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Physicochemical and nutritional characteristics of three infant composite flours based on tiger nut (*Cyperus esculentus*) and sweet potato (*Ipomoea batatas*) in the Korhogo department, northern Côte d'Ivoire

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Abstract

Child malnutrition remains a major concern in developing countries, where low-income households have limited access to fortified infant flours. This study aims to characterize the physicochemical and nutritional parameters of infant composite flours based on tiger nut (*Cyperus esculentus* L) and sweet potato (*Ipomoea batatas*), northern Côte d'Ivoire. Three flours were prepared (F1, F2, F3) combining tiger nut flour with sweet potato flour from different varieties. Analyses revealed moisture (5.08 to 6.26%), dry matter (93.74 to 94.92%), and ash (2.88 to 3.23%) contents. Nutritionally: protein (9.12 to 11.76%), lipid (13.60 to 14.82%), carbohydrate (75.57 to 77.35%), fiber (8.86 to 21.16%), and low total sugar (3.07 to 3.60%) and reducing sugar (0.26 to 0.47%) contents. The energy value is high (434.84 to 440.32 kcal). These composite flours show promising parameters and could serve as a dietary supplement for infants.

Keywords: Infant malnutrition, composite flour, *Cyperus esculentus*, *Ipomoea batatas*, physicochemical parameters

Introduction

Child malnutrition is a nutritional imbalance in children resulting from insufficient, excessive, or inadequate intake of essential nutrients. It leads to serious consequences for child growth and health. It mainly affects children under five years of age, particularly those aged 6 to 24 months, and manifests as stunting (22%), wasting (6.8%), and overweight or obesity (5.6%). Moreover, 340 million children suffer from micronutrient deficiency [1]. To effectively combat this scourge, breastfeeding must be combined with infant flours fortified with essential nutrients. These flours must ensure an adequate caloric and vitamin intake to protect infants against common infections [2]. These fortified infant flours have reportedly reduced the prevalence of iron-deficiency anemia by nearly 50% and enabled the recovery of about 75% of malnourished children [3, 4]. Despite these substantial recovery rates, child malnutrition continues to claim victims. Indeed, low-income populations in the most affected areas have very limited access to these fortified flours, compounded by a lack of adequate infrastructure [5]. To overcome this scourge, rural populations rely on locally produced food resources to formulate infant flours that are effective and affordable. Indeed, several studies conducted in this area have yielded satisfactory results. In Niger, an infant flour formulated from millet, soybean, and local spirulina achieved an 80% recovery and nutritional rehabilitation rate among malnourished children. Similarly, in Benin, the incorporation of palm kernel cake, maize, and soybean gave a success rate of 78% [6, 7]. It is within this context that the present study is set, with the aim of contributing to the fight against child malnutrition through the formulation of infant composite flours based on tiger nut (*Cyperus esculentus* L) and sweet potato (*Ipomoea batatas*), in the Korhogo department, northern Côte d'Ivoire. The physicochemical and nutritional parameters of these composite flours will be determined. Both tubers are recognized for their richness in macronutrients and micronutrients essential to meet the body's needs [8, 9].

Materials and Methods

Biological Material

The biological material consisted of tiger nut tubers (*Cyperus esculentus*) and three sweet potato varieties (*Ipomoea batatas*), purchased at the Korhogo market in northern Côte d'Ivoire. The sweet potato varieties selected were white-skinned, white-fleshed sweet potato, purple-skinned, white-fleshed sweet potato, and yellow-skinned, orange-fleshed sweet potato (Figure 1). The sweet potato tubers were first washed in clean water, peeled, then cut into thin slices before being weighed. The tiger nut tubers were carefully sorted to remove impurities, then washed in clean water. After cleaning, each tuber was dried in an oven at 60°C for 24 to 48 hours, then individually ground using an electric mill (RETSCH, Type AS 200) to obtain a fine powder, which was stored in labeled containers. These flours were used for the formulations.

