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Formulation of Infant Flours Based on Fonio Enriched with Bambara Groundnut *Anacardium* (Cashew) and African Locust Bean Fruit Pulp

Lawrence Roselynn Kra KouaKou[1], Pierre Martial Thierry Akely[1,2], Albarin Grodji Gbogouri[1], Françoise Kouame[1]

[1]Laboratory of Food Biochemistry and Tropical Product Technologies, UFR of Food Sciences and Technology, Nangui-Abrogoua University, Abidjan, Ivory Coast
[2]Department of Science et Technologie, Section (SVT), Ecole Normale Supérieure, Abidjan, Côte d'Ivoire
Email: lawrence_roselynn@yahoo.fr, akely_pierre@yahoo.fr, albaringrodji@yahoo.fr, francoiseak@yahoo.com

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Abstract

Infant malnutrition is a significant issue in Côte d'Ivoire, and this study aims to address it by formulating infant flours using local ingredients. Fermentation, germination, and malting methods were used to enhance the quality of six formulated flours, all based on Fonio and supplemented with Bambara groundnut, African locust bean fruit pulp, and cashew kernels. Results showed that Fonio had the highest carbohydrate content, while Bambara groundnut and Cashew kernels were rich in protein and lipid content. African locust bean fruit pulp was rich in fiber and Vitamin C, with a high β-carotene value. The cashew kernel had the highest energy value. Regarding mineral composition, African locust bean fruit pulp had the highest potassium content, while Bambara groundnut and African locust bean fruit pulp were rich in sodium. Cashew kernel and Fonio had higher iron and calcium content. Bambara groundnut had a higher zinc content, while cashew kernel had a higher magnesium content. The formulated flours made from fermented Fonio grains and enriched with Bambara groundnut, African locust bean fruit pulp, and cashew kernel had varying protein, fiber, carbohydrate, ash, and fat contents. The flour formulated with sprouted Fonio and enriched with the same ingredients had higher protein content and energy value than the other fermented seed-based flours. The mixed flours produced with fermented seeds and the flour produced from sprouted seeds met international standards. Overall, these findings offer valuable insights into the nutritional composition of the formulated flours and their potential to combat infant malnutrition in Côte d'Ivoire.

Keywords

Infant Flours, Formulation, Fonio, Groundnut, African Locust Bean Fruit Pulp

1. Introduction

Feeding a child during the first 1000 days is critical for long-term physical and brain development [1]. From 6 months of age, breast milk becomes qualitatively and quantitatively insufficient for the child while their nutritional needs increase [2]. Persistence of nutritional deficiencies can lead to child malnutrition, such as protein-energy malnutrition (PEM), micronutrient malnutrition, or vitamin and mineral deficiencies. Foods initially given to infants in addition to breast milk are very often porridges. Complementary foods, such as industrial flours for children rich in nutrients for child growth sold in supermarkets or large commercial chains, have very high prices that are mostly inaccessible to the large population. Thus, in developing countries like Côte d'Ivoire, complementary flours made from local products are produced to fight child malnutrition. Generally, the raw materials mostly used are cereals (rice, millet, sorghum, corn), roots (cassava), or tubers (yams) combined with legumes such as soybeans, beans, or cowpeas [3]. Fonio *(Digitaria exilis)*, a traditional cereal, is usually underused in the production of complementary flours despite its socio-cultural, nutritional, and economic importance [4], whereas it has the potential to improve nutrition and contribute to food security and sustainable land use [5] [6]. Among the local legumes, Bambara groundnut (*Vigna subterranea*) is a high-caloric plant rich in vitamins, minerals, and balanced proteins [7]. This legume could play an important role in improving the nutritional quality of local cereal-based infant flours. Cashew kernel*s* are a good source of protein, carbohydrates, and fat [8]. Cashew kernels are particularly rich in essential fatty acids such as linoleic and oleic acids, which respectively make up to 20% and 60% of the fat content. They are also rich in protein content and have an amino acid composition similar to soybeans.

In Côte d'Ivoire, complementary foods are mostly prepared from local foodstuffs, especially starchy products (like cereals and tubers). Most of the time, these starchy products are used alone without any enzymatic pre-treatment in the local manufacture of porridges and without any addition of protein sources [9] [10]. This explains some studies [11] [12] focusing on the formulation of local infant flours that comply with international standards. Several methods are being explored to produce infant flours that meet international standards. For example, [13] reported that the protein content of cereals combined with legumes is better than that produced from cereals alone. Moreover, one of the ways recommended by WHO is the combination of cereals and legumes as an alternative solution to protein deficiency, particularly in developing countries. This combination provides good quality protein [14]. However, few studies have focused on cereal and legume combinations, such as fonio and legumes like Bambara groundnut, for infant nutrition improvement. In this study, a combination of various cereals and legumes was explored to contribute to infant nutrition improvement. The overall objective of this study is to provide the local population with an alternative infant nutrition food with nutritional qualities that meet international standards. To achieve this goal, the physico-chemical and nutritional characteristics of raw materials and the characteristics of formulated infant flours that comply with international standards were determined.

2. Material and Methods

2.1. Biological Materials

White fonio (*Digitaria exilis*) is the main raw material used in the formulation of infant flours. This cereal was enriched with cream-colored bambara groundnut (*Vigna subterranea*) speckled with red, light gray *cashew* (*Anacardium occidentale*) speckled with black, and African locust bean fruit pulp (*Parkia biglobosa*). The variety of African locust bean used is the one with long pods and yellow pulp. The biological materials were purchased at the Abobo market and treated separately in lab.

