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Biochemical, nutrients, functional and sensory properties of *Dockounou* flours enhanced with soybean and Voandzou

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Abstract

In light of the current pandemic, there is an urgent need for high-quality nutrient-dense infant food in developing countries. This study aimed at the development of infant flours with high nutritional potential from senescent plantains. Thus, some enriched flours were created using senescent plantains in *Dockounou* technology production. Flours were analysed physicochemically, biochemically, nutritionally, functionally and organoleptically. Results showed an enhancement of protein, fat, iron, and zinc content in the flours as compared to the traditional (conventional) types. Higher concentrations of polyphenols 218.24 ±11.53 mg/100 g of dry matter and flavonoids 8.03 ±2.53 mg/100g of dry matter observed in the flours may be beneficial to consumers' bodies. The positive correlation between rheological properties and carbohydrate, protein, fat content and organoleptic characteristics suggests that enriched *Dockounou* flours can be used in infant porridges and other complementary foods. However, cassava and maize *Dockounou* showed the best characteristics for the dietary needs of children post weaning and could be used as infant flour.

Keywords: Senescent plantain; *Dockounou*; Infant flours; Malnutrition; Proteins; Complementary food

1. Introduction

The COVID-19 pandemic and the Russia-Ukraine crisis have exacerbated an already disastrous food security and nutrition situation in most low-income countries, with 12.9% undernourished and nearly 45% of children under five dying [1]. Most of the ingredients used to make infant formula have had their exports halted [2], and the price of infant formula has risen in most low-income countries where it is available [3].

Due to the exorbitant cost of infant food, households with limited financial resources are left with no other alternative than to purchase local flours of lower nutritional quality at public markets. The works of [4] on "*anagobaka*", [5], [6], and [7] on these flours expose the poor nutritional quality and the presence of harmful colorants in such flours. The poor quality of these flours poses a real threat to food and nutrition security and could eventually lead to an increase in infant malnutrition rates. The solution to these problems is to use locally available, accessible, and less expensive resources to make foods of high nutritional quality at a lower cost for infant feeding.

Dockounou plantain food, prepared with senescent plantain pulp and local flours like corn and rice, is a remedy for child malnutrition. Plantain is the primary local resource used to manufacture *Dockounou* [8]. According to the Food and Agricultural Organization, Statistical Database [9], Côte d'Ivoire is Africa's third-largest producer, with an estimated

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annual production of 1,883,063 tons. Local resources utilized to manufacture this foodstuff, such as maize (1,006,000 tons), rice (3,516,258 tons), and soybeans (606 tons), are abundant due to their production, availability, and accessibility throughout the Ivorian region, tropical countries (Mali, Burkina Faso, Ghana, Togo, Nigeria, Cameroun, etc.) and intertropical regions (Algeria, Tunisia, Morocco, India, etc.) [9]. Using these local resources through the technology of making *Dockounou* would be advantageous in the formulation of low-cost infant food of high nutritional quality.

Dockounou is an energy-dense (390.07 to 390.78 Kcal) and carbohydrate-based (29.47% to 37.37%) food that is high in vitamin C and minerals. The protein (1.21% to 1.5%), fat (0.027% to 0.28%), iron (0.56% to 0.69%), and zinc (0.19% to 0.23%) contents are comparatively low [8]. The consumption of the nutrition-deficient plantain *Dockounou* would ensure that the nutritional needs of consumers, particularly children after weaning are not adequately met. In addition, this food has a shelf life of 3 to 5 days at room temperature and 10 to 12 days in the refrigerator [10].

The method involves the enrichment of *Dockounou* with protein, fat, iron, and zinc via the incorporation of foods with high nutritional potential like soybean and voandzou to potentially fill these nutritional gaps, the *Dockounou* would then be processed into flour to make it easier to consume in various ways. Processing the mixture into flour would also maximize its consumption tremendously. This study aimed to assess the physicochemical, biochemical, nutritional, and functional properties of *Dockounou* flours enriched with soybean and voandzou for infant feeding.

2. Material and methods

2.1. Materials

Senescent plantain (*Musa spp*) fruits, millet (*Panicum miliaceum*), soybean (*Glycine max*), maize (*Zea mays*), rice (*Oryza sativa*), voandzou (*Vigna subterranean*), and cassava (*Manihot esculenta*) roots were used in this investigation. The plant material and the leaves of *Thaumatococcus daniellii* used to package the various types of *Dockounou* were acquired from the Gouro market in Adjamé (Abidjan, Côte d'Ivoire). Millet, maize, rice, voandzou and soybean grains together with cassava roots were ground into flour.

2.2. Development of several types of *Dockounou* enhanced with soybean and voandzou

The different types of *Dockounou* plantains enhanced with soybean and voandzou flour were produced using the method described by [11]. To make the paste, senescent plantain fruits were washed, peeled and crushed. Exactly 0.20% of ascorbic acid was added to prevent enzymatic browning and thoroughly mixed. Depending on the type of *Dockounou* desired, corn, cassava, millet, rice, soybean and voandzou flours were mixed into various amounts of senescent plantain paste (Table 1). The various mixtures were combined and fermented for three hours (3 h), wrapped in *Thaumatococcus danieilii* leaves and baked for one hour at 150 °C.

