g DM)	109.3 ± 1.57b	101.6 ± 0.60c	169.6 ± 1.73a	280-390
Phosphorus (mg/100 g DM)	360.9 ± 1.4b	365.7 ± 1.32b	487.5 ± 2.18a	160-250
Na/K ratio (%)	3.46 ± 0.14b	3.94 ± 0.04a	3.56 ± 0.07b	< 100
Ca/P ratio (%)	30.28 ± 0.34b	27.78 ± 0.07c	34.79 ± 0.20a	16 - 36

Values are expressed as means ± standard deviations of analyses performed in triplicate. Within the same row, values with different superscript letters are significantly different ($p < 0.05$).

3.4 Principal component analysis (PCA) and hierarchical cluster analysis (HCA) of the instant flours

Principal component analysis (PCA) of the physicochemical and nutritional characteristics of the instant flours shows that the first two dimensions explain 95.40% of the total variability of the parameters studied, namely 74.40% for the first dimension (F1) and 21.00% for the second (F2). The first component (F1) is mainly characterized by lipid, ash, fibre, sodium, calcium and magnesium contents, as well as protein and carbohydrate contents and energy value. The second component (F2) is characterized mainly by moisture and potassium, iron and phosphorus contents.

Projection of the flours and reference data onto the F1 × F2 factorial plane (Figure 1a) shows that flours F4BS and F5BS are close to each other and are mainly associated with carbohydrate and protein contents and energy value. Flour F6BS is distinguished by its position on the factorial plane, while the reference data are located in the positive part of the first dimension.

Hierarchical cluster analysis (HCA) confirms this differentiation by identifying two clusters (Figure 1b). The first cluster groups flours F4BS and F5BS with the reference data, whereas the second consists solely of flour F6BS.

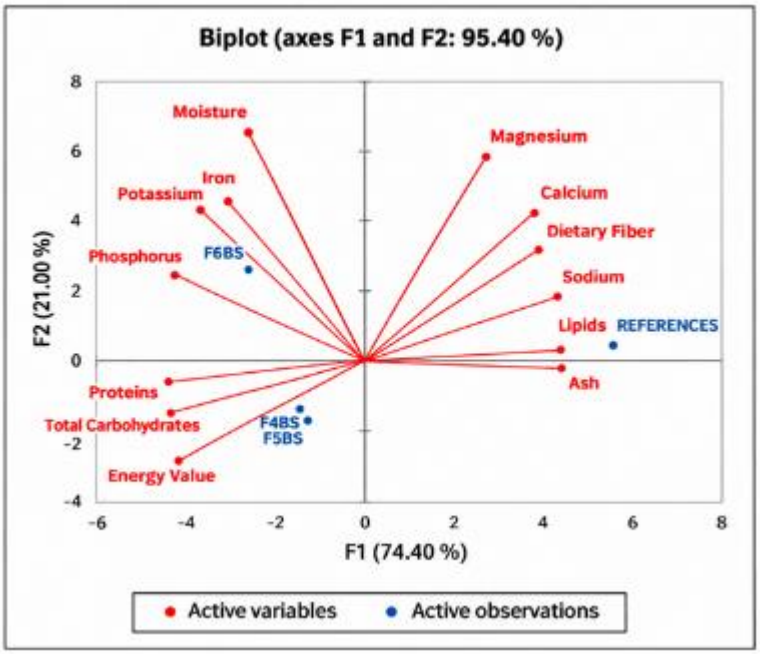


Figure 1a: Biplot showing the superimposition of physicochemical and nutritional contents with the different instant flours.