2.2. Methods

2.2.1. Flours Production Process

The raw materials were treated according to the method described by [15]. They were sorted, winnowed, and cleaned to remove any physical impurities. Fonio was washed using the method described by [6]. One kilogram of each sample (fonio and Bambara groundnut) was fermented sequentially for 2 hours for fonio control, 8 hours for Bambara groundnut control, and 24, 36, and 48 hours for the other samples. After fermentation, the fonio and Bambara groundnut were dried and roasted at temperatures between 120˚C and 150˚C. The *cashew nut* was shelled, and the kernel was washed and dried in an oven at 50˚C to 60˚C. Grinding of the samples was separately done for each raw material using a multifunctional grinder (Gaone, Grinder 2500 rp/w, 36000 rpm). The African locust bean fruit pulp was obtained by drying the seeds surrounded by the pulp in an oven at 50˚C to 60˚C, crushing the dried seeds in an African wooden mortar with low handling force to detach the pulp from any cracked seeds, and sieving the resulting mixture through a mesh sieve ranking between 50 - 300 µm. For the germination process, one kilogram of fonio was soaked for 24 hours and spread on a polypropylene bag for 3 days to allow dark germination. The unsprouted grains were separated from the sprouted grains, and all the samples were dried in an oven at 50˚C to 60˚C. Degermination was performed, and the grains were ground using grinder (2500 rp/w, 36,000 rpm). The physicochemical parameters of the produced flours were determined.

2.2.2. Procedure for Infant Flours Formulation

The formulations used in this study were described according to the method described [16]. Different flour blends were prepared by combining 100 g of single flours of fonio, Bambara groundnut, cashew kernel, and African locust bean fruit pulp in various proportions. The flour formulations were developed using the matrix method of formulation supported by Excel software (2010). This method allows for finding a solution that satisfies two nutrient needs using at least two ingredients [17]. Macronutrient values, such as protein, carbohydrate, lipid (g/100 g), and energy (kcal/100 g), were computed using the following equation:

$$a_{11}X_1 + a_{12}X_2 + \cdots + a_{1n}X_n = b1$$

$$a_{21}X_1 + a_{22}X_2 + \cdots + a_{2n}X_n = b2$$

$$a_{n1}X_1 + a_{n2}X_2 + \cdots + a_{nn}X_n = bn$$

a = nutrient contents (carbohydrates, proteins, lipids and energy). X = proportions of ingredients to mix. b = needs to be satisfied and n = series of combination.

2.2.3. Physicochemical and Nutritional Analyses

The dry matter, moisture, ash, protein, fiber, fat, and carbohydrate content were determined according to the method described by [18]. Mineral content was determined by the emission flame photometric method. The vitamin C and vitamin A (β-carotene) content were determined by the method of [19]. The swelling power and solubility index were determined using the method described by [20].

2.2.4. Statistical Analyses

The data were performed with a two-factor analysis of variance (ANOVA) using STATISTICA software (STAT 7.1 for Windows, USA). The results are the mean of three replications with standard deviations. Significant divergences are accounted at a statistical probability value of $P < 0.05$ using Duncan's test for comparison of formulations.

3. Results and Discussion

3.1. Biochemical and Energetic Characteristics of the Raw Materials

Table 1 presents the biochemical and energy composition of the raw materials, namely fonio, Bambara groundnut, cashew kernel, and African locust bean fruit pulp. Fonio has a high carbohydrate content (80.4%), Bambara groundnut and African locust bean fruit pulp (61.6% and 64.4%, respectively). Cashew kernel has the lowest carbohydrate content (23.4%). The protein analysis revealed that Bambara groundnut and cashew kernel are very rich in protein (22.1% and 20.8%, respectively), while low protein contents were observed in African locust bean fruit pulp (6.3%) and fonio (7.8%). Cashew kernel has the highest lipid content of 48.5%, which is higher than the contents of fonio, Bambara groundnut, and African locust bean fruit pulp (1.3%, 6.5%, and 2%, respectively). This content is higher than that of unfermented *cashew* flour reported by [21]. African locust bean fruit pulp had higher amounts of fiber (11.5%) and Vitamin C (640 µg/g) compared to fonio (1.3% and 119 µg/g), Bambara groundnut (3.8% and 160 µg/g) and cashew kernel (2% and 488 µg/g), respectively. Additionally, African locust bean fruit pulp had a high β-carotene value (88.7 µg/g) compared to fonio (6.3 µg/g), Bambara groundnut (5.7 µg/g) and cashew kernel (16.1 µg/g). Cashew kernel had the highest energy value (612.7 Kcal) and the lowest was observed in African locust bean fruit pulp (300.8 Kcal). The composition of the control Bambara groundnut was like that mentioned by [22]. Fonio had a composition like the two ecotypes studied by [4], and the cashew kernel had a similar composition to the study by [23]. The analyzed African locust bean fruit pulp had a composition like the work of [24].

Table 1. Biochemical and energetic characteristics of the raw materials.