Table 1 Formulation model of *Dockounou* flour enriched with soybean and voandzou

Inputs	**Type of *Dockounou* flours**			
	Cassava *Dockounou*	**Maize *Dockounou***	**Millet *Dockounou***	**Rice *Dockounou***
Senescent plantain (%)	75	75	75	75
Binder flour (%)	5	5	5	5
Ascorbic acid (%)	0.2	0.2	0.2	0.2
Soybean flour (%)	10	10	10	10
Voandzou flour (%)	5	5	5	5
Maize flour (%)	5	0	0	0
Millet flour (%)	0	5	0	0
Rice flour (%)	0	0	5	0
Cassava flour (%)	0	0	0	5
Cooking salt (%)	0.5	0.5	0.5	0.5
Total	100.7	100.7	100.7	100.7

2.3. Processing of enriched *Dockounou* into flour

Dockounou flour was made by slicing cooked *Dockounou* into thin strips. The slices were oven-dried for 48 hours at 50 °C. After drying, the slices were ground into flour using a homemade crusher and a Moulinex brand mixer (France). The flour was sieved using a 500 µm diameter sieve and stored in a glass jar at laboratory temperature.

2.4. Determination of chemical properties of enriched *Dockounou* flours

The chemical properties of enriched *Dockounou* flour were studied by the determination of titrable acidity and pH. The total titratable acidity was determined by the titrimetric method using a base (NaOH) according to the method described by the Association of Official Analytical Chemists [12]. The pH was determined by the method described by [13] by dipping the end of the pH meter directly into the solution.

2.5. Evaluation of the proximal composition of enriched *Dockounou* flours

The proximate composition of enriched *Dockounou* flours was determined using methods described by [12]. Thus, moisture (direct oven drying), crude protein (Kjeldahl method, N x 6.25), fat (Soxhlet extraction method using hexane) and ash (muffle furnace method at 550 °C) contents were determined by the [12] method. Reducing sugars were estimated by the method of [14] and the total sugars were determined by the method of [15]. The carbohydrate content was estimated by the difference between 100 and the total sum of moisture, fat, protein, crude fibre, and ash as described by [12]. Energy values for the samples were calculated from the energy-yielding constituents (protein, fat and total carbohydrates) by multiplying them by their corresponding Atwater-specific energy conversion factors [16].

2.6. Determination of mineral elements of enriched *Dockounou* flours

The content of mineral elements was determined using a flame ionized atomic absorption spectrophotometer (AAS) according to the method described by [12]. Sodium and potassium were measured using a flame photometer while phosphorus was determined by the vanadomolybdate colorimetric method [17].

2.7. Evaluation of bioactive compounds and antioxidant properties of enriched *Dockounou* flours

The phenolic compounds were extracted according to the method described by [18]. Thus, 1 g of each flour was homogenized in 10 mL of methanol prepared at 70% (v/v) and then centrifuged at 1000 rpm/10 min. The pellet was covered and then washed again under the same conditions before being recovered in a 50 mL vial for the tests to be carried out.

The flavonoid content was determined according to the method described by [19] using aluminum chloride (10%) and sodium acetate (1 M). Quantitatively, the flavonoid content was determined using a calibration line established from a stock solution of quercetin at a concentration of 1 mg/mL with the guiding coefficient of $y=ax+b$. The polyphenol content was determined according to the method of [18] using the Folin-Ciocalteu reagent and sodium carbonate. A standard range read at 700 nm was established from a stock solution of gallic acid (1 mg/mL) under the same conditions as the test for determining the polyphenols in the samples. The antioxidant activity was determined according to the method described by [20].

2.8. Determination of functional properties of enriched *Dockounou* flours

The water absorption and solubility index of enriched *Dockounou* flours were determined according to the methods described by [21], by showing the amount of water retained by 100 g of starch after saturation and centrifugation. The oil absorption capacity was determined according to the method described by [22] after energetic agitation and centrifugation at 4500 rpm for 10 minutes of 1 g of *Dockounou* flour enriched in refined palm oil and unrefined palm oil. The hydrophilic-lipophilic ratio was determined by dividing the water absorption capacity by the oil absorption capacity. Foaming capacity and foaming stability were evaluated according to the method of [23], the volume of foam formed after the incorporation of air by whipping and the collapse of the foam after 1 hour was measured. Bulk density was obtained by dividing the bulk mass by the bulk volume of each flour.

2.9. Sensory evaluation of *Dockounou* flour enriched with soybean and voandzou

The sensory evaluation was carried out following the method described by that of [24]. The organoleptic quality of enhanced *Dockounou* flours was compared to that of commercial flours (Farinor). The panel of tasters included 40 persons of both sexes and from different socioeconomic backgrounds, both trained and untrained. The selected individuals (panel) were employees of the university and they supplied information about the product's relative acceptability as well as its flaws.

2.10. Statistical analysis

The physicochemical and biochemical analyses were carried out in triplicate, and the mean and standard deviation were obtained using Microsoft Windows 10 Excel software. Using the statistical analysis software SPSS version 20, the means of the individual samples were compared using Duncan's test at the 5% level. Using the XLSTAT software (version 2020, XLSTAT, USA), a Principal Component Analysis (PCA) and a Hierarchical Ascending Classification (HAC) were done to find the samples with similar features.

