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PHYSICOCHEMICAL AND FUNCTIONAL PROPERTIES OF FLOUR PRODUCED BY SOLID-STATE FERMENTATION OF CASSAVA 'BONOUA 2', 'TMS 4(2)1425' AND 'BOCOU 2' VARIETIES GROWN IN CÔTE D'IVOIRE

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ABSTRACT

Manihot esculenta is a key resource in the bakery, culinary and pharmaceutical sectors. In Côte d'Ivoire, cassava is the second most important food crop after yams in terms of production volume, with 5 million tonnes produced in 2019. Despite cassava's importance for food security, the characteristics and chemical composition of its roots limit their effective use for food purposes due to their toxicity and limited shelf life. Consequently, in order to assess the quality of fermented flours derived from three cassava varieties 'Bonoua 2', 'TMS 4(2)1425' and 'Bocou 2', their physicochemical and functional properties were evaluated. The results showed significant differences ($p < 0.05$) in the physicochemical and functional properties of these flours. Solid-state fermentation reduced the HCN content to below recommended levels and produced cassava flours suitable for human consumption, with physicochemical and functional properties conducive to their use in food preparation. fermented flour (TMS) would be more suitable for food products requiring the flour to absorb water, such as porridges, pasta and thickeners. Bonoua 2 fermented flour was classified according to its oil absorption capacity, viscosity, gel consistency, syneresis, pH, titratable acidity and chroma. This suggests that the fermented flour (Bonoua 2) would be more suitable for sausages, bakery products, meat substitutes, yoghurts, cheese, jam and gelatine-based desserts. Bocou 2 fermented flour correlates with water activity, foaming capacity, whiteness index, porosity, moisture content, dispersibility and bulk density. This suggests that fermented flour (Bocou 2) may be better suited to long-term storage, food safety, visual appeal and consumer acceptance.

Keywords: Cassava flour, Solid-state fermentation, Cyanide, Physicochemical and Functional properti

1 INTRODUCTION

Cassava (*Manihot esculenta* Crantz) ranks as the third most significant caloric source in tropical areas, following rice and maize. It sustains well over 800 million individuals globally, providing an essential safeguard for food security due to its roots' resilience to impoverished soil and extreme drought conditions [1]. Cassava cultivation is primarily aimed at human consumption and is vital for maintaining food security for both rural and urban communities, while also providing financial income for rural inhabitants [2,3]. The cassava tuber serves as a fundamental resource in the baking, culinary, and pharmaceutical sectors [4]. In Côte d'Ivoire, cassava is the second largest food crop after yam in terms of production quantity, with 5 million tonnes in 2019 [5]. It is grown throughout the country, and the southern zone is the area of high production [6]. Cassava roots are transformed into culinary items including attiéké, placali, foutou, atoukpou, gari cassava flour, cake, and bread [7]. Among these products, attiéké (semolina) is the most extensively consumed, serving as a fundamental food that enhances household nutrition and supports local agrifood systems. Despite cassava's significance for food security, the characteristics and chemical makeup of its roots restrict their effective utilisation as food due to their toxicity and limited shelf life [8]. Consequently, methods like peeling, fermenting, grating, and drying [9] are crucial for mitigating toxicity, enhancing flavour, and ensuring preservation. In addition, cassava food products' qualities are affected by chemical composition, including cultivar, the geographical location, maturity stage of the plant, and environmental conditions. Cassava varieties are indeed classified into three groups based on cyanogenic glycoside content: sweet (low toxicity), medium, and bitter (high toxicity). This classification is widely supported by scientific literature [10]. It plays a very important role in the production of diversified food products due to inherent characteristics which vary from one cassava to the other. These varieties of cassava are used in the production of many fermented products because they are better suited to this processing method. Fermentation was found to be one of the suitable processing methods of cassava pulp which reduces toxic cyanogenic glucosides and improves the sensory properties, nutritional composition and flour functional properties. According to [11], the use of cassava flour in the processed food industry is growing rapidly, both as a single raw material and as a composite material. Nonetheless, the utilisation of cassava flour presents specific challenges, especially concerning quality, which frequently lacks consistency, consequently impacting the final products. The variation in cassava varieties utilised as raw materials is probably the cause; hence, [12] emphasised that characterising the properties of cassava flour is crucial for its effective use in various applications. The objective of this study was therefore to evaluate the effect of cassava fermentation on the cyanide content and functional properties of three different cassava varieties—two improved varieties (TMS 4(2)1425 and Bocou 2) and one indigenous variety (Bocou 2)—commonly grown in Côte d'Ivoire.