Raw materials	Biochemical (%) and energetic* characteristics									
	Dry matter	Moisture	Ash	Lipids	Proteins	Fiber	Carbohy-drates	Energy (Kcal)*	Vit C (µg/g)*	β-carotene (µg/g)*
Fonio control	94.7b ± 0.04	5.1b ± 0.04	0.7d ± 0.003	1.3d ± 0.03	7.8c ± 0.23	2c ± 0.14	80.4a ± 0.2	374c ± 0.36	119.5d ± 0.8	6.3c ± 0.01
Bambara groundnut control	97.5a ± 0.03	2.8d ± 0.03	3.5b ±0.03	6.5b ± 0.04	22.1a ± 0.1	3.8b ± 0.27	61.6c ± 0.36	393.7b ± 1.32	160.4c ± 0.8	5.7d ± 0.03
African locust bean fruit pulp	89.8c ± 0.07	10.2a ± 0.07	5.6a ± 0.08	2c ± 0.1	6.3d ± 0.19	11.5a ± 0.17	64.4b ± 0.08	300.8d ±1.1	644.6a ± 0.9	88.7a ± 0.04
Cashew kernel	97.2a ± 0.03	2.8c ± 0.03	2.6c ± 0.01	48.5a ± 0.35	20.8b ± 0.42	2c ± 0.02	23.3d ± 0.56	612.7a ± 1.9	488.2b ± 0.6	16.1b ± 0.01

Mean values _ standard deviations from three replicate analyses. Mean values followed by the same letter in the same column are not significantly different at P < 0.05. * mean % not applicable the component.

3.2. Mineral Composition of the Raw Materials

Table 2 presents the mineral composition of the raw materials (fonio, Bambara groundnut, cashew kernel and African locust bean fruit pulp). African locust bean fruit pulp had the highest potassium content (1392 mg/100 g) compared *to* Bambara groundnut, cashew kernel, and fonio, whose contents were respectively 1105, 600.8, and 91.2 mg/100 g. Bambara groundnut and African locust bean fruit pulp had the highest sodium contents, but their values were not significantly different at the 5% threshold, at 617.1 and 704.1 mg/100 g, respectively. Fonio had the lowest sodium content with 61.9 mg/100 g. Cashew kernel and fonio were rich in iron content with 12.2 and 11 mg/100g, respectively. However, Bambara groundnut and African locust bean fruit pulp had the lowest iron content, with 4.5 and 3.7 mg/100g, respectively. Bambara groundnut was richer in copper content, with 52.2 mg/100 g, than fonio, African locust bean fruit pulp, and cashew kernel, whose contents were 31.3, 30, and 4.5 mg/100 g, respectively. Phosphorus content was more abundant in cashew kernel (494.8 mg/100 g) than those of Bambara groundnut, fonio, and African locust bean fruit pulp, which were 283.9, 136.7, and 101.7 mg/100 g, respectively. Bambara groundnut was richer in zinc content with 22.2 mg/100 g than that of African locust bean fruit pulp, fonio, and cashew kernel, whose compositions were 13.1, 1, and 9.4 mg/100 g, respectively. Cashew kernel and fonio had the highest calcium contents but were not significantly different at the 5% threshold (1168 and 1100 mg/100 g). The cashew kernel was richer in magnesium content (279.6 mg/100 g). African locust bean fruit pulp and Bambara groundnut had the lowest magnesium contents, which were 178 and 170.6 mg/100 g, respectively. These values were not significantly different at the 5% level. The mineral composition of the control African locust bean fruit pulp was like that of the [22] study. Fonio had a mineral composition like the two (2) ecotypes studied by [4]. The cashew kernel had a composition like that obtained by [23].

Table 2. Mineral composition of raw materials.

Raw materials	Mineral composition (mg/100 g)							
	K	Na	Fe	Cu	P	Zn	Ca	Mg
Fonio control	91.2d ± 0.01	61.9d ± 0.2	109.1b ± 0.08	31.3b ± 0.1	136.7c ± 0.1	10c ± 0.2	1100a ± 0.3	233.8b ± 0.1
Bambara groundnut *control*	1105b ± 0.1	617.1a ± 0.1	4.5c ±0.7	52.6a ± 0.7	283.9b ± 0.3	22.2a ± 0.02	865b ± 0.1	170.6c ± 0.1
African locust bean fruit pulp	1392a ± 0.3	704.1a ± 0.08	3.7d ±0.01	30b ± 0.01	101.7d ± 0.4	13.1b ± 0.01	882b ± 0.1	178.9c ± 0.3
Cashew kernel	60.08c ± 0.3	415c ± 0.4	12.2a ± 0.01	45.5c ± 0.01	494.8a ±0.4	9c ± 0.01	1168a ± 0.4	279.6a ± 0.4

Mean values _ standard deviations from three replicate analyses. Mean values followed by the same letter (a, b, c, d) in the same column are not significantly different at P < 0.05.

3.3. Effect of Pre-Treatments on Biochemical Composition

Fermentation has a significant effect on the biochemical composition of fonio and Bambara groundnut flours (as shown in Table 3). During fermentation, there was a noticeable increase in the dry matter content of fonio and Bambara groundnut, with an increase from 94.7% to 97.5% for fonio and from 97.5% to 99% for Bambara groundnut. Moreover, there was a significant increase in the protein content of both flours. After 48 hours of soaking, the protein content of fonio increased from 7.8% to 8.7%, while that of Bambara groundnut increased from 22.1% to 25.4%. Bambara groundnut had the highest protein content (25.4%), which is like the protein content of Bambara groundnut *flours* soaked for 0 - 72 hours, as reported by [25]. The increase in protein content could be attributed to the optimal time of 48 hours for fermentation, which allowed for the release of more free amino acids and reduced the metabolism use of microflora proteins. This finding is consistent with previous research on fermented cereals and legumes, where dormant proteolytic enzymes were activated during fermentation, leading to the hydrolysis of proteins and the release of more free amino acids [26].