3. Results and discussion

3.1. Chemical properties of enriched *Dockounou* flours

The pH values of the various enriched *Dockounou* flours with soybean and voandzou are illustrated in Figure 1. The low value ($p < 0.05$) pH of enriched maize *Dockounou* flour (6.18) compared to the pH of the other types of *Dockounou* flour (6.47 - 6.66) suggests that this flour is more acidic than the others, there was no significant difference ($p > 0.05$). Acidity is connected to the existence of hydronium ions (H_3O^+), whose excessive concentration inhibits microorganism development [25]. Thus, the high acidity associated with the low moisture content of *Dockounou* flours may act as a significant barrier to the development of microorganisms in the various enhanced *Dockounou* flours with soybean and voandzou.

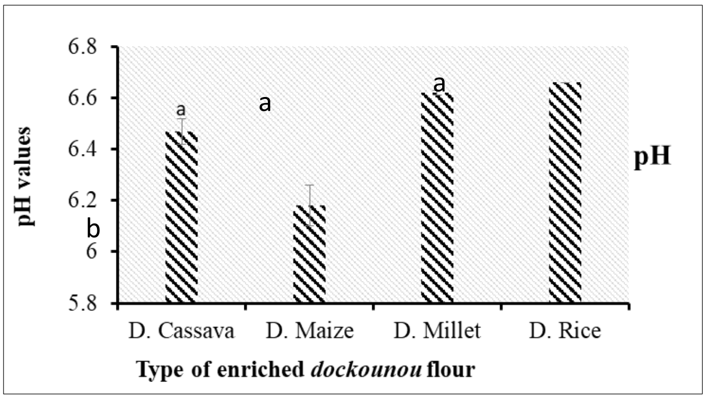

Figure 1 pH values of different *Dockounou* flours enriched with soybean and voandzou; D. = *Dockounou*. Data expressed as mean ± standard deviation. Values in rows with the same letter were not significantly different ($p < 0.05$)

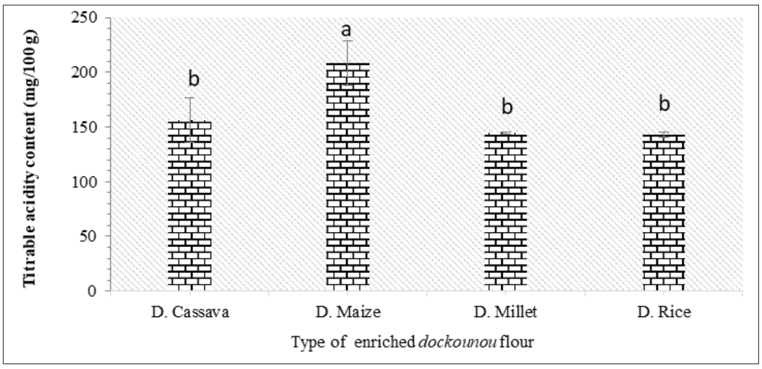

Figure 2 Titratable acidity of different flours of *Dockounou* enriched with soybean and voandzou. D. = *Dockounou.* Data expressed as mean ± standard deviation. Values in rows with the same letter are not significantly different ($p < 0.05$)

Figure 2 shows the titratable acidity of the different enriched *Dockounou* flour. Statistical analysis revealed a high total acid content of the enriched maize *Dockounou* flour compared to the other types of enriched *Dockounou* flour. The total acidity ranged from 142.78 mg/100g DM to 208.33 mg/100g DM for rice *Dockounou* flour and maize *Dockounou* flour, respectively. Titratable acidity or total acidity is a predictor of the impact of organic acids in the food on flavor [25]. It is primarily involved in taste and strikes a balance between sweet and acidic taste. Thus, the high titratable acidity value of maize *Dockounou* flour suggests that this food may have better organoleptic characteristics compared to other types of enriched *Dockounou* flour.

3.2. Proximate composition of enriched *Dockounou* flours

The dry matter and moisture content of the various enriched *Dockounou* flours are shown in Figure 3. The relatively low moisture content of the enriched *Dockounou* flours were 13.4% and 14.7% for enriched maize *Dockounou* flour and enriched millet *Dockounou* flour, respectively, is an advantage that may positively impact the shelf life. There was no significant difference at a 95% confidence level, this suggests that all flours may have a longer shelf life. Studies have shown that the presence of excess moisture in food items promotes the growth of microorganisms, resulting in degradation or deterioration and a reduction in nutritious value [26]. Thus, a food product's low moisture content improves the shelf-life tremendously.