2 MATERIAL AND METHODS

2.1 Cassava roots

Three mature cassava roots varieties "Bonoua 2," "Tropical Manihot Species (TMS 4(2)1425)," and "Bocou 2" grown under similar environmental conditions and cultural practices, were collected after 12 months of planting from Bonoua in southern Côte d'Ivoire). The cassava was planted in May 2025 and harvested in May 2026.

2.2 Cassava flours preparation

In brief, fresh cassava roots from each variety were peeled with an inox knife, washed, and ground into homogenised cassava mash using a laboratory cassava grinding machine. The resulting homogenised cassava smash was pressing using a mechanical press before undergoing spontaneous solid-state fermentation at 25 C for 24 hours. These fermented cassava samples were collected and dried to constant weight in an oven (Blue Pard, Yiheng Scientific Instruments Co., Shanghai, China) at 50°C for 48 hours. The dried material was then milled using a laboratory grinder and sieved through a fine-mesh (150µm) stainless steel sieve to obtain uniform fermented cassava flour before being packaged using an Audion-Vac VM 150H vacuum packaging machine (A1 Packaging Ltd, London, United Kingdom) into airtight polyethylene bags for later use.

2.3 Determination of physicochemical properties

The color was measured as lightness (L*), redness/greenness (a*), and yellowness/blueness (b*) using a Chroma meter (LOVIBOND® LC 100, England). Chroma and Whiteness index were deduced from L*a*b* using equation. The pH of 10% w/v suspension of flour was determinated with standard buffers of pH (4) and pH (7) using pH-meter (ATC, model HI-8915). The suspension was used to determine total soluble solids (TSS) using a digital bench top Hanna Digital

Refractometer (HI 96801, China). The water activity (aw) was measured using 1 g of flour with a water activity analyser (DECAGON; Aqua Lab model). Titratable acidity with 0.1 M NaOH using phenolphtalein as end-point indicator was determinated. The total HCN (ppm) of the flours was analysed using the AOAC silver nitrate titration method. Four 4% (w/v) of flour orthophosphoric acid solution was left at room temperature overnight. The solution was then distilled into 20 mL of 0.625M NaOH using steam distillation until its volume became 150 mL. The contents were then transferred to a 50-mL volumetric flask and made up to volume with distilled water. Next, 1.6 mL of 5% potassium iodide was added, and titration was performed with 0.01 M silver nitrate solution. The end point of titration was determined as color of the solution turned to bright yellow. The total HCN content, expressed in mg/kg, was calculated as follows:

$$HCN\ (ppm) = \frac{13.5 \times Titre\ value}{Mass\ of\ sample}$$

Starch and amylose were determined using iodine spectrophotometric methods reported by Du et al. [13]. Briefly, 0.1 g of flour samples were homogenised and mixed with 10 mL of extraction buffer dimethyl sulfoxide, followed by centrifugation to collect the supernatant. The supernatant was then reacted with the solution reagent (0.08 g of iodine and 1.1 g of potassium iodide dissolved in distilled water and adjusted to 500 mL in a volumetric flask). The absorbance was measured at 580 and 720 nm, respectively, for starch and amylose using a spectrophotometer (Agilent Technologies, Santa Clara, CA, USA). Starch and amylose content was calculated according Kacou et al., [14] based on a standard curve prepared with known amylose concentrations.

2.4 Determination of functional properties

Densities, water or refined oil absorption capacity, hydrophilic-lipophilic ratio, and solubility index were determined. The tapped density of the flour samples was determined after the bottom of the cylinder had settled completely. This allowed for the calculation of the Carr index, Hausner ratio and porosity. Light transmittance was determined by heating an aqueous cassava flour dispersion until the starch granules were fully gelatinised and then measuring it at 650 nm with a UV-Vis spectrophotometer. The emulsion, foam, swelling power, foaming capacity, wettability, dispersibility and gelling properties of the flours were evaluated as described in a previous study by Soro et al. [15]. Viscosity measurements were carried out by determining the flow times of flour suspensions using an AVS 400 capillary viscometer (Schott Gerate, Hofheim, Germany), fitted with an Oswald capillary tube, at a temperature of 25 ± 0.1 °C and immersed in a temperature-controlled water bath.

