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Biochemical, rheological properties and microbiological loads of some infant flours formulated from local products from Côte d'Ivoire

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Abstract

Most of the infant flours produced in Ivory Coast are of poor nutritional quality. The objective of this study is to formulate infant flours with good nutritional quality. Thus, eight infant flours (F1, F2, F3, F4, F5, F6, F7 and F8) differing in their raw material composition were formulated. These flours were formulated with local products such as sorghum, fonio, sweet potato, cashew kernel, voandzou and néré pulp. The biochemical, the rheological and the microbiological characteristics of these flours were evaluated and compared to that of a control flour which is a commercial infant flour (T). The results showed high protein contents for the control and Flour F1 (14.3%), high lipid contents for flour F8 (8.7%), high carbohydrate contents for flour F7 (68.4%) and high fiber contents for flour F5 (9.8%). Flour F2 is the most energetic (415.8 Kcal). Regarding rheological properties, the solubility index varied between 11.7 and 19.6% with the lowest index for flour F6 and the highest for the control (T). The swelling power of the composite flours varied from 6.9 to 9.1 ge/gMS with the lowest value for the F2 formulation and the highest value for the control. Regarding the microbiological quality, the load for the total flora is between 103 and 68.6.10^3 CFU/g with the lowest load for the control and the highest for F5. As for the yeast and mold load, it is between 10^2 and 31.6.10^2 CFU/g with the lowest load for F2 and the highest for the control.

Keywords: Formulation; Rheological Properties; Biochemical Properties; Microbiological Parameters

1. Introduction

Exclusive breastfeeding is a cornerstone of child survival and health. It provides essential and irreplaceable nutrition for child growth, resilience and development. It is the first vaccination of the child. It protects against respiratory infections, diarrheal diseases and other life-threatening conditions and prevents obesity [1]. According to WHO [1], early initiation of exclusive breastfeeding for the first six months of life and continuation of breastfeeding for two years or beyond is recommended, along with appropriate, adequate and safe complementary foods.

From the age of 6 months, breast milk becomes qualitatively and quantitatively insufficient for the infant whose nutritional needs are increasing [2]. This is when malnutrition begins in many infants, contributing significantly to the high prevalence of malnutrition in children under five years of age worldwide [3]. Children malnutrition is a public health problem worldwide, particularly in developing countries [4]. Complementary foods should be added to children's diets when breast milk is no longer sufficient to meet their nutritional needs. The transition from exclusive breastfeeding to family feeding (complementary feeding) generally covers the period from 6 to 24 months [5]. This period is very vulnerable. The quality of complementary foods used during this period is therefore of great importance. Infant flour is part of the generic group of complementary foods which designate any food intake other than breast milk given to infants or young children, with a view to fully meeting their nutritional needs [5].

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In Africa, during weaning, mothers generally feed their children with traditional porridges prepared from simple or compound flours from cereals and tubers. These cereals and tubers are foods rich in carbohydrates and low in protein [6]. Some raw materials such as sorghum, fonio, voandzou, cashew nuts, sweet potato and néré could play an important role in improving the nutritional quality of infant flours. Unfortunately, these raw materials are neglected or are very little used in the formulation of complementary foods.

Drought-resistant, traditional cereals are well adapted to local climatic conditions and contribute to environmental preservation by providing plant cover for poor, ecologically fragile soils [7]. In addition, these cereals have good nutritional values. Sorghum has a composition comparable to that of other naked cereals. It contains 84% carbohydrates, 3.5% lipids, 11% proteins and 1.2% minerals [8]. Among traditional cereals, fonio is very little used in the production of supplementary flours despite its socio-cultural, nutritional and economic importance [9]. It has the potential to improve nutrition, while contributing to food security and sustainable land use [10; 11]. In terms of nutritional composition, fonio contains 6.9% protein, 2.10% fat, 87.48% carbohydrates, 1.02% crude fiber and 2.44% mineral salts [12].