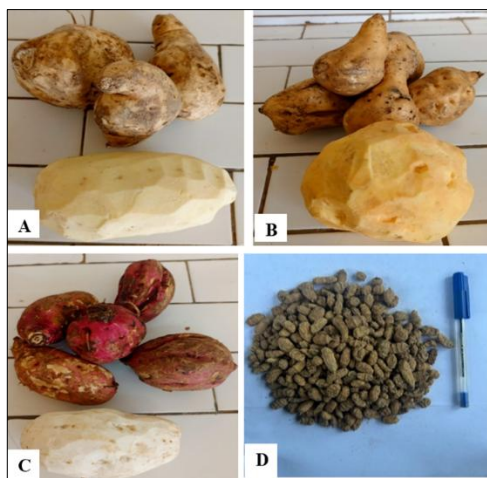


Fig 1: Biological material used

A: white-skinned, white-fleshed sweet potato; B: yellow-skinned, orange-fleshed sweet potato; C: purple-skinned, white-fleshed sweet potato; D: Tiger nut tubers

Technical equipment

The technical equipment used in flour preparation included an oven, used for drying the sweet potato slices and tiger nut tubers. The mass of each ingredient involved in the formulation was measured using a digital balance. A spectrophotometer and a pH meter were used to measure the optical density and pH of each preparation. Finally, various small laboratory items and glassware were also used to carry out this work.

Flour formulation method

The infant flour based on sweet potato and tiger nut was formulated using the Pearson square method. This method is a standard manual graphical technique for formulation from two ingredients^[10]. It consists of placing the target content of the selected nutrient at the center of a square, while the contents of the two ingredients are positioned at the left-hand corners. The differences calculated diagonally, expressed as absolute values, determine the respective proportions of each ingredient to be mixed to obtain the desired formulation. These calculations yielded three distinct formulations:

- **F1:** tiger nut flour (55.06 g) and white-skinned, white-fleshed sweet potato flour (44.94 g);
- **F2:** tiger nut flour (53.89 g) and yellow-skinned, orange-fleshed sweet potato flour (46.11 g);

- **F3:** tiger nut flour (53.07 g) and purple-skinned, white-fleshed sweet potato flour (46.93 g).

These three formulations were used to analyze the physicochemical and nutritional parameters

Determination of physicochemical parameters

Moisture and dry matter content

Moisture and dry matter contents were determined according to the AOAC method used by Sankhon *et al.* (2024)^[11]. To do this, 5 g of each formulation were individually weighed into pre-tared porcelain crucibles, with the crucible-plus-sample assembly recorded as M1. This assembly (M1) was then placed in an oven at 105°C for 24 hours. After removal from the oven and cooling in a desiccator, the assembly was weighed a second time (M2). Moisture and dry matter contents were then calculated using the following formulas:

$$\text{Moisture (\%)} = [(M1 - M2) / m] \times 100$$

$$\text{Dry matter (\%)} = 100 - \text{Moisture (\%)}$$

m = sample mass before drying (g); M1 = mass of crucible + sample before oven-drying (g); M2 = mass of crucible + sample after oven-drying (g).

pH and ash content

The pH and ash content were determined according to the AOAC method^[11]. The pH of each formulation was measured using a pre-calibrated pH meter. Ash content was determined by incineration. About 5 g of each formulated flour were weighed into a pre-tared crucible, then calcined in a muffle furnace set at 550°C for 3 hours, until a whitish ash free of carbonized particles was obtained. After incineration, the crucible was removed from the furnace, cooled in a desiccator for 30 minutes, then weighed. Ash content was calculated using the following formula:

$$\text{Ash content (\%)} = [(M_2 - M_0) / (M_1 - M_0)] \times 100$$

M₀ = mass of empty crucible (g); M₁ = mass of crucible + sample before incineration (g); and M₂ = mass of crucible + ash after incineration (g).