2.5 Statistical Analysis

All analyses were performed in triplicate. Means and standard deviations were calculated with Excel 2021. Statistical analyses were performed with Statistica 7.1. An ANOVA was conducted to compare variables. In case of significant difference, the Duncan test was used to classify means into homogeneous groups. The significance threshold was set at $p < 0.05$.

3 RESULTS AND DISCUSSION

3.1 Physicochemical Characterisation of Fermented Cassava Flour

The results presented in Table 1 and 2 show that there are significant differences ($p < 0.05$) in colour the physicochemical parameters of the fermented cassava flours. Colour characteristics are an important quality attribute of flour for consumer acceptability and food industries. All flours had L^* ranging from 83.61 to 85.67. The values obtained are higher than those reported (73.82) by Bolaniran et al. [16] for fermented composite flour derived from *Dioscorea bulbifera*. No noticeable variation ($p > 0.05$) was observed in the whiteness index of cassava flour across all varieties. Cassava flour's high values of lightness (L^*) and low values for chroma are considered ideal colour quality parameters for industrial applications [17]. This result may be explained by the fact that fermentation causes a change in the cellular pigments, thereby improving the whiteness of the cassava flour. Because the colour of cassava products is influenced by factors such as variety, maturity stage, and processing techniques, these findings' value in this study could be similar to or different from previous studies' values. According to Safi et al. [18], flours with a high whiteness index directly improve the visual appearance, brightness, and consumer acceptance of finished baked goods and noodle products. The moisture content of the cassava flour ranged from 7.82 to 11.33 %. The 'Bonoua 2' cassava flour had both a low moisture content and low water activity (0.490). This would suggest that this cassava variety is suitable, indeed ideal, for flour production.

Table 1: Color index of fermented cassava flours

Parameters	TMS 4	Bocou 2	Bonoua 2
*L**	83.61 ±1.33^{ab}	85.67 ±1.02^{a}	84.22 ± 0.85^{a}
*a**	4.37 ± 0.23^{a}	3.77 ± 0.55^{b}	4.85 ± 0.23^{a}
*b**	11.66 ± 0.44^{bc}	13.22 ± 1.32^{a}	12.55 ± 1.91^{ab}
Chroma	12.45 ± 0.18^{b}	13.75 ± 0.22^{a}	13.45 ± 0.25^{a}
Whiteness index	79.46 ± 0.86^{a}	80.14± 1.33^{a}	79.26± 1.08^{a}

Mean values with different superscripts in a column are significantly ($p \leq 0.05$) different from each other.

This moisture content range is ideal because it falls within the recommended range (8–12.5 %) for high-quality fermented cassava flour [19]. According to Hawa et al. [20], finished flours target a water activity level below 0.60. Maintaining Aw < 0.60 is the standard threshold to prevent any enzymatic activity, mould growth, or bacterial proliferation during storage. Water activity is also important to evaluate the stability, quality, and safety of spray-dried powders during handling, transportation, and storage [21]. Solid-state fermentation (24 hours) of cassava resulted in a decrease in pH (4.76–6.08). The titratable acidity (0.66–0.71%) and hydrocyanic acid content (7.97–9.20 mg/kg) varied significantly amongst the flours studied. The HCN negative correlation with pH (r = -0.960) and TTA (r = -0.967) (Figure 5) could be explained by the fact that fermentation breaks down cyanogenic glycosides and removes HCN, thereby producing organic acids. This leads to a fall in pH with an increase in titratable acidity in fermented flour. This is indicating an increase of microbial activity and acid production during fermentation. Acidification during fermentation by lactic acid bacteria and yeasts convert available carbohydrates and sugars into organic acids which lowers the pH of the environment [22]. This explains the low total soluble sugar (TSS) content (2.55–3.46) observed in the flours studied. Bamidele's [23] previous research had shown a reduction in TSS from 5.82 to 2.12 in cassava flour after 48 hours of fermentation. The high TSS content demonstrates the nutritional quality of fermented cassava flour, which contains an ideal amount of nutrients dissolved in sugars to provide energy. According to Bamidele (2025) [23], natural fermentation significantly reduces phytates, hydrogen cyanide (HCN) levels, and trypsin inhibitor activity, all major antinutritional factors in cassava pulp. In this study the flour pH range is appropriate; cassava flour with a lower pH (< 4) exhibits a characteristically sour taste that negatively impacts flavour, rendering it unsuitable for baking [24]. The HCN concentrations observed are in line with the recommended maximum acceptable limit of 10 ppm (FAO/WHO, 2020). The values obtained are lower than those of 11.19 to 61.70 mg/kg reported by Akely et al. [25] for six varieties of cassava flour: Bonoua 2, Yace, Yavo, Bocou 1, Bocou 2, Bocou 3 and TMS (2) 1425. A previous study conducted by Du et al. [13] showed that the amylose content did not vary significantly in cassava flour following fermentation. Therefore, the amount of amylose found in our study may be linked to the inherent amylose content (18.31–21.50 %) in the cassava varieties used to produce these flours.