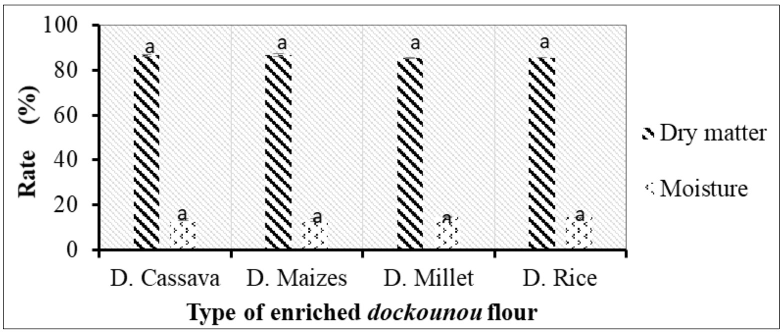

Figure 3 Dry matter and moisture content of different *Dockounou* flours enriched with soybean and voandzou. D. = *Dockounou.* Data expressed as mean ± standard deviation. Values in rows with the same letter are not significantly different ($p < 0.05$)

3.3. Biochemical composition of enriched *Dockounou* flour

Table 2 presents the biochemical characteristics of the different *Dockounou* flours enriched with soybean and voandzou. The protein and fat contents of the different enriched *Dockounou* flour were not significantly different at a 95% level of confidence. Protein contents ranging from 13.97 ± 1.25% to 14.74 ± 0.1% pose a nutritional advantage for consumers compared to traditional *Dockounou*. The high protein contents show that enriched *Dockounou* flours would be suitable for complementary feeding of infants and could replace traditional complementary foods sold in public markets in Côte d'Ivoire, which is one of the main causes of protein-energy malnutrition in weaned children. Protein digestibility, however, should be evaluated because the protein content can be inhibited by a high ash content [27]. The fat content was 7.42 ± 0.03% and 7.92 ± 0.19% for rice *Dockounou* flour and maize *Dockounou* flour, respectively. It constitutes an advantage in terms of nutritional intake so long as fats are involved in the energy needs of the body, the synthesis of hormones as well as enzymes, and constitute the means of transport of fat-soluble vitamins to target organs [28]. The high-fat contents of enriched *Dockounou* flours compared to traditional *Dockounou* suggest that their consumption could contribute to meeting energy needs, promoting the progress of metabolic reactions and the transport of fat-soluble vitamins to their target organs. The high carbohydrate content of cassava and maize *Dockounou* compared to millet and rice *Dockounou* flours suggests that the consumption of these flours could contribute to meeting energy needs. The high content of reducing sugars, total sugars and energy value of enriched maize *Dockounou* flour compared to other types of *Dockounou* suggests that consumption of this flour could better contribute to meeting the energy needs of the body. To improve the nutritional quality of complementary foods, studies have advocated the use of combinations of cereals and legumes or other locally available food materials, to increase the protein and energy density of complementary foods fed to young children in developing countries. [29], Food and Agriculture Organization/World Health Organization [30], recommended that foods given to infants should be adequate in protein and energy-dense; this is because low energy-dense foods tend to reduce total energy intake and other essential nutrients in children. Energy-dense foods are necessary for children to meet their energy needs taking into consideration their small stomach size [31]. The high starch content of millet *Dockounou* flour compared to other types of *Dockounou* flour suggests that consumption of this flour may have beneficial effects on intestinal transit [29].

Table 2 Biochemical characteristics of the different flours of *Dockounou* enriched with soybean and voandzou

Parameters	Type of *Dockounou* flour			
	D. cassava	D. maize	D. millet	D. rice
Fat (%)	7.43 ± 0.27[a]	7.92 ±0.19[a]	7.57 ± 0.04[a]	7.42 ± 0.03[a]
Carbohydrates (%)	59.99 ±0.39[a]	59.88 ±0.75[a]	59.54 ± 0.23[ab]	58.85 ± 0.08[b]
Protein (%)	14.74 ±0.1[a]	14.67 ±0.13[a]	13.71 ± 0.06[a]	13.97 ± 1.25[a]
Reducing sugars (%)	31.81 ±0.95[b]	34.61 ±0.55[a]	27.50 ± 0.72[d]	29.84 ± 0.45[c]
Total sugars (%)	56.6 ±0.15[ab]	61.2 ± 0.41[a]	66.5 ±0.99[a]	49.3 ±0.51[b]
Starch (%)	50.5 ±0.47[c]	54.61 ±0.98[b]	59.32 ±0.72[a]	43.96 ±0.58[d]
Energy value (Kcal)	365.79 ±1.79[b]	366.76 ±2.17[a]	361.13 ±2.59[c]	358.06 ±0.35[ab]

Values presented as mean± standard deviation. Values with different superscripts (a, b and c) on the same row are statistically significant ($p < 0.05$); D. = *Dockounou*.