During the fermentation of fonio, the fiber content decreased significantly from 2% to 0.7% after 48 hours in the control group. This reduction in total fiber content is a common trend observed in the fermentation of cereals, as reported by [27] and [28] during the fermentation of barley. The decrease in fiber content can be attributed to enzymatic fiber degradation by microorganisms which produce extracellular enzymes that hydrolyze and metabolize insoluble polysaccharides [29]. However, there is an increase in fiber content during the fermentation of voandzou, which increases from 3.8% to 4.7%. During the fermentation of fonio, a significant increase in carbohydrate content was observed, with the carbohydrate level increasing from 82.7% to 86.3% in the control group after 48 hours soaking. [30] reported a similar increase in carbohydrate content in fermented millet between 16 and 20 hours. This increase in carbohydrate content could be due to the low pH, which inhibits amylase activity and reduces starch degradation [31], or the presence of inhibiting amylotic enzymes such as tannins.

Table 3. Table type styles (Table caption is indispensable).

Raw materials	Biochemical (%) and energetic* characteristics									
	Dry matter	Moisture	Ash	Lipids	Proteins	Fiber	Carbohydrates (%)	Energy (Kcal)	Vit C (μg/g)	β-carotene (μg/g)
Fonio control	94.7g ± 0.04	5.1b ± 0.04	0.7d ± 0.003	0.9g± 0.03	7.8e ± 0.23	2e ± 0.14	80.4b ± 0.2	374e ± 0.36	119.5h ± 0.8	6.3a ± 0.01
Fonio 24 h	97.2f ± 0.01	2.7c ± 0.08	0.4d ± 0.01	1.6e ± 0.04	8.4d ± 0.18	1.4e ± 0.1	80.5b ± 0.08	390.8d ± 0.16	285.9e ± 0.9	6.5a ± 0.01
Fonio 36 h	98.2d ± 0.01	1.8d ± 0.08	0.5d 0.01	1.4f ± 0.04	8.8d ± 0.19	1.2ef ± 0.1	86.5a ± 0.32	393.1cd ± 1.8	531.5b ± 0.9	5.6c ± 0.01
Fonio 48 h	97.5b ± 0.01	0.9e ± 0.01	3.3b ± 0.01	1.4f ± 0.03	8.7d ± 0.19	0.7f ±0.01	86.5a ± 0.32	393.1cd ± 1.8	737.6a ± 1.3	6.5a ± 0.02
Sprouted Fonio	90.8h± 0.07	9.2a ± 0.08	1.1c ± 0.01	2.7d ± 0.08	6.8f ± 0.37	1.7de ± 0.04	78.4c ± 0.46	365f ± 0.23	214.3F ± 0.9	6b ± 0.01
Bambara groundnut control	97.5e ± 0.03	2.8c ± 0.03	3.5a ± 0.03	6.5c ± 0.04	22.1c ± 0.1	3.8c ± 0.27	61.6d ± 0.36	393.7c ± 1.32	160.4g ± 0.8	5.7c ± 0.03
Bambara groundnut 24 h	98.7c ± 0.01	1.6d ± 0.03	3.5a ± 0.02	7.1b ± 0.06	24.4b ± 0.27	4bc ± 0.4	59.6e ± 0.6	400.5b ± 1.4	276.2e ± 1.1	4.9d ± 0.01
Bambara groundnut 36 h	99.9a ± 0.02	0.1f ± 0.02	3.6a± 0.05	7.3a ± 0.03	25.3a ± 0.3	4.5ab ± 0.33	59.2ef ± 0.06	403.7a ± 1.3	339.2d ± 0.8	1.9f ± 0.01
Bambara groundnut 48 h	99b ± 0.01	0.9e ± 0.01	3.3b ± 0.08	7.3a ± 0.02	25.4a ± 0.2	4.7a ± 0.13	58.4f ± 0.21	400.8b ± 0.36	369.9c ± 0.7	2.9e ± 0.02

Mean values _ standard deviations from three replicate analyses. Mean values followed by the same letter (a, b, c, d) in the same column are not significantly different at P < 0.05. * mean % not applicable the component.

Fermentation, on the other hand, led to a reduction in the level of carbohydrates in the voandzou, which fell from 61.6% to 58.4%. Xiao *et al.*, 2018 found similar results when fermenting kidney beans (Phaseolus angularis). [32] also found a drop in carbohydrate levels during the fermentation of *Phaseolus vulgaris*. This decrease could be attributed to the fact that the microorganisms use carbohydrates as an energy source during fermentation. Fermentation caused a significant increase in the lipid level in both voandzou and fonio. In fact, the lipid rate went from 0.9% to 1.4% for fonio and from 6.5% to 7.1% for voandzou. [33] and [34] obtained similar results during the fermentation of *sweet potatoes* for some and red beans for others.

Similarly, the energy value of fonio and Bambara groundnut increases during fermentation, as reported by [32] in their study on *Moringa oleifera* seeds. The increase in energy value in both fonio and voandzou could be because there is an increase in the lipid level during the fermentation of fonio and voandzou. Fermentation also leads to an increase in vitamin C content, with the highest levels found at 48 hours of fonio's fermentation (737.6 μg/g) and the lowest at 119.5 μg/g. Bambara groundnut fermentation leads to an increase in vitamin C. This increase in vitamin C content is consistent with the results of studies on the fermentation of hybrid amaranth leaves [35].

The *β*-carotene content remains stable during fonio fermentation whereas it decreases during voandzou fermentation. [36] and [37] also obtained a reduction in *β*-carotene during fermentation.