Table 2: Physicochemical parameters of fermented cassava flours

Parameters	TMS 4	Bocou 2	Bonoua 2
Moisture (%)	10.50 ± 0.04^{b}	11.33 ± 0.04^{b}	7.82 ± 0.04^{a}
Water activity	0.567± 0.001^{ab}	0.612± 0.001^{a}	0.490 ± 0.004^{c}
Ph	5.66 ± 0.09^{b}	4.94 ± 0.04^{c}	6.08 ± 0.02^{a}
TTA (% lactic acid)	0.66 ± 0.12^{ab}	0.68 ± 0.02^{a}	0.70 ± 0.06^{a}
HCN (mg/kg)	9.20 ± 0.44^{a}	7.97 ± 0.93^{b}	8.43 ± 0.15^{b}
TSS (°Brix)	3.46 ± 0.25^{a}	2.55 ± 0.22^{b}	3.10 ± 0.29^{a}
Starch (%)	76 ± 2.67^{a}	64 ± 1.99^{c}	69 ± 2.06^{b}
Amylose (%)	21.50 ± 1.33^{a}	18.31 ± 2.54^{b}	15.44 ± 1.57^{c}
Amylopectin (%)	57.29 ± 0.91^{a}	53.19 ± 1.22^{b}	51.43 ± 0.56^{bc}

Mean values with different superscripts in a column are significantly ($p \leq 0.05$) different from each other.

Person correlation (figure 5) showed amylose content inversely proportional to water absorption (r= -0.945). However, prolonged fermentation of cassava is thought to promote the conversion of amylose into simple sugars by amylase. This would result in a significant reduction in the amylose content of the final flour [26].