3.4. Ash and minerals composition of enriched *Dockounou* flours

Table 3 presents the ash and mineral content of the different *Dockounou* flours enriched with soybean and voandzou. Cassava and millet *Dockounou* flours had higher ash contents than maize and rice *Dockounou* flours. This means that these foods have very high mineral contents and their consumption could therefore meet the mineral needs of the consumer's body [29]. The ash content which varies from 4.13 ± 0.2% to 4.66 ± 0.23%, respectively for Cassava *Dockounou* flour and Maize *Dockounou* flour is significantly higher than the [30] recommendation with a minimum ash content of 3% for weaning food. However, the ash content was positively correlated with the iron content, zinc content, Na/K ratio and Ca/P ratio. This positive correlation suggests a positive impact on the consumption of the enriched *Dockounou* meal. The mineral contents of rice *Dockounou* and cassava *Dockounou* flours in phosphorus, potassium, magnesium, iron, zinc and sodium were comparatively higher than those of maize and millet *Dockounou* flours. The Ca/P ratio and Na/K ratio of the mixtures of the different enriched *Dockounou* flours ranged from 3.10 ±0.13 to 3.49 ±0.25 and from 0.20 ±0.21 to 0.22 ±0.41 for millet and maize *Dockounou* flours and rice and millet *Dockounou* flours, respectively. These observations show that all samples meet the [30] recommended values for Na/K ratio (<1.0) and Ca/P ratio (>2.0), indicating that consumption of enriched *Dockounou* flour could promote bone and tooth formation in children and could be safe for the infant's heart when taken as a complementary food.

Table 3 Ash and minerals content of enriched *Dockounou* flours

Parameters	Type of *Dockounou* flour			
	D. Cassava	D. Maize	D. Millet	D. Rice
Ash (%)	4.66±0.23[a]	4.13 ±0.23[b]	4.53 ± 0.05[a]	4.34 ± 0.05[ab]
Phosphorus	47.42±00[a]	49.62 ± 00[a]	47.1 ± 00[a]	46.78 ± 00[a]
Potassium	180.50±00[b]	180.25 ± 00[b]	173 ± 00[c]	184.75 ± 00[a]
Calcium	157.84±0.00[b]	155.63 ± 0.50[c]	150.9 ± 0.50[d]	162.97 ± 0.00[a]
Magnesium	35.75 ±0.30[a]	35.5 ± 0.12[a]	34.5 ± 0.23[a]	35.5 ± 0.05[a]
Iron	4.10 ±0;63[a]	2.43 ± 0.44[b]	2.83 ± 0.45[b]	3.10 ± 0.45[b]
Lead	0.42 ±06[b]	0.23 ± 43[c]	0.70 ± 11[a]	00 ± 00[d]
Zinc	10.44 ±0.60[a]	10.05 ± 0.85[a]	11.32 ± 0.81[a]	10.03 ± 0.71[a]
Sodium	37.77 ±0.83[a]	35.90 ± 0.58[a]	38.65 ± 0.19[a]	37.73 ± 0.45[a]
Na/K	0.21 ±0.30[a]	0.20 ±0.21[a]	0.22 ±0.41[a]	0.20 ±0.35[a]
Ca/P	3.33 ±0.14[ab]	3.14 ±0.13[b]	3.10 ±0.13[ab]	3.49 ±0.25[a]

Values presented as mean ± standard deviation. Values with different superscripts (a, b and c) in a row indicate a statistical difference ($p < 0.05$); D. =*Dockounou*.

3.5. Bioactive compounds and antioxidant properties of enriched *Dockounou* flours

Polyphenols, flavonoids, and antioxidants found in most plants including plantain, soybean, and voandzou help promote crop, food, and consumer health [32]. The incorporation of soybean and voandzou in the plantain *Dockounou* fortification process reveals interesting polyphenol, flavonoid, and antioxidant contents as shown in Table 4. Polyphenol levels were statistically significant ($p < 0.05$) in maize and millet *Dockounou* flours compared to rice and cassava *Dockounou* flours. These contents are comparable to those obtained by [33] at the level of H. sabdariffa leaves bleached for 45 min. However, these contents are lower than those obtained by [27] at the level of different Cucurbitaceae species. The phenolic compounds present in the *Dockounou* flours are possibly related to the antioxidant properties, with no significant differences between them ($p < 0.05$). The polyphenol, flavonoid, and antioxidant contents confirm the studies conducted by [34] on the role that polyphenols play in the antioxidant activity of foods. The presence of phenolic compounds as well as the observed antioxidant activity indicates that *Dockounou* flours enriched with soybean and voandzou contain free radical inhibitors that would attribute to these infant flours the possibility of being consumed as a source of antioxidants.

Table 4 Polyphenols, flavonoids and antioxidants contents of enriched *Dockounou* flours

Parameters	Type of D. flour			
	D. Cassava	D. Maize	D. Millet	D. Rice
Polyphenols (mg/100g)	138.36 ±5.43^{c}	218.24 ±11.53^{a}	213.97 ±4.42^{a}	193.30 ±3.88^{b}
Flavonoids (mg/100g)	8.03 ±2.53^{b}	3.63 ±0.88^{a}	7.49 ±1.16^{a}	6.79 ±0.49^{a}
Antioxidant (%)	26.98 ±2.28^{a}	27.04 ±1.91^{a}	29.40 ±0.36^{a}	26.98 ±1.40^{a}

Values presented as mean ± standard deviation. Values with different superscripts (a, b and c) in a row indicate a statistical difference ($p < 0.05$); D. =*Dockounou.*