Titrateable acidity

The acidity level of each composite flour was determined using the method described by^[12] Soro *et al.* (2013). For this purpose, a 5 g mass of each flour was homogenized in 25 mL of distilled water, and the resulting mixture was filtered through filter paper. To determine titrateable acidity, 10 mL of the filtrate was titrated with a 0.1 N NaOH solution, using phenolphthalein as a color indicator, until a persistent pink coloration appeared. The titrateable acidity value was calculated using the following equation

$$\text{Titrateable acidity (\%)} = [(V \times N) / (V_e)] \times 100$$

V = volume of NaOH used (mL); N = normality of the NaOH solution; V_e = sample volume (mL)

Determination of nutritional parameters of the infant composite flours

Protein content

The protein content of the composite flours was determined according to the Kjeldahl method^[13]. For each sample, 5 g of

flour were digested in a 400 mL flask with 2 g of catalyst (selenium/potassium sulfate mixture) and 15 mL of concentrated sulfuric acid (95%), in a digester at 400°C for 2 hours, until a clear digest was obtained. After cooling, the digest was transferred to a 100 mL volumetric flask and made up to volume with distilled water. Then, 10 mL of the digest was added to 10 mL of 40% (w/v) sodium hydroxide and distilled; the released ammonia was collected in 20 mL of boric acid containing a mixed indicator (methyl red + bromocresol green), until a violet distillate was obtained (10 min). The distillate was finally titrated with 0.1 N sulfuric acid until a green color change, indicating the equivalence point, with a blank test performed in parallel. The nitrogen and protein contents of each composite flour were calculated using the following formulas:

$$N (\%) = [(V_1 - V_0) \times N(H_2SO_4) \times 14 \times 100 / (m \times 1000)] \times (V_f / V_p)$$

$$\text{Protein } (\%) = N (\%) \times 6.25$$

V_1 = volume of sulfuric acid used to titrate the sample (mL); V_0 = volume used for the blank (mL); $N(H_2SO_4)$ = normality of sulfuric acid (0.1 N); 14 = molar mass of nitrogen (g/mol); m = sample mass (g); V_f = final volume of the volumetric flask (100 mL); V_p = volume of digest taken (10 mL); 6.25 = nitrogen-to-protein conversion factor.

Lipid content

The lipid content of each composite flour was determined by Soxhlet extraction according to the [13] AOAC (2023). For this, 5 g (m) of flour were placed in a pre-weighed WHATMAN extraction thimble, while 200 mL of hexane was poured into an extraction flask previously weighed empty (M_1). The flask containing the hexane was then placed on a heating mantle set at 110°C for 8 h of continuous extraction. After this period, the flask was removed from the Soxhlet apparatus and placed in an oven at 130°C for 1 h to ensure complete evaporation of residual solvent. After cooling, the flask was weighed a second time (M_2). Lipid content was finally calculated using the following formula:

$$\text{Lipid content } (\%) = [(M_2 - M_1) / m] \times 100$$

Total sugar content

Total sugars were determined using the phenol-sulfuric acid colorimetric method of Dubois *et al.* (1956), également utilisée par Bougma *et al.* (1956), also used by Bougma [14, 15]. This assay is based on the dehydration of sugars by concentrated sulfuric acid into furfural derivatives, which condense with phenol to form an orange-yellow colored complex whose intensity is proportional to sugar content. A calibration curve was established from a glucose stock solution at 1 g/L. For each point on the curve and for the samples, 0.1 mL of ethanol-soluble sugars was mixed with 0.9 mL of distilled water, then supplemented with 1 mL of 5% (w/v) phenol and 5 mL of concentrated sulfuric acid. A blank tube was prepared in the same way, substituting the sample with 1 mL of distilled water. After color development, absorbances were measured at 490 nm using a spectrophotometer, against the blank. Total sugar concentration was determined by graphical extrapolation from the calibration curve.

Reducing sugar content

Reducing sugars were determined according to Božinović *et al.* (2023) using 3,5-dinitrosalicylic acid (DNS) [16]. 150 μ L of ethanol-soluble sugars were placed in a test tube, and 300 μ L of the DNS solution were added. The mixture was then heated in a boiling water bath for 5 min. After cooling for 5 min on the bench, 2 mL of distilled water was added to the reaction medium. Optical density was read at 540 nm using a spectrophotometer against a blank containing 150 μ L of distilled water and 300 μ L of DNS. Optical density was converted into reducing sugar content.