At the level of local legumes, voandzou (*Vigna subterranea*) is mainly grown by farmers as a "bridging crop" because it has several natural agronomic advantages, including drought tolerance [13]. Voandzou is composed of approximately 20% protein, 6% lipid, 61% carbohydrate, 3% fiber, and 4% ash [14]. The proteins contained in voandzou seeds have a high lysine content, and their association with cereals in the diet provides a nutritional supplement for many local populations who cannot afford the high costs of animal protein [15]. Unfortunately, it is very little used for the formulation of complementary foods.

Sweet potato is also one of the most underutilized crops of the main crops in developing countries [16]. According to the work of Owori et al [17], sweet potato tubers are an excellent source of carbohydrates (96%), in the form of simples carbohydrates and dietary fiber, which play a key role in energy deficiencies. In addition to its carbohydrates, sweet potato is a good source of vitamins (A, C, E and those of group B) and minerals (Zinc, Sodium, Potassium and Calcium) essential for the proper functioning of the human body.

Another crop that adapts well to the climatic conditions of sub-Saharan Africa is the cashew tree. Indeed, the cashew tree is a resistant species, known for its adaptability and tolerance to pest attacks. According to Nascimento et al [18], cashew nuts are a good source of protein (20-24g / 100g), carbohydrates (23-25g / 100g) and fat (40-57g / 100g). Cashew nuts are rich in essential unsaturated fatty acids that are beneficial for both the heart and arteries and therefore, prevent the formation of arteriosclerosis and hypertension [19]. Despite the nutritional benefits of cashew nuts, its food use is limited to snacks [20].

To properly cover the nutritional needs of children with flours, it is also important to know the biochemical composition, rheological properties and microbiological loads of these flours which constitute important aspects of the quality of these flours.

The general objective of this study is to provide populations with infant flours formulated from local Ivorian products and complying with international standards. Specifically, it will involve evaluating the biochemical and rheological characteristics of the flours on the one hand and the microbiological quality of the flours on the other.

2. Material

The local raw materials used in the formulation of infant flours are white sorghum (*Sorghum bicolor*), cream-colored voandzou (*Vigna subterranean*) with red spots, white fonio (*Digitaria exilis*), cashew kernel (*Anacardium occidentale*), sweet potato (*Ipomoea batatas*) with purple skin and white flesh, and néré pulp (*Parkia biglobosa*). The néré variety used is the one with long pods and yellow pulp. All these raw materials were purchased at the large market in Abobo.

3. Methods

3.1. Flour production

3.1.1. Fonio flour production

The production of fonio flours was carried out according to the method described by Koréissi et al [11]. The hulled fonio grains were sorted and winnowed to remove impurities and any physical hazards. Then, the sorted grains were moistened and pounded several times using a wooden mortar and then winnowed to obtain the whitening of the fonio grains. After whitening, the whitened fonio underwent washing-desanding to remove fine sand, bran particles and dust mixed with the whitened fonio grains. The washing-desanding process was repeated several times until all impurities were removed. The bleached fonio was soaked sequentially in distilled water for 2 hours for the control fonio ; then 24, 36 and 48 hours for the other samples for natural fermentation. After fermentation, the fonio grains were oven-dried at 50-60°C, then roasted at temperatures between 120 and 150°C. One (1) kg of sorghum grains was used for each sample. The flours obtained were sieved using a 50–300-micron mesh sieve. The flours were stored in labeled freezer bags and kept in the freezer.

3.2. Production of sorghum flour

The production of sorghum flours was carried out according to the method described by Koréissi et al [11]. The unhulled sorghum grains were sorted and winnowed to remove impurities and any physical hazards. Then, the sorted and moistened grains were hulled using a wooden mortar and winnowed. Then, the hulled sorghum underwent washing-desanding to remove stones, sand, bran particles and dust mixed with the hulled sorghum grains. The washing-desanding process was repeated several times until all impurities were removed. The hulled sorghum was soaked sequentially in distilled water for 2 hours for the control, then 24, 36 and 48 hours for the other samples for natural fermentation. After fermentation, the sorghum grains were oven dried at 50-60°C and then roasted at temperatures between 120 and 150°C. One (1) kg of sorghum grains was used for each sample.