3.6. Functional properties of enriched *Dockounou* flours

The functional properties (Table 5) of flours depend not only on their biochemical composition (protein, fat, and carbohydrate content) but also on their physical properties such as water absorption capacity, oil absorption capacity, solubility index, foaming capacity, foaming stability and bulk density [27]. An interesting physical property of food flours is their bulk density. This property is an indicator of the wettability of the flour; high values of bulk density reflect the high dispersibility of the particles, while a low value is an advantage for the formulation of complementary feeds [35]. In this study, the results showed that cassava *Dockounou* enriched flour has the lowest value ($p<0.05$) of bulk density compared to the other types of *Dockounou* flour with no significant difference ($p>0.05$) between them. Water absorption capacity indicates the ability of flour to reconstitute under limited water conditions; the higher the water absorption capacity, the better the reconstitution capacity of the flour. The results indicated variable water absorption capacities at $p<0.05$ ranging from 467.30 ±0.87 % to 411.11 ±0.95% for cassava *Dockounou* and Mille *Dockounou* enriched flours, respectively. The water absorption capacities of *Dockounou* flours were higher than those obtained by [36] and suggest that *Dockounou* flours could easily reconstitute in water. With regards to the water solubility index, the results indicated no significant difference at $p>0.05$ within the different enriched *Dockounou* flours. This difference suggests that *Dockounou* flours can to absorb water and then swell to the desired consistency in the food system. According to [37], this property is an advantage and could improve the performance and consistency of the developed food product. Regarding the oil absorption capacity, the results show a significant difference ($p<0.05$) from one flour to another and it is higher in palm oil than in red oil. While maize *Dockounou* flour has the highest red oil absorption capacity, millet *Dockounou* flour has the highest palm oil absorption capacity. The palm oil absorption capacities however are comparable to [37] whose values ranged from 199.11% to 215.48%. The high oil absorption rates suggest that *Dockounou* flours may have a positive impact on flavor, mouthfeel, and taste when adding fat during the production of foods derived from these fortified flours [38]. The lipophilic hydrophilic ratio between 58.93 ±0.57% and 54.67±0.57% for maize *Dockounou* flour and millet *Dockounou* flour respectively, suggests that these flours could be used in combination with water for making infant porridges and other derived foods requiring water. In terms of foaming capacity and foaming stability, the results indicated a significant difference ($p<0.05$) between the flours. Foaming capacity is the ability of a substance to produce foam after it has been vigorously homogenized. This property depends on the protein content, fat content, protein denaturation state, and fat delipidation state [39]. The foaming capacities and the foam stability of cassava, millet, and rice *Dockounou* flours, were higher than those obtained by [27] which ranged from 4.25 ±0.02% to 11.23 ±0.01%, respectively for the species of *Cucurbit mannii* and *Cucurbit maxima*. Foaming stabilities close to 30% suggest that infant porridges and derived foods to be made from the enriched *Dockounou* flours will have good texture, consistency, and appearance [27].

Table 5 Functional properties of enriched *Dockounou* flours

Parameters	**Type of D. flour**			
	D. Cassava	**D. Maize**	**D. Millet**	**D. Rice**
Water absorption capacity (%)	467.30 ±0.87^{a}	445.89 ±0.86^{b}	411.11 ±0.95^{d}	437.77 ±0.86^{c}
Solubility index (%)	58.40 ±1.25^{a}	58.60 ±0.87^{a}	55.00 ±1.32^{a}	55.00 ±3.25^{a}
Red oil absorption capacity (%)	107.00 ±1.32^{c}	131.66 ±0.94^{a}	78.00 ±1.00^{d}	124.00 ±0.863^{b}
Palm oil absorption capacity (%)	129.00 ±1.21^{bc}	132.00 ±1.00^{b}	139.00 ±1.50^{a}	126.00 ±4.25^{c}
Hydrophilic/lipophilic ratio (%)	58.90 ±0.50^{a}	58.93 ±0.57^{a}	54.67±0.575^{b}	55.00 ±0.86^{b}
Foaming capacity (%)	13.33 ±7.35^{a}	7.49 ±2.89^{c}	11.00 ±0.57^{b}	10.33 ±8.96^{b}
Foaming stability (%)	29.08 ±8.76^{b}	37.83 ±12.51^{a}	29.08 ±8.76^{b}	21.16 ±4.20^{c}
Bulk density	0.86 ±0.57^{b}	0.92 ±0.57^{a}	0.92 ±0.57^{a}	0.933 ±0.57^{a}

Values indicated as mean ± standard deviation. Values with different superscripts (a, b and c) on the same row indicate a statistical difference ($p < 0.05$); D. =*Dockounou.*