Determination of fiber content

The crude fiber content of the composite flours was determined according to AOAC (2023) [13]. For this, 2 g of flour (Me) were treated with 50 mL of sulfuric acid (0.25 N) under reflux boiling (30 min), then with 50 mL of sodium hydroxide (0.31 N) under the same conditions (30 min). The resulting residue was filtered and washed with hot water until complete removal of alkalis, then dried in an oven at 105 °C for 8 h. After drying, the residue was weighed (M_1) and incinerated in a muffle furnace (550 °C) to obtain a mass (M_0) after cooling. Fiber content was calculated using the following formula:

$$\text{Crude fiber } (\%) = [(M_1 - M_0) / Me] \times 100$$

Me = sample mass (g); M_1 = mass of dried residue before incineration (g); M_0 = mass of ash after incineration (g).

Total carbohydrates

Total carbohydrates were determined by the difference method, using the formula below:

$$\text{Total carbohydrates } (\%) = 100 - (\text{Moisture}\% + \text{Protein}\% + \text{Lipid}\% + \text{Ash}\% + \text{Fiber}\%)$$

Energy value

Energy value was calculated from Atwater conversion factors, according to the updated recommendations of Grande *et al.*, 2024 using the formula below [17]:

$$\text{Energy value (kcal/100 g)} = (\text{Protein}\% \times 4) + (\text{Lipid}\% \times 9) + (\text{Carbohydrate}\% \times 4)$$

Statistical analysis

Experimental data were analyzed using SPSS software (version 26). Values were presented as mean $\pm$ standard deviation. To assess the significance of the observed differences, analysis of variance (ANOVA) was used, followed by Tukey's multiple comparison test at a 5% threshold.

Results and Discussion

Results

Physicochemical parameters

The physicochemical parameters of the infant composite flours (moisture, dry matter, ash content, pH, and titratable acidity) are presented in Table I. Moisture, dry matter, and ash content varied from 5.08 to 6.26%, 93.74 to 94.92%, and 2.88 to 3.23%, respectively. Flour F1 showed the highest moisture content (6.26%), followed by F2 (5.39%) and F3 (5.08%), while dry matter followed the opposite trend, with the highest values for F3 (94.92%) and F2 (94.61%), and the lowest for F1 (93.74%). Regarding ash content, flours F1

(3.23%) and F3 (3.21%) showed the highest values, compared to 2.88% for F2. pH and titratable acidity varied from 6.65 to 6.93 and 0.30 to 0.42%, respectively. The highest pH values were recorded for F2 (6.93) and F1 (6.92), corresponding to the lowest titratable acidities (0.36% and 0.30%). Statistical analysis revealed a significant difference between the parameters of the different formulations ($p < 0.05$).

Table 1: Physicochemical parameters of the infant composite flours

Parameters	Formulated composite flour types		
	F1	F2	F3
Moisture (%)	6.26 ± 0.00 ^a	5.39 ± 0.001 ^b	5.08 ± 0.001 ^c
Dry matter (%)	93.74 ± 0.00 ^b	94.61 ± 0.001 ^a	94.92 ± 0.001 ^a
Ash (%)	3.23 ± 0.001 ^a	2.88 ± 0.001 ^b	3.21 ± 0.001 ^a
pH	6.92 ± 0.01 ^b	6.93 ± 0.01 ^a	6.65 ± 0.02 ^c
Titratable acidity (%)	0.30 ± 0.02 ^b	0.36 ± 0.01 ^b	0.42 ± 0.01 ^a

Values followed by the same superscript letter within the same row do not differ significantly ($P > 0.05$).

1.2. Nutritional parameters of the composite flours

Le Table II presents the nutritional parameters of the composite flours (protein, lipid, total carbohydrate, fiber, total sugars, reducing sugars, and energy value). Protein, lipid, and total carbohydrate contents varied from 9.12 to 11.76%, 13.60 to 14.82%, and 75.57 to 77.35%, respectively. Flour F3 showed the highest protein (11.76%) and total carbohydrate (77.35%) contents, followed by F2 (10.28% and 76.77%). Conversely, formulations F1 (14.82%) and F2 (14.68%) recorded the highest lipid contents, compared to 13.60% for F3. Statistical analysis revealed a significant difference between the formulations ($p < 0.05$).

Fiber, total sugar, and reducing sugar contents varied from 8.86 to 21.16%, 3.07 to 3.60%, and 0.26 to 0.47%, respectively, with maximum values recorded for F3 for all three parameters. With the exception of F3, flour F1 showed the highest fiber (11.11%) and reducing sugar (0.35%) contents, while F2 recorded the lowest values for these two parameters (8.86% and 0.26%). For total sugars, the trend was reversed: F2 showed the highest content (3.22%) and F1 the lowest (3.07%).