Regarding the germination process, one (1) kg of unhulled sorghum was sorted and winnowed then soaked for 24 hours and spread inside a jute bag for 3 days away from light for germination. The sprouted grains were dried in an oven between 50 and 60°C. Degerming was done and the degermed grains as well as the other samples were ground separately using a multifunction grinder (Gaone, Grinder 2500 rp/w, 36000 rpm). The flours obtained were sieved using a 50 - 300-micron mesh sieve. The flours were stored in labeled freezer bags and kept in the freezer.

3.3. Production of voandzou flour

Voanzou flour was produced using the method described by Dialo et al [21].

The voandzou grains were sorted and winnowed to remove impurities and any physical hazards. The sorted grains were then washed several times and soaked sequentially, for 8 hours for the control sample; then 24, 36, and 48 hours for the other samples, for natural fermentation. After soaking, the wet voandzou grains were crushed with a wooden mortar to remove the seed coat. The seeds were then oven-dried at 50-60°C and roasted at temperatures between 120 and 150°C. The samples were ground separately using a multifunctional grinder (Gaone, Grinder 2500 rpm, 36,000 rpm). One (1) kg of voandzou grains was used for each sample. The flours obtained were sieved using a 50–300-micron mesh sieve. The flours were stored in freezer bags, labeled and kept in the freezer.

3.4. Production of cashew amond flour

The cashew amond flour produced was inspired by the method described by Sze-Tao and Sathe [22]. One (1) kg of shelled cashew kernels was washed and oven dried at 50-60°C. The dried almonds were ground for a short time (less than a minute) to avoid obtaining a paste due to the large amount of fat contained in the almonds. Grinding was done using a multifunction grinder (Gaone, Grinder 2500 rp/w, 36000 rpm). The flour obtained was sieved using a 50-300 μm mesh sieve. The flour was stored in labeled freezer bags and kept in the freezer.

3.5. Production of néré pulp flour

The production of the nere flour was carried out according to the modified method of Cissé et al [23].

The nere pods were cleaned and split. The seeds surrounded by the pulp were oven-dried at 50-60°C and then pounded in a wooden mortar without exerting excessive force so as to detach only the pulp without breaking the seeds contained within. Each sample was sieved using a sieve with a mesh size between 50 and 300 microns. The flour was stored in labeled freezer bags and kept in the freezer.

3.6. Production of sweet potato flour

Flour production was carried out using the modified method of Kabirou et al [24]. Sweet potato tubers were peeled, washed in hot water at 60°C and cut into thin slices of approximately 1mm thickness. The cut slices remained in hot water until the end of cutting to prevent browning. Then, the slices were oven-dried at 50-60°C and ground using a multi-function grinder (Gaone, Grinder 2500 rp/w, 36000 rpm). The flour obtained was sieved using a 50-300 µm mesh sieve. The flour was stored in labeled freezer bags and kept in the freezer.

3.7. Formulation of infant flours

The formulation was carried out according to the methods of Afolayan and Afolayan [25] and Olusayo et al [26]. Eight different flours (F1; F2; F3; F4; F5; F6; F7 and F8) were formulated from mixtures of ingredients in proportions of 100 per 100 g of simple flours of fonio, voandzou, cashew kernel, sorghum, sweet potato and néré pulp. The formulation of the flours was carried out using the matrix method of formulation assisted by Excel software. This method makes it possible to find the solution leading to covering at least the needs of two nutrients with at least two ingredients. The flours differ in their composition of raw materials. A commercial food was used as a control. The commercial food is Blédine banana milk flour. The raw material compositions of the different flours are as follows

- Formulation F1: Sorghum 48h (65%) + Voandzou 8h (10%) + Néré pulp (14%) + Cashew almond (11%)
- Formulation F2: Sorghum 48h (60%) + Voandzou 24h (10%) + Néré Pulp (18%) + Cashew almond (12%)
- Formulation F3: Fonio 24h (50%) + Voandzou 8h (27%) + Néré Pulp (12%) + Cashew almond (11%)
- Formulation F4: Fonio 24h (50%) + Voandzou 24h (26%) + Néré Pulp (12%) + Cashew almond (12%)
- Formulation F5: Fonio 48h (50%) + Voandzou 8h (25%) + Néré Pulp (23%) + Cashew almond (10%)
- Formulation F6: Fonio 48h (50%) + Voandzou 24h (25%) + Néré Pulp (11%) + Cashew almond (15%)
- Formulation F7: Potato (53%) + Voandzou 8h (27%) + Néré pulp (7%) + Cashew almond (13%)
- Formulation F8: Potato (58%) + Voandzou 24h (20%) + Néré pulp (8%) + Cashew almond (14%)
- Control Formulation (T): Blédine banana milk

