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Physicochemical, nutritional and functional characteristics of different flours made from sprouted millet, plantain and enriched with legum

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Abstract

The main objective of this work is to study the physicochemical, nutritional, and functional characteristics of different flours made from sprouted millet, plantain, and enriched with legumes. The results clearly show that the germination process has a positive impact on the resulting flours. Thus, the flours exhibit very high nutritional density with good protein, carbohydrate, and lipid concentrations. Furthermore, phytochemical levels are reduced after germination, which improves nutrient bioavailability. Although no causal link has been established between vitamin C content and germination, it should be noted that all flours contain significant levels of vitamin C. The low pH and low moisture content are also good indicators for the preservation of these flours. For the formulation of infant flours, millet germinated for three days is best suited because it contains essential nutrients for infants.

Keywords: Sprouted millet; Plantain; Nutritional characteristics; Flours

1. Introduction

Malnutrition in children is a public health problem worldwide, particularly in developing countries [1,4]**.** It generally appears during the period corresponding to the introduction of complementary foods to breast milk in infants [2,3,4]**.** Weaning food thus plays an essential role in the growth, development and mental health of children [3,5]**.** It is specially designed to meet their nutritional needs because after 6 months, breast milk is no longer sufficient to fully provide an infant's nutritional needs in terms of energy and protein [5]**.** The quality of infant formula used during this period is therefore of great importance [2,6]. Furthermore, commercial infant formulas are generally not used by low-income households because these foods are expensive and not always available [3,7]**.** Thus, in Côte d'Ivoire, weaning foods are, for the most part, prepared from local foods, particularly starchy products such as cereals, tubers, and legumes [8]**.** However, these foods do not undergo any pretreatment likely to improve the quality of the porridges. Thus, during cooking, these porridges thicken very quickly [9]**.** In this context, the child therefore consumes very little nutrient but seems to be satisfied given the small volume of his stomach of around 30g (ml)/kg of body weight [3,10]. Furthermore, although they are potential sources of minerals, cereals (corn, sorghum, millet) and legumes (soybeans) are often rich in antinutritional factors that reduce their bioavailability [11]. These antinutritional factors such as polyphenols, tannins and phytic acid constitute the main obstacle to covering children's protein and mineral needs [12]. This is because they can chelate minerals such as iron and zinc, and therefore limit their absorption and use by the body [11,12]. To overcome these problems, improving the energy density and fluidity of local porridges is necessary. Thus, the starch in flours must undergo technological treatments that promote the breaking of glycosidic bonds in order to reduce the swelling rate and consequently increase their fluidity and energy density during cooking. These technological treatments include fermentation and germination [13]. It is therefore appropriate to develop a complementary food that meets the desired characteristics, i.e., fluidity, energy density and has good nutritional value [14]. The products

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used for the formulation of our flours are; plantain, which is a very good source of magnesium, phosphorus and vitamin C. In Côte d'Ivoire, plantain ranks third among food crops, after yam and cassava [3,15]. Soybeans, a legume, are notable for their richness in protein, fat, minerals, and vitamins. Soy proteins are well balanced in essential amino acids [16]. Malted millet flour is used to reduce the viscosity of porridges and, consequently, increase their energy density [17]. The main objective of this work is to study the physicochemical, nutritional, and functional characteristics of different flours made from sprouted millet, plantain, and enriched with legumes. Specifically, this involves:

- Producing different flours from raw materials such as plantain, soybeans, and millet at different stages of germination
- Characterizing the flours produced
- Studying the functional properties of these flours.

2. Materials and Methods

2.1. Materials

For the formulation of infant flour, the raw materials used are plantain (Musa paradisiaca), soybean (Glycine max) and millet (Pennisetum Glaucum). They were chosen according to their nutritional values to meet the needs of children, the eating habits of the local population, their availability and their cost. For plantain, eighteen (18) kilograms (kg) of bananas in the dominant yellow-green stage of the cultivar corne 1 (Afoto) were used. The plantains were purchased at the Siporex market in the commune of Yopougon (Abidjan, Ivory Coast). For millet, five (5) kg of dry, healthy whole grains purchased at the "Gouro" market in Adjamé, commune of Abidjan (Ivory Coast) were used. For soybeans, five (5) kg of dry, healthy whole grains of the white variety purchased at the "Gouro" market in Adjamé, commune of Abidjan (Ivory Coast) were used.