The germination of fonio seeds results in a significant reduction in dry matter from 94.7% to 90.8%. Additionally, with a water content of 9.2%, sprouted fonio flour has a higher moisture content than all compared fermented fonio flours. This significant increase in moisture content could be attributed to the activation of a wide range of enzyme systems during the hydration process, which hydrolyzed and solubilized food reserves [38]. Moreover, germination leads to a significant increase in lipid content in fonio seeds, as observed in previous studies [39]. This increase could be explained by the early stages of seed development, during which lipids were practically devoid of triglycerides. Seeds develop with a rapid increase in triglyceride synthesis, leading to an increase in lipid content. In contrast, germination significantly reduces the protein content of fonio flour from 7.8% to 6.2% in the control compared to germinated fonio, as reported by [35] and [40]. These researchers found that germination led to pronounced metabolic changes in seeds, resulting in the modification of the structural profile of various organic components. [41] explained that protein is one of the major sources of energy for germ development. During germination, proteins are hydrolyzed into simple peptides and amino acids by protease activity and transported to the developmental axis [42]. Lastly, a significant drop in carbohydrate content was observed in sprouted fonio flour due to metabolism. During germination, carbohydrates in fonio seeds may have been digested into simple sugars by amylolytic enzymes, which were then absorbed by the growing germ as an energy source [43]. Germination also leads to a significant increase in vitamin C content, which increases from 111 µg/g in the control to 214.3 µg/g.

3.4. Effect of Pretreatments on Mineral Composition

The mineral composition of raw materials was evaluated after pretreatments, and the results are presented in **Table 4**. The highest zinc rate was found in the control Bambara groundnut with 22.2 mg/100g, while the flours from fonio grains soaked for 48 h and 36 h had the lowest rate at 0.7 mg/100g. The highest levels of calcium (1233 mg/100g) and magnesium (264 mg/100g) were found in sprouted fonio, whereas the control Bambara groundnut had the lowest rate of calcium (865 mg/100g) and magnesium (170.6 mg/100g). Fermentation of Bambara groundnut led to a significant increase in iron (45.5 - 61.1 mg/100g), copper (52.6 - 63.5 mg/100g), magnesium (170.6 - 229.1 mg/100g), and calcium (865 - 913 mg/100g). However, during the fermentation of the African locust bean fruit pulp, there was a decrease in the sodium level (617.1 - 506.9 mg/100g). Like [44], a drop in sodium level was observed during the fermentation of three varieties of sorghum. Fermentation of Bambara groundnut had no significant effect on potassium. The fermentation of fonio led to an increase in the rate of sodium and phosphorus. The increase in certain minerals in fermented samples may be due to the release of minerals bound to other compounds such as anti-nutrients by the microorganisms responsible for fermentation [45]. The mineral contents of fonio grain flours soaked for 24 and 48 hours were higher than those reported by [46]. Germination significantly increased the content of sodium, phosphorus, calcium, and magnesium. This increase could be explained by the fact that germination enhances the retention of these minerals [47] [48]. However, germination induced a drop in iron levels. The reduction of other minerals could be due to their leaching in the steeping water during the germination process [49].

Table 4. Effect of the pretreatment on the mineral composition.

Raw materials	Mineral composition (mg/100g)							
	K	Na	Fe	Cu	P	Zn	Ca	Mg
Fonio control	9.1b ± 0.01	61.9c ± 0.2	11a ± 0.08	31.3f ±0.1	136.7e ± 0.1	10e ± 0.2	1100bc ±0.3	233.8b ± 0.1
Fonio 24 h	7b ± 0.2	61.8c ± 0.1	11.5a ± 0.01	43d ±0.2	109.1f ± 0.3	8f ± 0.01	1080bc ±0.1	197.2c ± 0.06
Fonio 36 h	6.6b ± 0.1	63c ± 0.1	11a ± 0.2	50c ± 0.2	369.2g ± 0.1	7f ± 0.01	1080c ± 0.3	190.2d ± 0.06
Fonio 48 h	26b ± 0.06	62.9c ±0 .08	11a ± 0.1	53.6b ± 0.1	371.7a ±0.3	7g ±0.01	1173ab ±0.06	177.6d±0.1
Sprouted Fonio	15b ± 0.4	120.4d ± 0.4	8.5b ±0.06	37e ±0.06	242.4d ± 0.08	8f ± 0.01	1233a ± 0.4	264a ± 0.4
Bambara groundnut control	110.5a ± 0.1	617.1a ± 0.1	45.5g ± 0.7	52.6bc ± 0.7	283.9c ±0.3	22.2a ± 0.02	865c ± 0.1	170.6d ± 0.1
Bambara groundnut 24 h	109.7a ± 0.3	538.2ab ± 0.1	55.5f ± 0.06	54.1b ±0.4	277c ± 0.06	19.1c ± 0.2	903d ± 0.3	201.8c ± 0.1
Bambara groundnut 36 h	113.2a ± 0.1	373.8b ± 0.7	55.5f ± 0.01	51.4bc ± 0.1	296.4b ± 0.7	20.4b ± 0.1	906d ±0.1	238.7b ± 0.1
Bambara groundnut 48 h	111a ± 0.08	506.9ab ± 0.3	61.1c ± 0.01	63.5a ± 0.01	371.7a ± 0.3	18.2d ± 0.7	913d ± 0.1	229.1b ± 0.7

Mean values _ standard deviations from three replicate analyses. Mean values followed by the same letter (a, b, c, d) in the same column are not significantly different at P < 0.05.

3.5. Formulation of Mixed Flours

The different combinations of the raw materials, along with their respective soaking times, are presented in **Table 5**. The control fonio and Bambara groundnut were combined with African locust bean fruit pulp and cashew kernel to produce F0 flour. Subsequently, each fonio flour obtained at different soaking times was mixed with each Bambara groundnut flour obtained at different soaking times. Finally, the mixture was supplemented with African locust bean fruit pulp and cashew kernel. The best-performing combinations are listed in **Table 5**.