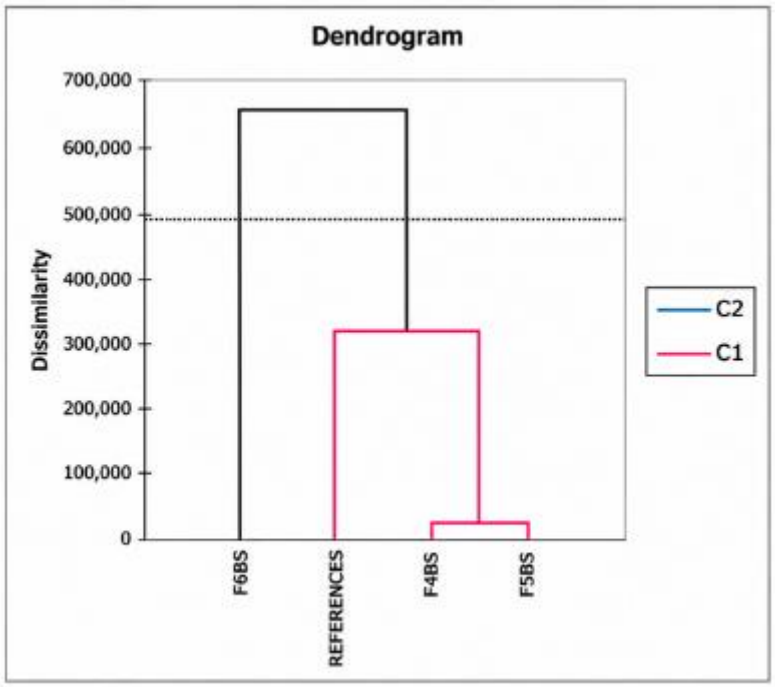


Figure 1b: Classification of all instant flours according to their similarity in physicochemical and nutritional characteristics.

4 DISCUSSION

Physicochemical analysis of the instant flours revealed pH values ranging from 5.10 ± 0.05 to 5.18 ± 0.03, indicating that they are slightly acidic. These values are lower than the value of 6.66 ± 0.04 reported by [21] for soybean-enriched yam-based infant flours. According to these authors, flour acidity may help limit the growth of certain microorganisms and promote preservation. Thus, the acidic nature of the formulated flours could be a factor contributing to their microbiological stability. This stability is further supported by the low water (moisture) content observed. Indeed, moisture contents in the instant flours, ranging from 3.00 ± 0.20% to 4.47 ± 0.64%, are below the 8% value

recommended by [12]. However, they remain higher than the value of 2.45% reported by [22] for composite flours based on soybean and spirulina. According to [23] and [24], water content is an important parameter in the preservation of food products. The low moisture contents observed could therefore help limit deterioration and promote flour stability during storage.

Ash contents, ranging from 1.93 ± 0.23% to 2.20 ± 0.20%, are below the reference value of 3% established for infant flours by [25]. According to [26], [27] and [28], ash content is an indicator of the total mineral fraction of a food. The values obtained therefore indicate the presence of mineral constituents in the three formulations.

Mineral analyses confirmed the presence of minerals, particularly magnesium, at contents ranging from 55.15 ± 0.13 to 73.80 ± 0.90 mg/100 g dry matter (DM). Magnesium is involved in many enzymatic reactions and is an important cofactor in numerous cellular metabolic reactions [29]. Its presence in the formulated flours therefore represents an interesting nutritional contribution. Flour F6BS has the highest content, which may be related to the proportions of raw materials used in its formulation.

Zinc contents range from 3.00 ± 0.60 to 5.29 ± 0.20 mg/100 g DM, with a significantly higher concentration in flour F6BS. Zinc is an integral component of many enzymes and is important for the human body [30]. The concentrations observed suggest that these flours could contribute to young children's dietary zinc intake. According to [31], zinc-rich foods may be used in the management of growth retardation and skin lesions. Zinc also plays a role in insulin storage and regulation, which in turn regulates blood glucose levels.

Iron plays an important role in the body. As a constituent of haemoglobin, it enables oxygen to be transported throughout the body. Iron is also involved in numerous metabolic and enzymatic reactions, proper brain function and the maintenance of body homeostasis [32]. The presence of iron in a food may help prevent iron-deficiency anaemia in children. Thus, the instant flours (8.08 ± 1.31 to 9.39 ± 0.30 mg/100 g DM) could provide a source of iron for children who consume them.

Instant flours F4BS, F5BS and F6BS have high magnesium, iron and zinc contents. These amounts are reported to be capable of covering more than 60% of the daily magnesium requirements of children aged 6–36 months, 100% of their daily iron requirements and more than 100% of their daily zinc requirements [33]. They could therefore be good sources of these minerals and could be used as complementary foods for older infants (6–12 months) and young children (12–36 months).

The Na/K ratios, ranging from 0.0346 to 0.0394, indicate that potassium predominates over sodium in the three flours. Conversely, the Ca/P ratios, ranging from 0.278 to 0.348, indicate a relatively low proportion of calcium compared with phosphorus. These results suggest that particular attention should be paid to the calcium contribution of the formulated flours, taking into account other foods consumed and mineral bioavailability. The sodium/potassium ratio (below 1) is considered to indicate a potentially favourable balance between these two minerals. Potassium-rich foods are also important for the formation of body cells, while sodium is important for maintaining osmotic pressure, protein synthesis and enzymatic reactions [29].