2.2. Methods

2.2.1. Preparation of samples for flour production

Rotten or insect-bitten bananas are rejected to prevent any contamination of the product. The fruits were washed to remove any impurities that may be on the banana skin. The fruits were blanched with the skin in boiling water (100°C) containing citric acid for 10 minutes. Blanching inactivates the enzymes responsible for browning by heat, inhibits the growth of mold and eliminates intercellular gases responsible for oxidation reactions. The bananas were chilled for 25 minutes. The fingers were peeled and soaked in a citric acid solution for 30 minutes. The pulps were then cooked in boiling water containing citric acid and di-sodium dihydrogen pyrophosphate (antioxidants) for 15 minutes. After complete cooking, the pulps were cooled at room temperature for 25 minutes, cut into cubes, and dried in a hot air dryer (65°C) for 24 hours. After drying, the chips were packaged in polyethylene bags for subsequent production of the various flours.

2.2.2. Preparation of soybeans

The soybeans underwent various treatments described below to be transformed into flour. The soybeans were removed from all foreign matter (straw, sand, insect carcasses). The seeds were immersed in water for four hours and then drained. The advantage of this process lies in the fact that the sugars that cause flatulence (galactosides) will largely dissolve in the soaking water. The seeds were hulled and winnowed to remove their hulls, which are rich in indigestible cellulose fiber. The soybeans were roasted in a charcoal pan until cooked. The heat significantly reduces the anti-nutritional activity of the seeds. The product is stirred constantly during this process to ensure even cooking. Once roasted, the seeds are quickly cooled to reduce the risk of proliferation of certain microorganisms and facilitate the detachment of the skins. After drying, the grains are packaged in polyethylene bags for the subsequent production of various flours.

2.2.3. Preparation of millet grains

The millet grains are sorted, washed, and then soaked. After soaking, the grains undergo germination before being dried in the sun. Next, they are hulled, roasted, and then packaged.

2.3. Production of different composite flours

Dried plantain chips, roasted and dehulled soybeans and malted and roasted millet were weighed in the proportions of 45% banana, 35% soybeans and 20% malted millet. The resulting mixture was ground with a miller (forplex, France) containing a 50 µm sieve.The different flour formulations produced from a mixture of plantain, soy and sprouted millet are:

- F1 = Banana + soybeans + unsoaked, ungerminated millet (BSMNTG)
- F2 = Banana + soybeans + millet soaked for 24 hours (BSMTJ0)
- F3 = Banana + soybeans + millet germinated for 1 day (BSMGJ1)
- F4 = Banana + soybeans + millet germinated for 2 days (BSMGJ2)
- F5 = Banana + soybeans + millet germinated for 3 days (BSMGJ3)
- F6 = Banana + soybeans + millet germinated for 4 days (BSMGJ4)

2.4. Physicochemical analysis

The physicochemical analyses focused on:

Dry matter content ; Flour ash content ; Sample pH ; Titratable acidity ; Total carbohydrate content ; Total lipid content ; Crude protein content ; Vitamin C, phosphorus, trace elements (zinc, iron), copper, total polyphenols, tannins, and flavonoids