Table 5. Formulation of flours

Flours	Formulation flours
	Ingredients combination **(%)**
F0:	Fonio 2 h (54%) +Bambara groundnut 8 h (28%) + African locust bean fruit pulp (8%) + cashew kernel (10%)
F1:	Fonio 24 h (59%) +Bambara groundnut 24 h (20%) + African locust bean fruit pulp (6%) + cashew kernel (15%)
F2:	Fonio 36 h (44%) +Bambara groundnut 48 h (23%) + African locust bean fruit pulp (23%) + cashew kernel (10%)

Continued

F3:	Fonio 48 h (42%) +Bambara groundnut 24 h (25%) + African locust bean fruit pulp (23%) + cashew kernel (10%)
F4:	Fonio 48 h (42%) +Bambara groundnut 36 h (25%) + African locust bean fruit pulp (23%) + cashew kernel (10%)
F5:	Fonio 24 h (41%) + Bambara groundnut 24 h (25%) + African locust bean fruit pulp Pulp (11%) + cashew kernel (15%) + sprouted fonio (8%)

3.6. Biochemical Composition and Energy Value of Composite Flours

Table 6 presents the biochemical and energy composition of the formulated infant flour. The dry matter content in the flour ranges from 92.4% to 97.3%, with the lowest dry matter content observed in F3 and the highest in F1. The moisture content in the fermented composite flours and sprouted flour varies from 2.7% to 7.5%. These moisture contents are lower than those found in the fermented infant flours of [50], whose moisture contents range from 10% to 10.70%. Of the flours studied, those produced from fermented seeds F0 and F1, as well as the sprouted compound flour F5, have water contents of 4.5%, 2.7%, and 5.2%, respectively, which meet the standard of 5% or less in infant flour established by [35]. F2 and F4 have the highest water contents, which are not significantly different (7% and 7.1%). Flours F0, F1, and F5 are expected to have a longer shelf life than the others because a large amount of water in the flour can compromise its shelf life. In fact, water promotes the growth of microorganisms that produce amylase, which is necessary for starch hydrolysis in flours, and this facilitates the acidification of the flours [51]. The ash content of the infant flour varies from 1.7% to 2.5%. Fermented composite flours F2, F3, and F4, as well as germinated composite flour F5, have the highest ash content and are not significantly different from each other. F1 has the lowest ash content (1.7%). The analyzed formulations of infant flours showed a lipid content ranging from 7.2% to 8.1%, with F4 having the lowest and F1 having the highest lipid content. These levels fall within the range of 7% - 9% recommended by [52] for infant flours. The lipid content in this study is lower than that reported by [53], whose values ranged from 12.76 to 14.59%. Although high-fat flours provide high energy, they are prone to hydrolytic and oxidative rancidity, which affects both the taste and storage stability of the product [54]. The low fat content in the flours analyzed may enhance their storage stability, if they are packaged properly. The protein content of the compound flours ranged from 12.7% to 13.4%, with the highest content found in the control formulation. These values are lower than those reported by [55], whose protein levels of fermented and roasted flours varied from 18.58% to 25.74%. However, the protein levels in the current study fall within the [52] recommended range of 12% - 15% for infant flour. The higher protein content observed in the sprouted compound flour may be attributed to the combined contribution of the soaked bambara groundnut and cashew almond. The fiber content of the formulations ranged from 3.1% to 4.7%, with the lowest content found in fermented compound flour F1 and the highest in fermented compound flour F2. These values are higher than those reported by [55], ranging from 0.54% to 0.86%. The fiber levels observed in this study are consistent with [56] recommendations of less than 5%. A low fiber content in complementary diets reduces food bulk and promotes the high digestibility and absorption of nutrients such as proteins and minerals. This encourages children to consume the food samples to meet their daily energy and essential nutrient requirements [57]. The carbohydrate flour composition in the formulations varied from 65.9% to 72.7%. The rates of the various flours tested in this study are like those found in a previous study by [55] which reported rates of 57.14% - 71.4%. The F0 flours and compound flour that were germinated had carbohydrate content percentages of 68.5% and 68.1%, respectively, which comply with [52] standards of [68% - 70%] for infant flours. The energy content of the formulated flours ranged from 382.8 to 410.7 kcal. Except for fermented mixed flour F1, the other fermented composite flours had lower energy values than the germinated composite flour F5. The flours F1 with an energy value of 410.7 kcal meet [56] standards of [400 - 425 kcal]. The vitamin C content of the flours varied from 149 to 973.6 µg/g, with the control having the lowest level and the fermented composite flour F1 having the highest. The germinated composite flour had a vitamin C content of 509.9%. Vitamin C is a reducing agent and a powerful antioxidant that can limit the harmful effects of free radicals. It also facilitates the absorption of non-heme iron from plant foods [58]. The β-carotene content of the flours ranged from 10.1 to 30.5 µg/g. Carotenoids are involved in many biological processes, including photosynthesis, vision, and free radical scavenging, due to their ability to dissolve in fat [59] [60].

Table 6. Biochemical and energy composition of the formulated flours.