3.2 Functional properties of Fermented Cassava Flour

Determining the functional properties of starchy flours is crucial in food formulations. The functional properties of fermented flours from selected cassava ‘Bonoua 2’, ‘TMS4’ and ‘Bocou 2’ varieties grown in Côte d’Ivoire are presented in Figures 1–4. There was significant difference in functional properties of the flours (p =0.05). The bulk density of the fermented flours ranged from 0.51 to 0.59 g/mL. The flour produced from the ‘Bocou 2’ variety had the highest bulk density, suggesting that it is finer and more compact, as indicated by its high tapped density (0.67 g/mL). Shankaraswamy & Okechukwu-Ezike [27] found a high value of 0.79 g/cm^3 for TMS4 fermented cassava flour. The same authors reported that high bulk density is desirable for greater ease of dispersibility of food powder and reduction of paste thickness. However, Fermented flours with a low bulk density, are beneficial in the infant food formulation due to their high nutritional density combined with a low volume. Shankaraswamy & Okechukwu-Ezike [27] found a high value of 0.79 g/cm^3 for TMS419 fermented cassava flour. The same authors reported that a high bulk density is desirable for greater ease of dispersibility of food powder, while a reduction in bulk density is also desirable for improving the dispersibility of food powder and reducing paste thickness. However, fermented flours with a low bulk density are beneficial in the infant food formulation due to their high nutritional density combined with a low volume. Indeed, fermentation leads to cell breakdown and a transformation of the biopolymers into particles that are more porous, more irregular in shape and of lower density [28]. These fermented flours hausner ratios (1.14–1.16) < 1.20, indicating excellent flow properties [28]. Furthermore, due to its low Carr index (11.94 %), the flour produced from the Bocou 2 variety is thought to have better flow properties than the other flours. In food engineering and powder technology, the flowability of flour is a key factor in determining the efficiency of its processing and handling, as well as its uniformity. It determines how easily the flour can flow through hoppers, conveyors, mixers and industrial packaging systems without becoming clogged or forming stable arches [29]. The viscosity (0.291 - 0.424 Pa.s) was higher for Bonoua 2 fermented flour. The maximum level of amylose in Bonoua 2 flour favours its higher viscosity. Indeed, fermentation intensity affects starch and its apparent amylose concentration, contributing to a decrease in viscosity [28]. However, TMS(4) flour's low viscosity indicates that it is suitable for making weaning foods for newborns. [30]. The swelling power (12.33-14.51) was higher for Bocou 2. The difference in sweling powercould be due to the size of the particles, the variety, wich affect how much a flour can swell. Bonoua 2 flour's low swelling power could suggest stronger bonding forces within the interiors of starch granules and more amylose-lipid complex. In this study, both the porosity (85.00–88.06 %) and the dispersibility (65.44–70.55 %) of the ‘Bocou 2’ fermented cassava flour were found to be high. Fermentation significantly improves both the porosity and dispersibility of fermented cassava flour, making it a highly versatile gluten-free substitute for conventional cereal flours. These two parameters in this study show a positive correlation (r = 0.905), as shown in the correlation matrix in Figure 5. The wettability time (12.33-14.51 s) was lower for the TMS(4) fermented flour, while the water absorption capacity (318-379 %) was high. This study reveals WAC had a positive correlation (r = 0.962) with amylose and swelling index (r = 0.962) (Figure 5). The linear structure of amylose explains the correlation by the fact that it promotes the formation of numerous hydrogen bonds with water, thereby conferring a greater water absorption capacity. The wettability time measured was less than twenty seconds (< 20 s) for all the flours, indicating that they were dissolved in water in a short time, which is an advantage when preparing baby porridge. A previous study by Shankaraswamy & Okechukwu-Ezike [27] revealed that as the fermentation periods increased, the time of wettability of the flours decreased. Indeed, fermentation increases the breakdown of starch and proteins, resulting in increased hydrophilic groups that enhance interaction and penetration of water molecules and increased wettability and water absorption. The increase in water absorption capacity is functionally relevant and can lead to enhanced moisture retention and softer food texture and aid in dough formation [31], suggesting that these flours are suitable for baked foods, weaning foods, and other moisture-dependent food applications. However, the high oil absorption capacity (316 g/100 g) of Bonoua 2 flour suggests that it would be more suitable for use in the production of bakery products or meat-based products where fat absorption is desirable. Gel consistency is used to characterise the fluidity or firmness of starch-rich flours such as cassava flour. In this study, the gel consistency (32.43–25.78 mm) was higher for the fermented Bonoua 2 flour. Fermentation alters the consistency of the gel due to changes in the starch. Furthermore, the amylose-to-amylopectin ratio, which varies by cultivar, is a determining factor. In the study, the negative correlation (r = -1.00) shown in Figure 5 indicates that the higher the amylose content, the lower the consistency of the gel. Freeze-thaw stability (syneresis) is an important parameter for their use in frozen and chilled food products. This syneresis varies considerably depending on the botanical origin of the starches [32]. In this study, the syneresis value (22.78–26.5 %) was found to be high in Bocou 2 fermented flour. During the fermentation process, changes to the starch affect its gelatinisation and retrogradation, leading to a reorganisation of the gelatinous network which expels water, thereby causing an increase in syneresis. These changes to the starch may explain the negative correlation between syneresis and starch (r = -1.00), amylose (r = -0.988) and amylopectin (r = -0.903). Emulsion activity (42.88-61.89), emulsion stability (42.55-48.84) and foaming stability (32.76-36.51) were high for TMS4 fermented flour, whereas foaming capacity (23.44-25.59) was high for Bocou 2 fermented flour. According to Bamidele and Chimphepo et al. [23,24], fermentation results in minor changes or slight improvements in foaming and emulsifying properties due to the partial hydrolysis of the starch and a slight increase in protein content derived from microbial biomass. Fermented cassava flour exhibits moderate emulsion stability, as the breakdown of the starch increases the interactions between water and oil, which promotes the suspension of the droplets. However, it is less effective than specific commercial emulsifiers or protein-rich legumes [33].