3.8. Determination of macronutrient and energy contents

The different macronutrient (protein, carbohydrate, lipid) and energy (Kcal/100 g) contents of the flours were calculated according to the recommendations of WHO [1] and FAO/WHO [27] relating to nutrient content (carbohydrate, protein and lipid). The calculations were made according to equation (1).

$$\begin{cases} a_{11}X_1 + a_{12}X_2 + \dots + a_{1n}X_n = b1 \\ a21X_1 + a22X_2 + \dots + a2nXn = b2 \\ a_{n1}X_1 + a_{n2}X_2 + \dots + a_{nn}X_n = b_n \end{cases} \quad (1)$$

With

- a = nutrient contents (carbohydrates, proteins, lipids, and energy).
- X = the proportions of ingredients to be mixed.
- b = the needs to be met. With
- a = nutrient contents (carbohydrates, proteins, lipids, and energy).
- X = the proportions of ingredients to be mixed.
- b = the needs to be met.

3.9. Determination of rheological properties

3.9.1. Determination of solubility

The protocol of Corke and Li [28] was used for the determination of solubility. A flour suspension (0.3 g + 15 ml of distilled water) was heated from 50 °C to 95 °C, then kept at 95 °C for 15 min under maximum stirring and centrifuged at 2800 rpm. The supernatant was removed and dried at 105 °C for 24 h, then the residue was weighed. The percentage of flour dissolved in water determines the solubility (S). It is expressed by the formula (2).

$$\mathbf{S}\ (\%) = \frac{\mathbf{E\,x100}}{\mathbf{m}} \qquad (2)$$

With

- S = Solubility
- E = mass of the supernatant after drying;
- m = mass of the sample collected.

3.10. Determination of swelling

The protocol of Corke and Li [28] was used for the determination of swelling. A flour suspension (0.3 g + 15 ml of distilled water) was heated from 50 °C to 95 °C, then kept at 95 °C for 15 min under maximum stirring and centrifuged at 2800 rpm. The pellet was immediately weighed, dried in an oven (MEMMERT UM 500, MEMMERT Gmbh+Co.KG, Germany-Schwabach) at 105 °C for 24 h and reweighed. The swelling power (G) was determined according to the formula (3)

$$G\ \left(\frac{ge}{gMS}\right) = \frac{((mh - ms))}{(ms\ )} \qquad (3)$$

with

- G = Swelling
- mh = mass of the wet pellet
- ms = mass of the oven-dried pellet (g).

3.11. Determination of Fluidity

Fluidity was measured using a Bostick viscometer. After cooking, the porridges were cooled to 45 °C. The reservoir section was filled with 75 ml of each slurry. The guillotine door was lifted using a mechanism that instantly released the product. Each porridge was poured along the inclined plane. The distance traveled by the porridge represents the fluidity, recorded in millimeters/30s.

3.12. Microbiological analyses

3.12.1. Mesophilic flora count

Mesophilic flora enumeration was done by inoculation of Plate Count Agar (PCA) medium according to ISO 4833 [29].

3.12.2. Preparation of Biokar dehydrated medium (BK161 HA)

A quantity of 21.5 g of dehydrated Biokar media (BK161 HA) was suspended in 1 liter of distilled water. The medium was slowly brought to a boil with constant stirring for the time required for its complete dissolution. The media were distributed into two 500 ml flasks and autoclaved at 121 °C for 15 minutes. Then, they were cooled and maintained at 50 °C. Approximately 15 ml of media was poured into sterile Petri dishes and allowed to solidify on a flat surface.