From a biochemical perspective, lipid contents range from 12.27 ± 0.31% to 13.53 ± 0.31%, corresponding to energy contributions of 25.34% to 27.31%. These proportions meet the Codex Alimentarius recommendation [25], according to which at least 20% of the energy intake from complementary foods should come from fats. The contents obtained are higher than the 5.21–7.77% reported by [34] for protein-enriched yam-based infant flours. This difference could be attributed to the nature of the ingredients used, particularly the addition of soybean, shea caterpillars and palm oil. Lipids contribute to the energy density of foods and, in particular, act as carriers for fat-soluble vitamins to their target organs [35]. Their presence in the formulations is therefore an advantage for complementary feeding of young children.

Protein contents in the instant flours range from 16.41 ± 0.18% to 16.64 ± 0.07%, corresponding to 14.72%–15.27% of total energy intake. These values are markedly higher than the 4.58% reported by [36] for a composite flour made from plantain banana and breadfruit, and the 3.9 ± 1.7 g/100 g obtained by [37] for a precooked flour based on maize (*Zea mays*) and soybean (*Glycine max*). This high protein content could be explained by the addition of soybean and shea caterpillars, which are recognized for their high protein content. In view of the Codex Alimentarius recommendations [25], the protein energy contributions of flours F4BS and F5BS fall within the generally recommended range of 6–15%, whereas that of F6BS (15.27%) slightly exceeds the indicative upper limit.

Total carbohydrate contents, ranging from 64.59 ± 0.45% to 65.40 ± 0.15%, show that carbohydrates are the main macronutrients in the three formulations. This predominance may be attributed to the high proportion of senescent plantain flour used in the mixtures. Carbohydrates are the body's main energy source, supplying energy to organs and muscles [38]. They also play an important role in supporting the immune system by providing it with energy [39]. Their high levels could therefore help meet children's energy requirements during the complementary feeding period.

Fibre contents in the instant flours range from 0.59 ± 0.15% to 2.13 ± 0.76% and remain below the reference value of 5% recommended by the Codex standard [25]. These results are comparable to those obtained by [40], who reported a content of 2.16 ± 0.08 g/100 g DM for enriched fonio flours, and by [41], who reported 2.95 ± 0.18 g/100 g DM for composite yam- and soybean-based flours. According to [42] and [43], fibre helps reduce cholesterol and blood glucose levels, stimulates microbial activity in the colon and increases the absorption of certain micronutrients, such as calcium. The relatively moderate contents observed could help limit digestive bulk in complementary foods while still providing some dietary fibre.

The energy values of the instant flours range from 435.73 ± 2.39 to 445.80 ± 1.40 kcal/100 g. They are higher than the minimum value of 400 kcal/100 g dry matter recommended by the Codex Alimentarius for formulated complementary foods [25]. These values indicate an interesting energy density, which may be related to the combined contribution of carbohydrates, lipids and proteins. According to [44] and [27], the energy value of a food results from the energy released by its nutrients during metabolism. The flours developed therefore have potential to contribute to the energy intake of children aged 6–36 months. However, their actual ability to meet these needs would also depend on the quantities consumed and the energy density of the porridges after reconstitution.

Principal component analysis (PCA) and hierarchical cluster analysis (HCA) highlight the similarity between the physicochemical and nutritional profiles of flours F4BS and F5BS, which are grouped with the reference data. This similarity may be explained in particular by their dry matter and lipid contents and their energy values. In contrast, flour F6BS is distinguished by higher concentrations of potassium, calcium, zinc and magnesium. These differences may be related to variations in the proportions of soybean and shea caterpillars incorporated into the formulations. Nevertheless, all three flours have energy values above 400 kcal/100 g and moisture contents below 5%. These observations suggest that the formulations have interesting nutritional characteristics, despite the differences highlighted by the multivariate analyses.

5 CONCLUSION

This study showed that instant flours made from senescent plantain banana, soybean, shea caterpillars and palm oil have physicochemical and nutritional characteristics that are of interest for the complementary feeding of children aged 6–36 months. The three formulations are characterized by low moisture contents, contributions of protein, lipids and minerals, and energy values above 400 kcal/100 g. PCA and HCA revealed similar profiles for flours F4BS and F5BS and the reference data, whereas F6BS was distinguished by its higher content of certain minerals. However, improvement of the calcium/phosphorus balance and further studies on microbiological quality, nutrient bioavailability and storage are still required. These results confirm the potential for valorizing senescent plantain banana in the development of infant flours from local resources.

STATEMENTS ON COMPLIANCE WITH ETHICAL STANDARDS

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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