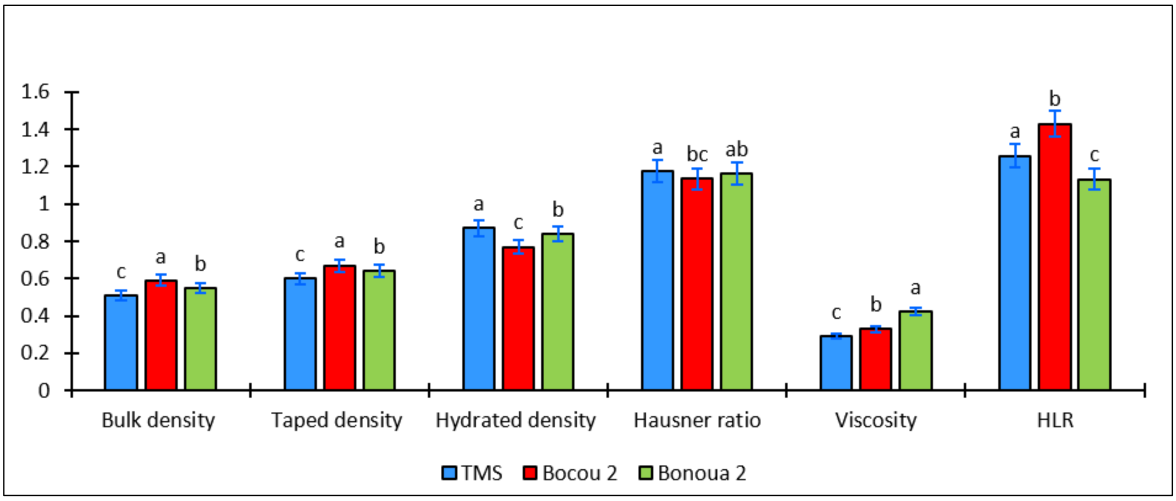


Figure 1: Densities, Hausner ratio, viscosity and HLR of fermented flours

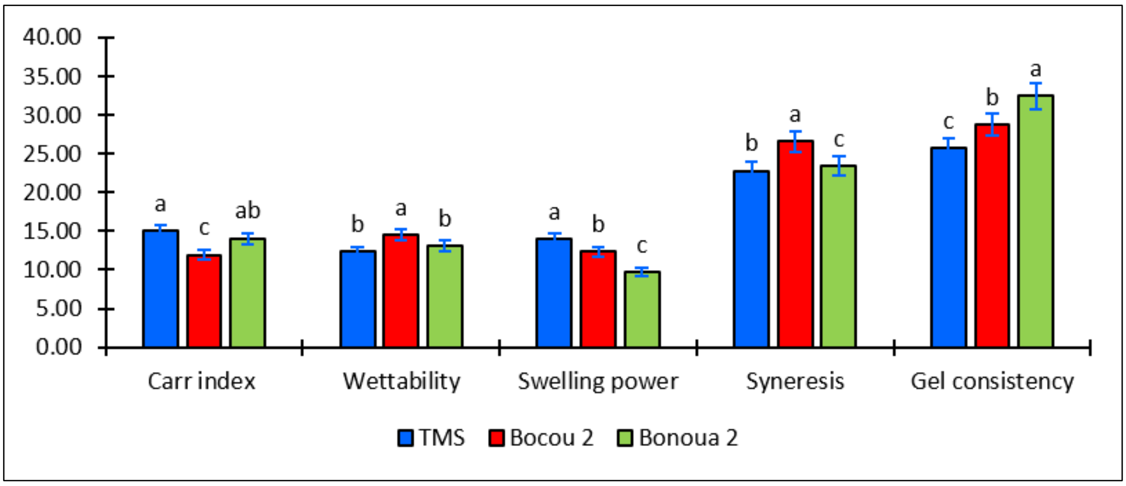


Figure 2: Car index, wettability, swelling, syneresis, gel consistency of fermented flours