3.12.3. Surface seeding

A quantity of 100 µl of the decimal dilutions of each sample (10-1 to 10-4) was inoculated on the surface using a Spiral inoculating device. The petri dishes were incubated at 30 °C for 72 h. Petri dishes with between 30 and 300 colonies were considered.

$$\boldsymbol{N} = \frac{\sum \boldsymbol{C}}{\boldsymbol{V}\ \boldsymbol{X}\ \mathbf{1.1} \times \mathbf{d}} \qquad (4)$$

With

- N = Number of microorganisms per gram or milliliter of product
- ∑ C: Sum of the total mesophile colonies obtained on the selected plates
- V: Volume of inoculum placed in each plate, in milliliters
- d: Dilution rate corresponding to the first dilution.
- 1.1: Correction coefficient

3.12.4. Yeast and mold count

Glucose Agar with Yeast Extract and Oxytetracycline (Oxytetracycline-Glucose-Agar) was used for the enumeration of yeasts and molds according to NF V08 [30].

3.12.5. Preparation of the agar medium

A quantity of 40 g of dehydrated medium (BK053) was suspended in 1.1 liters of distilled water. The medium was slowly brought to a boil with constant stirring for the time required for its complete dissolution. The medium was distributed into three 440 ml flasks and autoclaved at 121 $^{\circ C}$ for 15 minutes. Then, they were cooled and kept at 50 $^{\circ C}$. The Oxytetracycline supplement (BS008) was reconstituted by adding 5 ml of sterile distilled water. The flask was shaken until complete dissolution, avoiding foaming. Then, 4 ml of supplement was added and the mixture was mixed. Finally, approximately 15 ml of media was poured into sterile Petri dishes and left to solidify on a flat surface.

3.12.6. Surface seeding

One hundred microliters (100 µl) of decimal dilutions of each sample (10^{-1} to 10^{-4}) were inoculated onto the surface using a Spiral inoculating device. The petri dishes were incubated at 25°C for 5 days.

Petri dishes with between 30 and 300 colonies were considered.

The average count was calculated according to formula (8).

$$\boldsymbol{N} = \frac{\sum \boldsymbol{C}}{\boldsymbol{V}\ \boldsymbol{X}\ \mathbf{1.1} \times \mathbf{d}} \qquad (8)$$

With:

- N = Number of microorganisms per gram or milliliter of product
- ∑ C: Sum of the total mesophile colonies obtained on the selected plates
- V: Volume of inoculum placed in each plate, in milliliters
- d: Dilution rate corresponding to the first dilution.
- 1.1: Correction coefficient

3.13. Statistical analysis

Analysis of variance (ANOVA) was performed with Statistica software version 7.1 to study the degree of difference between variables. In case of significant difference between the studied parameters, the ranking of means (homogeneous groups) is carried out with the Duncan test. The significance threshold (α) is 0.05. Statistical differences with a probability value less than 0.05 were considered significant.

4. Results

4.1. Biochemical and energetic composition of formulations

The biochemical and energetic composition of the formulations is presented in Table 1. The moisture content varies from 2.7% to 7.8% with the lowest value for the control and the highest value for formulation F8. Formulations F6 and

F7 have moisture contents that are not significantly different at the 5% threshold. The same applies to formulations F3 and F4 as well as F1 and F2. All formulations have moisture contents higher than the control.

The ash content of the formulations ranges from 1.6 to 3.2%, with the highest rate for the control and the lowest for formulation F1. Formulations F1, F2 and F3 have ash rates that are not significantly different at the 5% threshold. This is also the case for F4, F5 and F6, as well as F7 and F8. All formulations have lower ash rates than the control.

The lipid contents of the composite flours vary between 7.3 and 8.7%, with the lowest for the control and the highest for the F8 formulation. Formulations F2, F5 and F8 have lipid levels that are not significantly different at the 5% threshold. Flours F6, F3 and the control have the same lipid level.

Protein content ranges from 9.5 to 14.3%. The lowest protein content is observed in F8 flour. The highest values are observed in the control and F1 flour. F1 and control flours have similar protein levels at the 5% threshold. Also, F3 and F6 flours have similar protein levels at the 5% threshold.