Flours	Biochemical (%) and energetic* characteristics									
	Dry matter	Moisture	Ash	Lipids	Proteins	Fiber	Carbohydrates (%)	Energy* (Kcal)	Vit C* (µg/g)	β-carotene* (µg/g)
F0	95.5b ± 0.15	4.5d ± 0.15	2.1b ± 0.11	7.6d ± 0.06	13.4a ± 0.10	3.9b ± 0.06	68.5b ± 0.23	395.8b ± 1.1	149e ± 0.8	13.3d ± 0.1
F1	97.3a ± 0.03	2.7e ± 0.03	1.7c ± 0.01	8.1a ± 0.1	12.7c ± 0.29	3.1d ± 0.13	72.7a ± 0.39	410.7a ± 0.8	498.3d ± 0.7	10.1e ± 0.06
F2	93d ± 0.08	7b ± 0.08	2.5a ± 0.01	7.4e ± 0.04	12.2d ± 0.13	4.7a ± 0.13	66.3d ± 0.21	380.2d ± 0.7	572.9c ± 0.5	30.5a ± 0.02
F3	92.4e ± 0.14	7.5a ± 0.14	2.4a ± 0.06	7.9b ± 0.04	12.3d ± 0.03	3.9b ± 0.11	65.9d ± 0.07	384.2c ±0.35	852.2b ± 0.9	27.5b ± 0.02
F4	92.9d ± 0.06	7.1a ± 0.06	2.4a ± 0.04	7.2f ± 0.02	12.6cd ± 0.16	3.8b ± 0.05	66.9c ± 0.13	382.8c ±0.25	973.6a ± 0.4	27.3b ± 0.03
F5	94.8c ± 0.09	5.2c ± 0.09	2.5a ± 0.06	7.7c ± 0.09	13.1b ± 0.17	3.4c ± 0.07	68.1b ± 0.4	394.4b ± 0.7	509.9d ± 0.7	19.8c ± 0.02

Mean values _ standard deviations from three replicate analyses. Mean values followed by the same letter (a, b, c, d, e) in the same column are not significantly different at P < 0.05. * mean % not applicable to the component. with; **F0**: Fonio 2 h (54%) + Bambara groundnut 8h (28%) + African locust bean fruit pulp (8%) + cashew kernel (10%); **F1**: Fonio 24 h (59%) + Bambara groundnut 24 h (20%) + African locust bean fruit pulp (6%) + cashew kernel (15%); F2: Fonio 36 h (44%) +Bambara groundnut 48 h (23%) + African locust bean fruit pulp (23%) + cashew kernel (10%); **F3**: Fonio 48h (42%) +Bambara groundnut 24 h (25%) + African locust bean fruit pulp (23%) + cashew kernel (10%); **F4**: Fonio 48 h (42%) +Bambara groundnut 36 h (25%) + African locust bean fruit pulp (23%) + cashew kernel (10%); **F5**: Fonio 24 h (41%) + Bambara groundnut 24 h (25%) + African locust bean fruit pulp (11%) + cashew kernel (15%) + sprouted fonio (8%).

3.7. Mineral Composition of Composite Flours

Table 7 displays the mineral composition of the mixed flours. The potassium levels range between 199.1 and 552.1 mg/100 g, with the fermented flour composed of F2 having the lowest content, and the germinated flour mixed F5 having the highest. However, the potassium level of the germinated composite flour is lower than that of [11]. Only flour F0, with a value of 514.4 mg/100 g, has a potassium content substantially equal to the recommended standard of 516 mg/100 g according to [56]. The sodium content ranges from 175 to 250.9 mg/100 g, with F0 having the lowest content and F4 having the highest. The sodium contents of the fermented F1 and germinated F5 composite flours are not significantly different from the control, while fermented flours F3 and F4 have significantly higher sodium levels than the control. The sodium levels of the whole flours are higher than those of [11], but all flours have sodium levels below the standard of 296 mg/100 g, according to [56]. The iron content of the flours ranges between 62.2 and 76.3 mg/100 g. The germinated composite flour has about the same amount of iron as the unmodified flour, but all fermented compound flours have more iron than the unmodified flour. All the flours have more iron than the WHO standard of 16 mg/100 g [56]. The copper content ranges from 33.9 to 70.7 mg/100 g. The flour with the lowest copper content is F0 and the flour with the highest copper content is F5. F3 and F4 have more copper than the unmodified flour, but all the copper levels are below the WHO standard of 160 mg/100 g [56]. The phosphorus content ranges from 195.1 to 242.5 mg/100 g, with the lowest content in F3 and the highest in F0. The fermented and sprouted composite flours have less phosphorus than the unmodified flour and the WHO standard of 456 mg/100 g [56]. However, these levels are similar to the phosphorus content in some artisanal infant flours from Cameroon [61] which have between 177.7 and

Table 7. Mineral composition of compound flours.

Raw materials	Mineral composition (mg/100g)							
	K	Na	Fe	Cu	P	Zn	Ca	Mg
F0	514.4b ± 0.06	175d ± 0.1	62.4c ± 0.2	33.9d ± 0.06	242.5a ± 0.08	5.2a ± 0.06	978.6a ± 0.08	229.8a ± 0.08
F1	452.6c ± 0.5	180.7d ± 0.08	78.3a ± 0.1	34.7d ± 0.06	206.9c ± 0.5	4.8b ± 0.5	846.1bc ±0.1	228.1a ± 0.4
F2	199. 1f ± 0.4	199.1c ± 0.08	76.3a ± 0.5	45c ± 0.2	231.1b ± 0.1	3.6c ± 0.4	981.3a ± 0.2	216.5a ± 0.4
F3	211.4e ± 0.5	211.4b ± 0.4	67.2b ± 0.2	46.4bc ± 0.5	195.1d ± 0.4	4.7b ± 0.06	883b ± 0.5	222a ± 0.5
F4	250.9d ± 0.2	250.9a ± 0.06	66.1b ± 0.5	47.4b ± 0.2	203.5d ± 0.08	2.7d ± 0.1	784.5c ± 0.5	219.6a ± 0.1
F5	552.1a ± 0.1	177.9d ± 0.08	62.2c ± 0.2	70.7a ± 0.2	225.6b ± 0.06	2.9d± 0.06	852.3bc ± 0.08	229.9a ± 0.2