3.7. Sensory characteristics of enriched *Dockounou* flours

The results of sensory evaluation of the enriched *Dockounou* flours are given in Table 6. The statistical analysis showed that the panel rated the enriched flours differently based on different descriptors. The *Dockounou* flours enriched with soybean and voandzou did not differ from commercial flours (farinor) in terms of texture and taste. For texture, the scores obtained were 6.26 ±1.61 and 6.54 ±1.40 for *Dockounou* maize flour and commercial flour farinor, respectively. Concerning the taste of the various flours, the scores obtained were 5.74 ±1.91 and 7.51 ±1.54 for the millet *Dockounou* flour and the commercial flour farinor, respectively. The scores for aroma revealed a significant difference ($p< 0.05$) between enriched *Dockounou* flour and commercial flour (farinor) with higher scores for commercial flours. The scores were 5.49 ±1.52 and 6.97 ±1.85 for enriched *Dockounou* millet flour and Farinor flour, respectively. In terms of colour, the statistical analysis revealed a significant difference ($p<0.05$) between the scores of the different *Dockounou* flours and the commercial flours. Thus, the scores were higher for the commercial flours than for the different enriched *Dockounou* flours. They vary from 5.94±1.57 to 7.11±2.26, respectively for the enriched *Dockounou* millet flour and the commercial farinor flour. In terms of the acceptability of the different flours, the results showed that the acceptability of *Dockounou* flours is relatively similar to the commercial flour farinor, however, different from farinor flour. The scores obtained were 6.06±1.66 and 7.37±1.83, respectively for the enriched rice *Dockounou* flour and the farinor flour.

Table 6 Hedonic test for sensory evaluation of different *Dockounou* flours enriched with soybean and voandzou

Descriptors	**Type of D. flour**				
	D. cassava	**D. maize**	**D. millet**	**D. rice**	**Farinor**
Color	6.11 ±1.30^{b}	6.11±1.53^{b}	5.94±1.57^{b}	6.43±1.44^{ab}	7.11±2.26^{a}
Aroma	5.83±1.36^{b}	5.80±1.23^{b}	5.49±1.52^{b}	5.83±1.42^{b}	6.69±1.77^{a}
Taste	6.26±1.54^{a}	6.00±1.59^{a}	5.74±1.91^{a}	6.26±1.66^{a}	6.60±1.92^{a}
Texture	6.46±1.54^{a}	6.26±1.61^{a}	6.54±1.52^{a}	6.34±1.66^{a}	6.54±1.40^{a}
Acceptability	6.43±1.42^{b}	6.40±1.50^{b}	6.14±1.45^{c}	6.06±1.66^{c}	6.91±1.78^{a}

Data presented as mean± standard deviation. Values with different superscripts (a, b, and c) on the same row indicate statistically significant at 95% confidence level. Difference ($p < 0.05$); D. =Dockounou.

3.8. Correlation between physicochemical, biochemical, sensorial characteristics and technological properties of *Dockounou* flours enriched with soybean and voandzou

Principal component analysis was conducted to show the links between the chemical and biochemical composition, sensory analysis, and technological properties of *Dockounou* flour enriched with soybean and voandzou (Figure 4). Pearson's linear correlation coefficient assessed both the strength and direction of relationship between the different variables (Figure 4). The Pearson test showed that the energy value of the different enriched *Dockounou* flours was positively correlated with the fat (r = 0.58; p < 0.05), carbohydrate (r = 0.94; p < 0.05) and protein (r = 0.85; p < 0.05) contents of the enriched flours. This strong positive correlation means that these nutrients, present in sufficient quantity, effectively contributed to the enhancement of the energy value. This energy value, which is dependent on the protein, fat, carbohydrate and titratable acidity content (r = 0.75; p < 0.05), is strongly correlated with the general acceptability (r = 0.97; p < 0.05) of *Dockounou* flours. This means that these nutrients have a strong impact on the organoleptic characteristics of the enriched flours and their consumption could be beneficial to children aged 6-59 months. The strong positive correlation of titratable acidity with its nutrients is in agreement with the predictions of [25] regarding the presence of organic acids responsible for the taste of the food. In addition, the energy value is strongly correlated with the water absorption capacity (r = 0.70; p < 0.05), solubility index (r = 0.94; p < 0.05), hydrophilic to lipophilic ratio (r = 0.92; p < 0.05), and foaming stability (r = 0.87; p < 0.05) of the enriched *Dockounou* flours. This strong positive correlation with the functional properties of the flours reflects the importance of these nutrients in the preparation of infant porridges and the suitability of their use for the development of complementary products.

Principal component analysis (PCA) revealed a total cumulative variance of 82.80%, of which 48.68% of the variables correlated with axis 1 (F 1) and 34.12% of the variables correlated with axis 2 (F 2) (Figure 4) in terms of the variables used. In this regard, cassava and maize *Dockounou*, which were positively correlated with axis 1 (F1), were located on the right side of the graph, while millet and rice *Dockounou* were located on the left side of the graph, and were negatively correlated with axis 1 (F1). On axis 2 (F2), only the rice *Dockounou*, located at the top, was positively correlated with it. This distribution of enriched *Dockounou* flours in the factorial plane allows us to classify the different flours into three distinct groups. The first group, constituting cassava and maize *Dockounou* flours were positively correlated with protein content, lipophilic hydrophilic ratio, solubility index, foaming stability, carbohydrate content, energy value, acceptability and titratable acidity. The second group is rice *Dockounou* flour, whose intrinsic correlation is positively related to pH, moisture, polyphenol and flavonoid contents. However, water absorption capacity, colour, taste, aroma, red oil absorption capacity and foaming capacity were correlated with the cassava, maize and rice *Dockounou* flour. The third group, millet *Dockounou* flour was correlated with texture, antioxidant activity, palm oil absorbency, sodium potassium ratio and zinc content. The distribution of *Dockounou* flours into three groups after the PCA test was consistent with the hierarchical clustering (HCA) in Figure 5, which also indicated the three groups of *Dockounou* based on their degree of similarity. Thus, cassava and maize *Dockounou* are strongly related to biochemical properties and have a higher food preference compared to the other types of *Dockounou*.