3. Results

3.1. Physicochemical characteristics of flours

The results show that the moisture content of different flours varies between 8.11 ± 0.17% and 5.68 ± 0.04%. The different values obtained are 7.01 ± 0.11%, 6.42 ± 0.01%, 5.68 ± 0.04%, 8.11 ± 0.17%, 7.73 ± 0.03% and 7.02 ± 0.08% respectively for F1, F2, F3, F4, F5 and F6. Furthermore, the highest water content is observed in flour F4. The dry matter contents of the different samples analyzed were significantly different (Table II). The results show that the dry matter contents of the different flours ranged from 91.89% to 94.32%. The ash contents of the different flours were significantly different at the 5% level. Flours F5 (3.10 ± 0.42%) and F6 (3.00 ± 0.28%) had the highest contents, followed by F3, F4, F2, and F1. Flours F2 and F3 did not differ statistically from each other, nor did flours F3, F4, F5, and F6. However, F3 and F5 differ statically from F1, F2 and F4. These ash rates increased significantly at the 5% threshold depending on the millet germination time. Furthermore, the ash rate varied significantly ($P \leq 0.05$) regardless of the formulation. The pH of the different composite flours decreased depending on the millet germination time. The pH of the six infant flours was significantly similar and varied between 5.74 and 6.12. However, statistical analysis showed that there was a significant difference ($P \leq 0.05$) between the pH of the six formulations.The titratable acidity of the different flours determined is different. This acidity is from 13.56 ± 0.19 meq / 100 g to 18.44 ± 0.038 meq / 100 g. It increases in the different compound flours depending on the germination time of the millet. The lowest titratable acidity content was observed in flour F1 where the millet did not undergo any particular treatment. However, the statistical analysis shows a difference between the different flours. However, there is no significant difference between F2 and F3 and between F5 and F6 ($P \geq 0.05$). The titratable acidity of the different flours determined is different. This acidity is from 13.56 ± 0.19 meq / 100 g to 18.44 ± 0.038 meq / 100 g. It increases in the different compound flours depending on the germination time of the millet. The lowest titratable acidity content was observed in flour F1 where the millet did not undergo any particular treatment. However, the statistical analysis shows a difference between the different flours. However, there is no significant difference between F2 and F3 and between F5 and F6 ($P \geq 0.05$).The fiber levels of flours from different formulations varied significantly ($P \leq 0.05$) from one formulation to another. The fiber levels of the formulations ranged from 6.70 ± 0.00% to 10.61 ± 0.06%. The lipid levels of infant flours from different formulations varied significantly ($P \leq 0.05$) from one formulation to another. These levels increased in the different formulated flours as a function of millet germination time. They vary from 9.51 ± 0.12%, 12.03 ± 0.21%, 13.66 ± 0.16%, 15.84 ± 0.08%, 17.89 ± 0.54% and 19.95 ± 0.71% respectively for flours F1, F2, F3, F4, F5 and F6. Statistical analysis shows a significant difference ($P \leq 0.05$) between the different formulated flours. The highest lipid content is observed in flour F6 where the millet germination time is 4 days. The protein content of the flours obtained increased with germination time. The values obtained were significantly different at the 5% threshold.Regarding vitamin C content, the levels of formulations F2 to F6 were not significantly different. There was a significant difference at the 5% threshold between these formulations and formulation F1. The highest vitamin C content was 30.50±0.71 mg/100 g, found in formulation F1.The mineral composition of the different flours is presented in Table III. Of all the minerals analyzed, phosphorus was the most abundant in the flours, with levels ranging from 203.6±7.4 mg/100 g to 140.2±5.5 mg/100 g. Copper levels were very low in the flours, with a maximum content of 0.72±0.05 mg/100 g. Iron and zinc content values did not vary significantly ($P \geq 0.05$) in the different flours.The total polyphenol levels in the flours of the different formulations decreased with millet germination time. These levels ranged from 686.51 ± 0.00 to 767.19 ± 0.57 mg/100 g of dry matter. The lowest levels of phenolic compounds were recorded on the third and fourth days of millet germination, at

699.74 ± 0.57 and 686.51 ± 0.00 mg/100 g for F5 and F6, respectively. The highest level was observed in F2 flour, where the millet was soaked for 24 hours. Statistical analysis showed no significant difference between the different formulated infant flours. The tannin content of the different flour formulations decrease with millet germination time. They range from 978.67 ± 5.31 to 913.40 ± 2.09 mg/100 g dry matter. Statistical analysis revealed significant differences ($P \leq 0.05$) between the different flours, whether sprouted or not. However, there was no significant difference at the 5% level between formulations F4, F5, and F6, where the germination time was 2, 3, and 4 days, respectively. The highest tannin content was recorded in formulation F2, where the millet was soaked for 24 hours.Flavonoid levels decreased with germination time in the different flour formulations. These values ranged from 20.16 ± 0.13 to 11.74 ± 0.16 mg/100 g dry matter. The lowest levels were recorded in flours F4, F5, and F6, where the millet germination time was 2, 3, and 4 days, respectively. The highest value was observed in formulation F2, where the millet was soaked for 24 hours. Thus, statistical analysis revealed a significant difference between the different formulated flours based on germination time.The dispersibility of the different flours increased significantly from 0 to 40 min for flours F1, F2, and F3, and from 0 to 60 min for flours F4, F5, and F6. Beyond 60 min, the dispersibility of the different flours stabilized and became constant. The mixed flours containing germinated millet are less dispersible than the flours composed of ungerminated or soaked millet. The flour F3 containing millet with a germination time of one day is the most dispersible (Figure 12). The viscosity of the different mixed flours decreases according to the germination times of the germinated millet grains. The statistical analysis showed a significant difference ($P \leq 0.05$) between the different formulations with the exception of F4, F5 and F6.