Mean values _ standard deviations from three replicate analyses. Mean values followed by the same letter in the same column are not significantly different at P < 0.05. with; **F0**: Fonio 2 h (54%) + Bambara groundnut 8 h (28%) + African locust bean fruit pulp (8%) + cashew kernel (10%); **F1**: Fonio 24 h (59%) + Bambara groundnut 24 h (20%) + African locust bean fruit pulp (6%) + cashew kernel (15%); F2: Fonio 36 h (44%) + Bambara groundnut 48 h (23%) + African locust bean fruit pulp (23%) + cashew kernel (10%); **F3**: Fonio 48 h (42%) + Bambara groundnut 24 h (25%) + African locust bean fruit pulp (23%) + cashew kernel (10%); **F4**: Fonio 48 h (42%) + Bambara groundnut 36 h (25%) + African locust bean fruit pulp (23%) + cashew kernel (10%); **F5**: Fonio 24 h (41%) + Bambara groundnut 24 h (25%) + African locust bean fruit pulp (11%) + cashew kernel (15%) + sprouted fonio (8%).

281.6 mg/100 g. Phosphorus is important for energy production, bone and tooth health, and forms calcium phosphate, which is important for bone strength [62]. The zinc content ranges from 2.7 to 5.2 mg/100 g. The composite flours from fermented seeds have less zinc than the unmodified flour but more than the WHO standard of 3.2 mg/100 g [56]. Zinc, along with iron, is one of the most concentrated minerals in the brain, which is important for infant brain growth. Zinc is also important for immunity and can reduce the incidence and severity of children's diarrhea [63]. The calcium content of the flours ranges from 784.5 to 978.6 mg/100 g. The fermented and sprouted composite flours have less calcium than the unmodified flour but more than the WHO standard of 500 mg/100 g [56]. The control and fermented and germinated mixed flours have higher magnesium contents than the WHO standard of 76 mg/100 g [64].

3.8. Swelling Power and Solubility of Formulations

Table 8 presents the swelling power and solubility of the different formulations. The swelling power of the composite flours ranges from 7.1 to 12.7 ge/gMS. F5, which is the germinated composite flour, has the lowest swelling power, while the fermented flour F3 has the strongest power. It is worth noting that all these flours have greater swelling powers than infant flours made of plantain banana and cashew kernel, whether fermented or not [21]. On the other hand, the solubility index ranges from 14.5 to 25.2%, with the lowest index observed for the control flour and the highest index for the fermented compound flour F3. These solubility indices are like those reported in previous works [21].

Table 8. Swelling power and solubility of formulated flours.

Raw materials	Biochemical and energetic characteristics	
F0	11.4ab ± 0.7	14.5b ± 0.9
F1	10.7b ± 1.2	15.1b ± 0.8
F2	12.7a ± 0.08	23.4a ± 0.08
F3	12.3ab± 0.2	25.1a ± 0.06
F4	12.1ab ± 0.2	25.2a ± 1.2
F5	7.1c ± 0.1	16b ± 0.8

Mean values _ standard deviations from three replicate analyses. Mean values followed by the same letter in the same column are not significantly different at $P < 0.05$. with; **F0**: Fonio 2 h (54%) + Bambara groundnut 8 h (28%) + African locust bean fruit pulp (8%) + cashew kernel (10%); **F1**: Fonio 24 h (59%) + Bambara groundnut 24 h (20%) + African locust bean fruit pulp (6%) + cashew kernel (15%);F2: Fonio 36 h (44%) + Bambara groundnut 48 h (23%) + African locust bean fruit pulp (23%) + cashew kernel (10%); **F3**: Fonio 48 h (42%) + Bambara groundnut 24 h (25%) + African locust bean fruit pulp (23%) + cashew kernel (10%); **F4**: Fonio 48 h (42%) + Bambara groundnut 36 h (25%) + African locust bean fruit pulp (23%) + cashew kernel (10%); **F5**: Fonio 24 h (41%) + Bambara groundnut 24 h (25%) + African locust bean fruit pulp (11%) + cashew kernel (15%) +sprouted fonio (8%).

4. Conclusion

In conclusion, it is worth noting that spontaneous fermentation led to an increase in protein content of fonio and bambara groundnut flours, while germination resulted in an increase in lipid levels in fonio flour. The pretreatments caused changes in the composition of the raw materials, thus improving the nutritional value of the simple flours. The resulting formulations made from these simple flours met the WHO standards for infant flours, especially in terms of protein, lipid, carbohydrate, fiber, and moisture contents. Fermentation, followed by roasting and germination, helped to further improve the nutritional value of the formulations to produce flours in accordance with international standards. These composite flours could, therefore, play a crucial role in providing adequate nutrition to children if they are introduced at the right time during weaning, thus reducing child malnutrition. To further ensure that the nutrients in the formulations are well absorbed, it would be useful to conduct an analysis of anti-nutrients. All formulations (F0 to F5) met FAO/WHO standards for fat, protein, and fiber content. However, only F0, F1, and F5 composite flours complied with the FAO/WHO recommendations for moisture content in infant flours. In addition, F0 and F5 formulations also complied with FAO/WHO standards for carbohydrate content. It is found that the formulations made from simple flours from fermented or sprouted seeds, along with cashew kernel and African locust bean fruit pulp, made it possible to obtain infant flours based on fonio enriched with voandzou that meet FAO/WHO standards for protein, lipid, carbohydrate, fiber, and moisture content. These compound flours could, therefore, help address infant malnutrition if introduced at the right time during weaning. This study could be further supplemented by an analysis of anti-nutritional factors.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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