Regarding the energy values produced by each formulation, they ranged from 434.84 to 440.32 kcal. The energy value of F2 (440.32 kcal) was clearly higher than that of F1 (436.14 kcal), which was itself significantly higher than the energy provided by F3 (434.84 kcal).

Table 2: Nutritional parameters of the infant composite flours

Parameters	Formulated composite flour types		
	F1	F2	F3
Protein (%)	9.12 ± 0.10 ^c	10.28 ± 0.10 ^b	11.76 ± 0.10 ^a
Lipid (%)	14.82 ± 0.00 ^a	14.68 ± 0.00 ^b	13.60 ± 0.001 ^c
Total carbohydrates (%)	75.57 ± 0.01 ^c	76.77 ± 0.01 ^b	77.35 ± 0.01 ^a
Fiber (%)	11.11 ± 0.16 ^b	8.86 ± 0.16 ^c	21.16 ± 0.16 ^a
Total sugars (%)	3.07 ± 0.01 ^c	3.22 ± 0.01 ^b	3.60 ± 0.01 ^a
Reducing sugars (%)	0.35 ± 0.01 ^b	0.26 ± 0.01 ^b	0.47 ± 0.01 ^a
Energy (kcal)	436.14 ± 0.01 ^b	440.32 ± 0.01 ^a	434.84 ± 0.01 ^c

Values followed by the same superscript letter within the same row do not differ significantly ($P > 0.05$).

Discussion

In order to assess the nutritional value of the infant composite flours formulated from tiger nut and sweet potato, physicochemical and nutritional analyses were carried out on the different formulations. Evaluation of the physicochemical parameters first revealed that the moisture, dry matter, and ash contents of the flours obtained varied from 5.08 to 6.26%,

93.74 to 94.92%, and 2.88 to 3.23%, respectively. These moisture levels are below the critical threshold of 10% set by WHO/UNICEF for infant flours. This low water content is confirmed by the high dry matter content obtained. Both parameters would ensure satisfactory stability and a reasonable shelf life, while limiting microbial development [18]. Similar results were obtained with infant flours formulated from maize and fonio, then fortified with milk, in Guinea, with respective moisture and dry matter contents of 6.17% and 93.53% [11]. Moreover, the observed ash content would reflect a mineral richness contributed by tiger nut and sweet potato, both recognized for their mineral composition [19]. These results corroborate those of Gampoula *et al.* (2020), who observed ash contents ranging from 2.10 to 3.56% in protein-fortified yam-based infant flours [20]. Finally, the infant composite flours showed pH and titratable acidity ranging from 6.65 to 6.93 and 0.30 to 0.42%, respectively. These results suggest that the pH of the composite flours is very close to neutrality and that their acidity is very low, thereby strongly reducing fermentative activity in the flours. These characteristics would be favorable for organoleptic and digestive tolerance in infants, while contributing to the biochemical stability of the product during storage [21]. Studies conducted in Burkina Faso on infant flours reported similar pH values, ranging from 5.55 to 6.36 [15]. Overall, the physicochemical characteristics of the infant composite flours would ensure their stability as well as their organoleptic and digestive qualities for infants.

Analysis of the nutritional parameters of the infant composite flours based on tiger nut and sweet potato showed that protein, lipid, and total carbohydrate contents varied from 9.12 to 11.76%, 13.60 to 14.82%, and 75.57 to 77.35%, respectively. The protein content of the composite flours could be explained by the concentration effect associated with drying, which promotes the accumulation of macronutrients, as well as by the complementary protein contributions of each ingredient [15]. Similar results were reported by Sankhon *et al.* (2024), whose formulated flour contained 11.44% protein [11]. However, the protein content of the flours formulated in this study remains slightly lower than that of BLEDINE (13.69%), a commercial infant flour, as well as the 14.52% obtained for a protein-fortified yam-based infant flour [12, 20]. This difference could be explained by the absence of an animal- or legume-based protein supplement in the formulation of the flours studied. Proteins are an essential nutrient in infant flours, as they support infant growth [2].