The flours have a fiber content ranging from 3.9 to 9.8%, with the lowest value for the control and the highest value for F5 flour. F5 and F8 flours have similar fiber contents at the 5% threshold.

The carbohydrate content ranges from 68.4 to 74%, with the lowest value for F6 flour and the highest value for F7 flour. Flours F1 and F6 have identical carbohydrate content at the 5% threshold. Flours F2, F5, and the control have carbohydrate content that is not significantly different at the 5% threshold.

The energy value of the composite flours ranges from 393.7 to 415.8 Kcal, with the lowest value for F6 flour and the highest value for F2 flour. Flours F2 and F5 have similar energy values at the 5% threshold. The same applies to F1 and F4 as well as F3, F6 and F8. Flours F7 and the control also have similar energy values at the 5% threshold.

The β-carotene content of the formulations ranged from 23.1 to 35.6µg/g with the lowest content for the control and the highest for F8. Flours F1, F3, F5, F8 and the control had similar β-carotene contents at the 5% threshold.

The vitamin C content of the composite flours is between 274.1 and 378.5µg/g with the lowest content for F1 flour and the highest for the control.

Table 1 Biochemical and energetic composition of the formulations

	Dry matter (%)	Humidity (%)	Ash (%)	Lipids (%)	Proteins (%)	Fibers (%)	Carbohydrates (%)	Energy (Kcal)	β -caroten (μg/g)	Vit C (μg/g)
F1	95.1^{b}±0.1	4.9^{de}±0.1	1.6^{e}±0.2	7.6^{b}±0.1	14.3^{a}±0,2	8^{b}±0.1	68.4^{c}±0.2	399.2^{c}±0.1	27.4^{bc}±0.1	274.1^{f}±0.3
F2	97^{a}±0.1	3de±0.1	1.7^{e}±0.2	8.2^{a}±0.3	12.6^{cd}±0.1	4.3^{dc}±0.3	72.9^{b}±0.1	415.8^{a}±0.1	30.1^{ab}±0.1	321.9^{cd}±0.4
F3	95.4^{b}±0.1	4.6^{e}±0.1	1.8^{e}±0.1	7.3^{c}±0.1	13.7^{b}±0.3	4.8^{c}±0.3	68.5^{c}±0.2	394.5^{d}±0.1	24.1^{bc}±0.1	351.3^{b}±0.2
F4	95.5^{b}±0.1	4.5^{e}±0.1	2^{c}±0.1	7.6^{b}±0.1	13.4^{bc}±0.1	8^{b}±0.3	69^{b}±0.3	398^{c}±0.1	22.4^{c}±0.1	324.4^{cd}±0.4
F5	97.5^{a}±0.1	2.5^{bc}±0.1	2^{c}±0.1	7.9^{ab}±0.3	13.1^{d}±0.1	9.8^{a}±0.2	72.6^{b}±0.2	413^{a}±0.1	27.1^{bc}±0.1	260.4^{g}±0.3
F6	94.8^{b}±0.1	5.2^{cd}±0.2	2^{c}±0.1	7.3^{c}±0.1	13.6^{b}±0.3	8.7^{b}±0.1	68.4^{c}±0.2	393.7^{d}±0.1	28.7^{abc}±0.1	315.2^{d}±0.1
F7	94.6^{c}±0.2	5.4^{cd}±0.1	2.6^{b}±0.1	8,6c±0,3 7.1^{dc}±0.2	12.2^{e}±0.3	4.1^{d}±0.2	74^{a}±0.2	408.7^{b}±0.1	35.6^{a}±0.1	291.3^{e}±0.1
F8	92.2^{d}±0.2	7.8^{a}±0.1	2.5^{b}±0.1	8.7^{a}±0.2	9.5^{f}±0.1	9.5^{a}±0.3	69.8^{bc}±0.1	395.6^{d}±0.1	25.8^{bc}±0.1	334.3^{c}±0.2
T	97.3^{a}±0.1	2.7^{b}±0.1	3.2^{a}±0.1	7.3^{c}±0.3	14.1^{a}±0.3	3.9^{d}±0.3	71.6^{b}±0.3	407.3^{b}±0.1	23.1^{bc}±0.1	378.5^{a}±0.2

Data followed by the same letters in the same column indicates the absence of a significant difference at the 5% threshold.