4. Discussion

This study aimed to assess the impact of millet germination time on the physicochemical parameters, phytochemical composition, and functional properties of different infant flour formulations. In terms of physicochemical parameters, the results indicate that, overall, the different flours have relatively low water contents compared to the standard. These results are logical because the drying process that these flours underwent helped eliminate a large portion of the water. These low water contents suggest their good shelf life over a long period. Indeed, it has been shown that low water content limits the growth of microorganisms. These results are similar to those autors [12,13], who had a content of 8% for millet. Regarding the pH of the different formulations, they are all acidic. This acidity may be beneficial for infant nutrition, indeed most enzymatic reactions are favored in acidic environments [13]. Overall, the total and reducing sugar levels increased during germination, while the total carbohydrate levels decreased. This situation may be due to the fact that endogenous enzymes will transform complex carbohydrates to provide the simple sugars necessary for the future plant. This phenomenon will therefore contribute to increasing the nutritional density of the flours and facilitating their digestion.The results obtained also suggest an increase in the quantity of proteins and lipids in the different formulations as the germination process progresses. This increase in the quantity of these nutrients could result from the activity of certain endogenous enzymes (hydrolase) which would have promoted nutritional densification. Indeed, the hydration of the seed will lift the dormancy process thanks to amylases, lipases, proteases, and release the nutrients necessary for the development of the future plant. The results also show that the flours produced have relatively high ascorbic acid (vitamin C) levels compared to the norm. This high accumulation is thought to be related to the role of ascorbate in the detoxification of reactive oxygen species produced by cellular metabolism. Vitamin C is an important nutrient because it has been attributed various fundamental biological functions. Among these biological properties in the body is its ability to act as a reducing agent for biological compounds [13]. Vitamin C is an essential cofactor in various biological reactions and as an aqueous-phase antioxidant [14]. Therefore, the vitamin C contained in the infant flours produced would contribute to strengthening the immune system and children's well-being. In addition, vitamin C has the ability to facilitate the absorption of non-heme iron; this contributes to the fight against iron anemia in children [14,15]. The high phosphorus levels in various flours are normal because phosphorus is present in large quantities in phytates, which constitute a reserve. Furthermore, during germination, phytates are hydrolyzed, releasing the phosphorus contained in these compounds. Similarly, the relatively low levels of iron, zinc, and copper are explained by the fact that these minerals are among the trace elements present in small quantities in plants. In all cases, the bioavailability of these minerals is largely dependent on the content of antinutritional factors such as polyphenols, tannins, and phytates.

When considering the phytochemical compounds (polyphenols, tannins, and flavonoids) contained in formulated flours, the results obtained indicate that their levels decrease with germination. This decrease in phytochemical compounds could be an advantage for the proper utilization of the minerals contained in flours for infants. Indeed, these compounds are known for their chelating or antinutrient properties, which contribute to reducing mineral absorption in the intestinal lumen. Combining germination and fermentation could help further reduce these compounds. However, it should be noted that these compounds at conventional doses can be useful because they possess antioxidant properties [15,16]. In terms of functional properties, the dispersibility percentage of the various formulated flours increases with millet germination time. When the dispersibility percentage is high, the flour has a high capacity to reconstitute in water to produce a fine and coherent porridge. Indeed, the dispersibility of a flour is an indicator of its reconstitution power, making it a useful functional parameter in the formulations of various food products [14]. A high dispersibility percentage is also an indicator of good water absorption capacity [13,15]. The dispersibility percentages of the infant flours produced are close to those of local Nigerian rice (56-66%) [15,17]. The results also showed a decrease in viscosity with increasing germination time. This decrease is believed to be due to the degradation of macromolecules such as starch. This fluidification is very important for young children because their fragile digestive physiology is not adapted to the ingestion of substances with high viscosity.

5. Conclusion

The main objective of this study was to study the physicochemical, nutritional, and functional characteristics of a weaning food made from malted millet and plantain, enriched with legumes. The results clearly show that the germination process has a positive impact on the resulting flours. Thus, the flours exhibit very high nutritional density with good protein, carbohydrate, and lipid concentrations. Furthermore, phytochemical levels are reduced after germination, which improves nutrient bioavailability. Although no causal link has been established between vitamin C content and germination, it should be noted that all flours contain significant levels of vitamin C. The low pH and low moisture content are also good indicators for the preservation of these flours. For the formulation of infant flours, millet germinated for three days is best suited because it contains essential nutrients for infants.

For further study, several perspectives are worth considering:

- Determining the digestibility of the resulting flours
- Performing a germination-fermentation combination to further reduce phytochemicals
- Evaluating the organoleptic and hedonic quality of porridges obtained from these flours.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declare no conflict of interest.

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