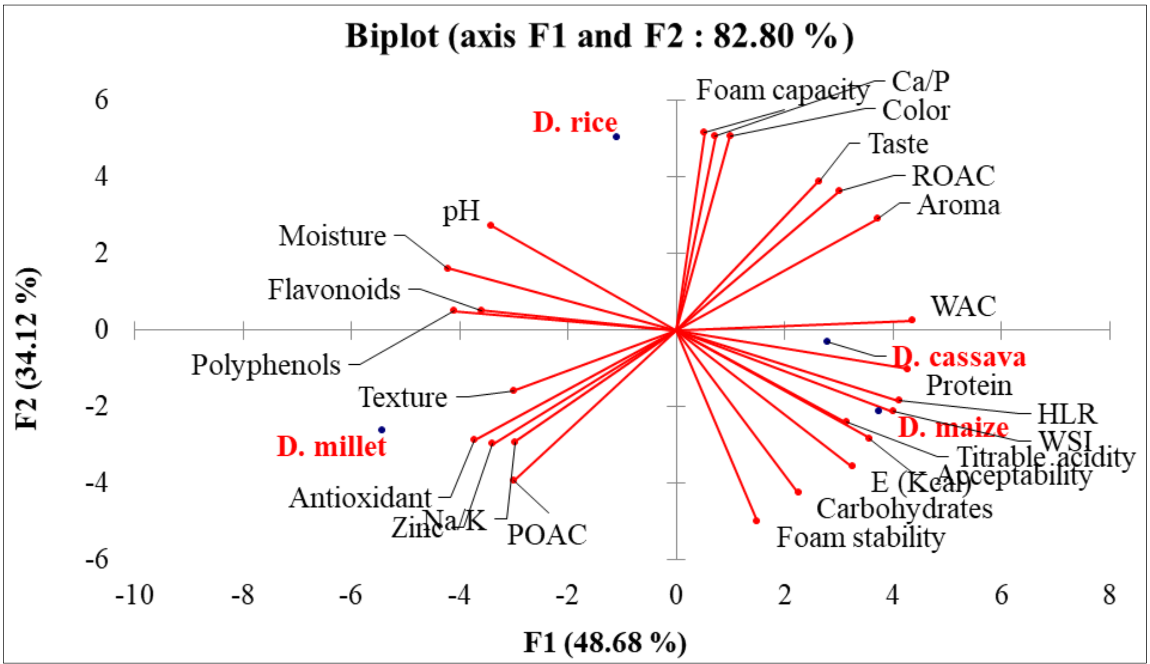

Figure 4 Factor map resulting from the superposition of the physicochemical and biochemical parameters of the different flours (D. =*Dockounou*)

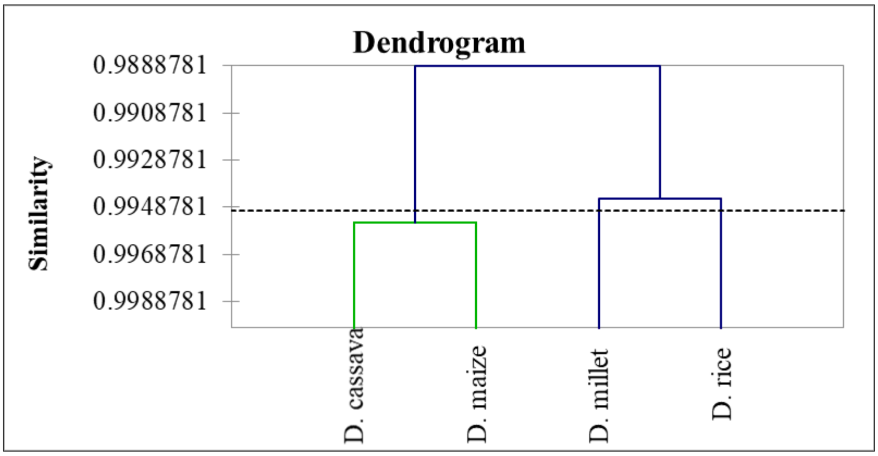

Figure 5 Classification of enriched *Dockounou* flours according to their similarity in physicochemical and biochemical characteristics (D. =*Dockounou*)

4. Conclusion

The use of the plantain *Dockounou* technology allowed the production of different types of enriched *Dockounou* flours with interesting nutritional properties. The physicochemical, biochemical and nutrient analysis revealed that the protein, fat, iron and zinc contents were significantly improved after enrichment compared to traditional types indicating the high nutritional potential of these flours. Functional properties revealed the suitability of these enriched flours in the formulation of complementary food for children after weaning. Organoleptic tests showed that the enriched *Dockounou* flours had different organoleptic characteristics from those of commercial flours. Statistical analysis indicated that cassava and maize *Dockounou* flours had the best nutritional potential, while rice *Dockounou* flours were more suitable for long-term storage.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declare that they have no competing interests.

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