4.2. Rheological properties of formulations

Table 2 presents the rheological properties of the formulations. The solubility index varies between 11.7 and 19.6% with the lowest index for F6 and the highest for the control (T). Formulations F3 and F5 have solubility indices that are not significantly different at the 5% threshold. This is also the case for formulations F4 and F8.

The swelling power of the composite flours ranges from 6.9 to 9.1 ge/gMS with the lowest value for formulation F2 and the highest value for the control. Formulations F4, F7 and F8 have identical swelling powers at the 5% threshold. The same applies to formulations F1 and F6.

Regarding the fluidity of the flours, the values ranged between 60 and 103 mm/30s with the lowest value for formulation F3 and the highest for formulation F8. Apart from formulation F8 which has the highest fluidity (103 mm/30s), no significant difference was observed in the fluidities of the other flours at the 5% threshold.

Table 2 Functional properties of the formulations

Formulations	Solubility (%)	swelling power (ge/gMS)	Fluidity (mm/ 30s)
F1	14.2^{e}±0.2	7.7^{d}±0.1	75^{b}±0.1
F2	17.7^{b}±0.3	6.9^{e}±0.1	73^{b}±0.1
F3	15.5^{d}±0.2	7.9^{cd}±0.2	60^{b}±0.1
F4	17^{c}±0.1	8.3^{b}±0.2	67^{b}±0.1
F5	15.6^{d}±0.2	8^{c}±0.4	77^{b}±0.1
F6	11.7^{g}±0.2	7.7^{d}±0.1	80^{b}±0.1
F7	13.5^{f}±0.2	8.3^{b}±0.2	80^{b}±0.1
F8	17.1^{c}±0.1	8.3^{b}±0.2	103^{a}±0.1
T	19.6^{a}±0.1	9.1^{a}±0.2	82^{b}±0.1

Data followed by the same letters in the same column indicates the absence of a significant difference at the 5% threshold.

4.3. Microbiological load of flours

The microbiological load of the flours is presented in Table 3. The load for the total flora is between 10^3 and $68.6.10^3$ CFU/g with the lowest load for the control and the highest for the F5 formulation. The F4, F6 and F8 formulations have total loads that are not significantly different at the 5% threshold.

As for the yeast and mold load, it varies from 10^2 to $31.6.10^2$ CFU/g with the lowest load for formulation F2 and the highest for the control. Formulations F4, F6, F8 and the control have similar yeast and mold loads at the 5% threshold. Formulations F1, F2 and F3 also have similar yeast and mold loads at the 5% threshold.

Table 3 Microbiological load of formulations

Parameters	F1	F2	F3	F4	F5	F6	F7	F8	T
Total flora (CFU/g)	35.10^3 e±0.3	27.10^3 f±0.3	30.10^3 d±0.3	40.10^3 c±0.3	$68.6.10^3$ a±0.2	$55.3.10^3$ b±0.3	52.10^3 b±0.2	48.10^3 b±0.4	10^3g±0.1
Yeasts and molds (CFU/g)	2.10^2 c±0.1	10^2c±0.1	$2.5.10^2$ c±0.3	$7.5.10^2$ b±0.2	$1.5.10^2$ c±0.1	5.610^2 b±0.3	$31.6.10^2$ a±0.1	4.910^2 b±0.1	$8.2.10^2$ b±0.2

Data followed by the same letters on the same line indicates the absence of a significant difference at the 5% threshold.

5. Discussion

The macronutrient contents of different formulations vary. In terms of moisture content, apart from F8 flour, which has a high moisture content, other flours have a moisture content of less than or equal to 5%. According to FAO/WHO [31], the moisture content of infant flours must be less than 5%.

The water contents of the present study are lower than those of the flours of Ijiratomi and Keshinro [20]. This difference may be related to the difference in raw materials used in each of the formulations of the studies. According to Kikafunda [32], the low water content is important for the preservation of infant flours. Indeed, the low water content of flours inhibits the biochemical activities of invading microorganisms, which thus prevents food deterioration during storage.