The high lipid content (13.60 to 14.82%) of the composite flours based on tiger nut and sweet potato could be explained by the particular biochemical nature of tiger nut. Unlike other tubers, which store their energy mainly as starch, tiger nut stores it both as starch and as lipids, similar to an oilseed [23]. Indeed, a study conducted in Burkina Faso reported fat contents ranging from 22.40 to 30.08% in this tuber [21]. The lipid contents obtained in the present study were higher than those reported by Gampoula *et al.* (2020) and Sankhon *et al.* (2024) for their flours formulated respectively in Congo-Brazzaville and Guinea, with contents of 7.77% and 6.45% [20, 11]. This difference could be explained by the diversity of ingredients used in the formulation of infant flours. However, this lipid content largely exceeds the maximum threshold of 8.5% recommended for infant flours by the FASONORM standard [11]. This excess could limit digestibility in infants and accelerate the degradation of the formulated flours. It would therefore be necessary to slightly reduce the

incorporation rate of tiger nut in favor of sweet potato in each formulation.

The formulations also show a high total carbohydrate content (75.57 to 77.35%), which could be explained by the starchy nature of sweet potato and tiger nut, both recognized for their richness in carbohydrates [24, 25]. Similar carbohydrate contents (67.10 to 76.29%) were obtained with an infant flour formulated from orange-fleshed sweet potato, brown teff, and red kidney beans [26]. Similarly, a carbohydrate content of 73.78% was recorded in an infant flour formulated from sweet potato, Bambara groundnut, and brown rice [27]. Indeed, carbohydrates and lipids play a fundamental role in infant nutrition, covering energy needs estimated at 400–900 kcal/day [28]. These energy needs would confirm the nutritional value of the flours formulated in this study, whose energy value ranges from 434.84 to 440.32 kcal. Carbohydrates would provide 55 to 65% of total energy intake, making them the main caloric source necessary for infant growth and development. As for lipids, beyond their energy contribution they would also be involved in the transport of fat-soluble vitamins as well as in the development of the central nervous system [29].

The infant composite flours based on tiger nut and sweet potato showed fiber, total sugar, and reducing sugar contents ranging from 8.86 to 21.16%, 3.07 to 3.60%, and 0.26 to 0.47%, respectively. The fiber content of the infant composite flours could be explained by the intrinsic fiber composition of tiger nut and sweet potato. Tiger nut tubers reportedly contain a substantial proportion of insoluble and soluble fiber, ranging from 9 to 20%, while sweet potato has a lower fiber content, on the order of 3 to 5% [21, 24]. Comparable fiber contents were reported by Araro *et al.* (2020) and Alomatu *et al.* (2025), namely 10.2% and 12.2%, respectively, in locally formulated infant flours [25, 26]. Fiber plays an essential role in infant nutrition: it promotes intestinal transit, regulates blood glucose and nutrient absorption, and produces fatty acids beneficial to intestinal health [28]. Furthermore, the low total sugar and reducing sugar contents of the composite flours could be explained by the raw material processing methods: drying and milling of tiger nut and sweet potato would reduce free sugar content while favoring the relative accumulation of starch. These results are corroborated by the work of Araro *et al.* (2020) and Sankhon *et al.* (2024), who also reported very low reducing sugar and total sugar values in their infant flours [11, 26]. This low simple sugar content offers considerable nutritional value, as it limits the risk of overweight and glycemic spikes in infants [30].

Conclusion

The aim of this study was to evaluate the physicochemical and nutritional parameters of composite flours formulated from tiger nut and sweet potato in the Korhogo department. Analysis of the physicochemical parameters of the infant composite flours showed that these flours had low water and titratable acidity contents, a pH value close to neutrality, as well as a high dry matter content and a normal ash content. These physicochemical characteristics would ensure microbiological stability, extended shelf life of the composite flours, and acceptable organoleptic quality. Nutritionally, these composite flours are distinguished by a high content of lipids and total carbohydrates, responsible for the dense energy profile observed. Adequate protein and fiber values were also obtained, along with low simple sugar contents. These flours could thus meet the recommended nutritional and energy needs as a dietary supplement for infants.

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