All formulations have lower ash levels than the control. However, the ash contents are similar to those of Fogny et al [33].

All flours have lipid levels between 7 and 9%. These lipid levels are consistent with the FAO/WHO [27] standards, which recommend 7 to 9% lipid levels in infant flours. These levels are lower than those of fonio-based infant flours of Fogny et al [33]. which are between 10 and 14%. High-fat flours provide high energy; however, these foods are susceptible to both hydrolytic and oxidative/enzymatic effects. These effects cause rancidity, which is responsible for off-flavor and this affects both general acceptability and storage stability [34].

In terms of protein, except for F8 flour, the other flours comply with the FAO/WHO [27] standards, which recommend 12 to 15% protein for infant flours. The contents obtained in this study are lower than those obtained by Temitope [35], which are between 16.23 and 21.08%.

Regarding fiber, only flour F2, F3, F7 and the control correspond to the FAO/WHO standards [31], which recommend a fiber content of less than 5%.

Carbohydrate levels are similar to those of Temitope [35]. Apart from F2, F5 and F7 flours, the other flours (F1, F3, F4, F6 and F8) are consistent with FAO/WHO [27] standards. According to FAO/WHO [27], the carbohydrate levels of infant flours should be between 68 and 70%.

For the energy value, only F2, F5 and F7 flours comply with the FAO/WHO standards [31]. According to these standards, the energy value of infant flours must be between 400 and 425kcal for the energy value.

The study of the swelling powers of the formulations gave results whose values are superior to the infant flours composed of plantain banana and cashew almond, fermented or not, of Fofana et al [36]. The swelling power determines the tendency of a substance to hydrate and constitutes one of the means of measuring the quality of food [37].

Complementary foods must provide balanced proportions of major nutrients such as proteins, lipids, and carbohydrates [38]. Since malnutrition in Africa is often protein-energy malnutrition, energy value is also an important factor to consider. Taking these factors into account, flours with the best protein, lipid, and carbohydrate levels and the best energy values are assets if they also have a good amino acid, fatty acid, and sugar profile.

The solubility indices studied are similar to those found by Kouton et al [38]. Flour solubility is an indicator of its quality and digestibility [39]. To increase the fluidity of the porridges while maintaining their energy density, a pinch of germinated sorghum flour was added to each porridge after cooking. The incorporation of malt leads to an increase in the flow rate associated with an increase in the dry matter and energy density of the porridges [40; 41].

The microbiological loads detected in the flours are higher than those of the work of Sika et al. [42]. However, the detected loads comply with the microbiological criteria applicable to infant flours by Codex Stan [43]. According to Codex Stan [43], the total flora load must be less than 10^5 CFU/g, while the yeast and mold load must be less than 10^3 CFU/g. The compliance of these microbiological loads could be explained by the low water content of the flours due to the drying of the raw materials. Also, the roasting/drying coupling would have allowed a significant reduction in the load of yeasts and molds and the total flora in the flours as was the case for Tarhouni et al [44] and Loba et al [45]. An acceptable total flora is an indicator of the absence of alteration and good general microbiological quality for consumers [46].

6. Conclusion

The study revealed that the formulated flours vary in terms of biochemical, rheological, and microbiological properties. Some of these flours meet FAO/WHO standards. However, others do not. Also, only F8 flour has a moisture content higher than the standard and a protein content lower than the standard. Regarding lipid content, all formulations have a lipid content that meets the standards. Regarding fiber, only F2, F3 and F7 flours have fiber levels that meet international standards. Regarding carbohydrates, only F5 flour has a carbohydrate content lower than the standard. Regarding energy values, only F2, F5 and F7 flours have values that meet the standards.

As for the microbiological load of flours, all formulations have satisfactory total flora and yeast-mold loads.

Also, all flours presented satisfactory swelling powers, solubility and fluidity indices.

Considering all the parameters of this study, flours F2, F5 and F7 presented the best protein, lipid, carbohydrate levels and the best energy values and the best rheological characteristics and microbiological loads. Thus, these flours F2, F5 and F7 could be selected for a study of amino acid, fatty acid and sugar profile.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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