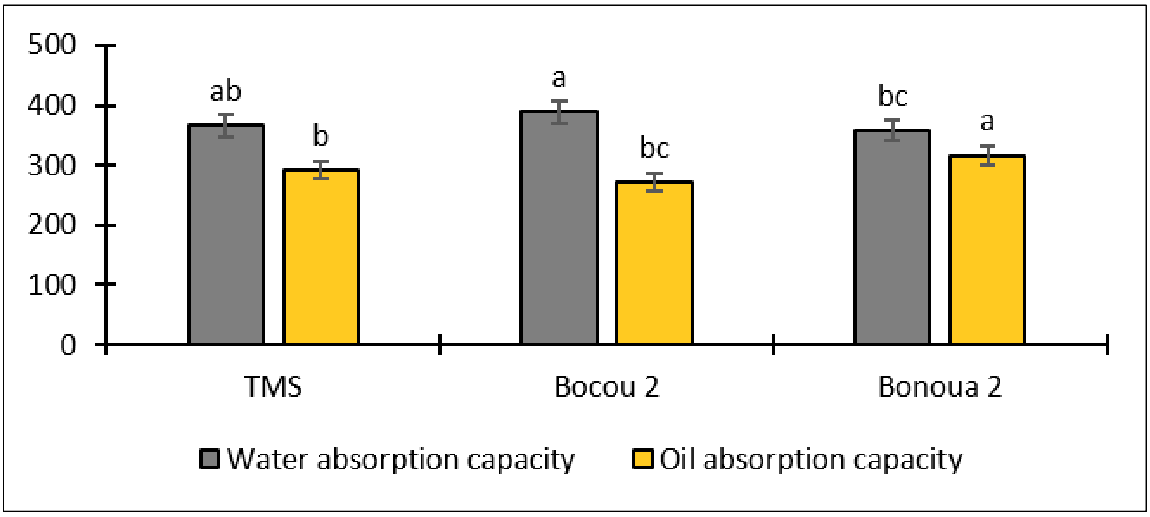


Figure 3 : Water and oil absorption capacities of fermented cassava flours

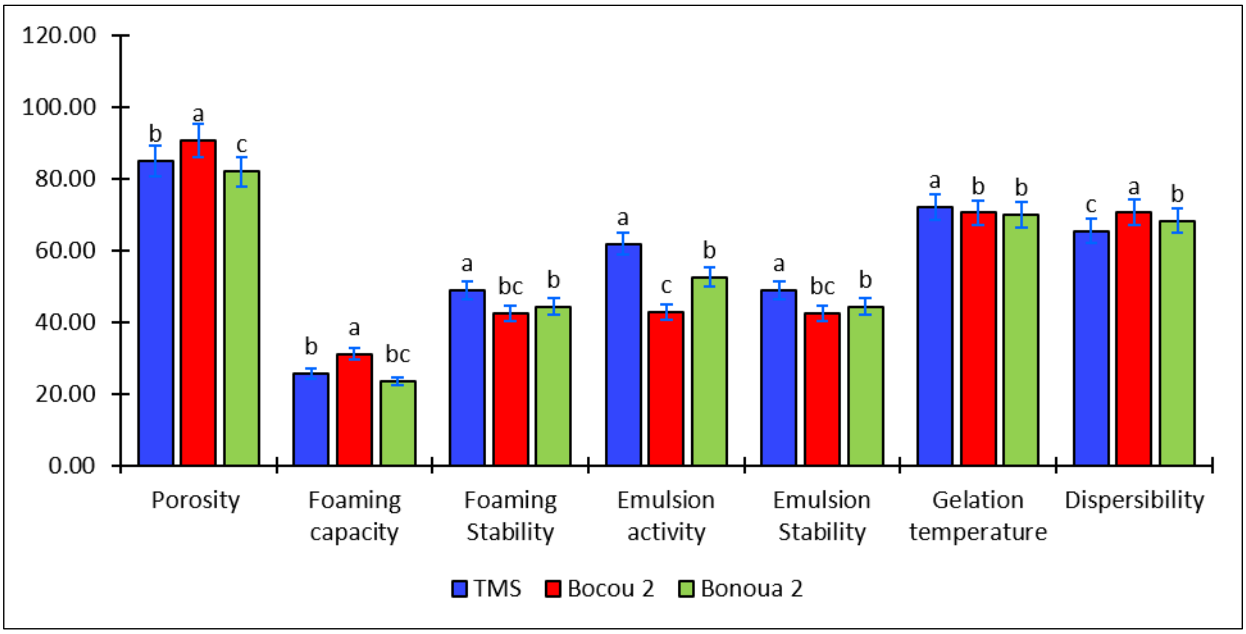
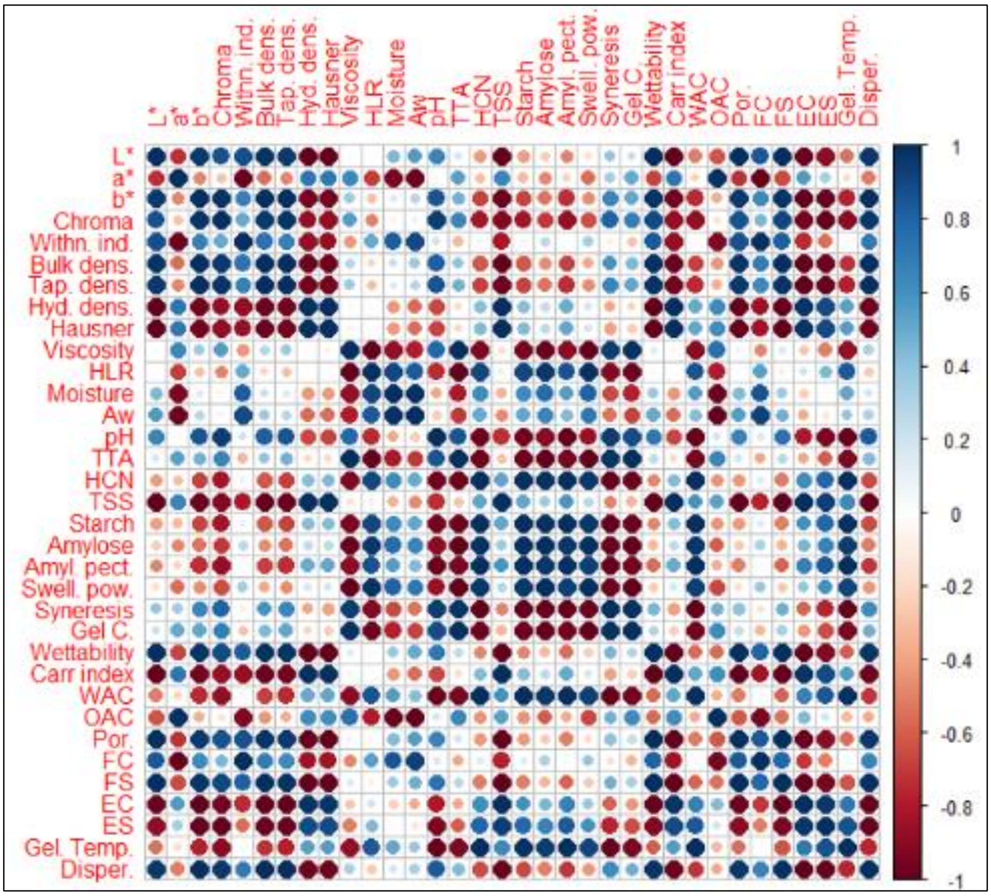


Figure 4: Porosity, foaming, emulsion gelation and dispersibility of fermented flours



Disper.: Dispersibilty, Swell. pow.: Swelling, Withn. ind.: Withness index, Por.: Porosity, C.: Consistency, Tap:. Taped, Hyd :. Hydrated, Emul.: Emulsion, LGC.: Least Gelation Concentration, R.: Ratio, D.: Density, Gel. Temp.: Gellation Temperature.

Figure 5: Correlogram matrix between physicochemical and functional properties

3.3 Principal Component Analysis (PCA)

Principal component analysis (PCA) was employed to visualize the variation in properties among the fermented flours resulting from the various cultivar used in this study. The results of the analysis are shown in Figure 6 below. This statistical method reduces a large number of variables to a few, known as principal components (PCs), which describe the greatest variance in the analyzed data. PCA plots provide an overview of the similarities and differences between flours, as well as the relationships between the measured properties. The first and second PCs explained 61.81% and 38.19% of the variance, respectively. Together, the first two PCs represent 100.00% of the total variability (Figure 6). Based on the plot, these fermented flours from 'Bonoua 2', 'TMS4' and 'Bocou 2' cultivar had significative ($p < 0.05$) variabilities in physicochemical and functional properties representing three cluster in bipolt (Figure 6). TMS4 fermented flour is distinguished by its gelation temperature, emulsifying capacity, emulsion stability, amylopectin content, water absorption capacity, total soluble sugar content, total HCN content, starch content, amylose content, swelling capacity, water absorption capacity, hydrated density, HLR ratio and Hausner ratio.

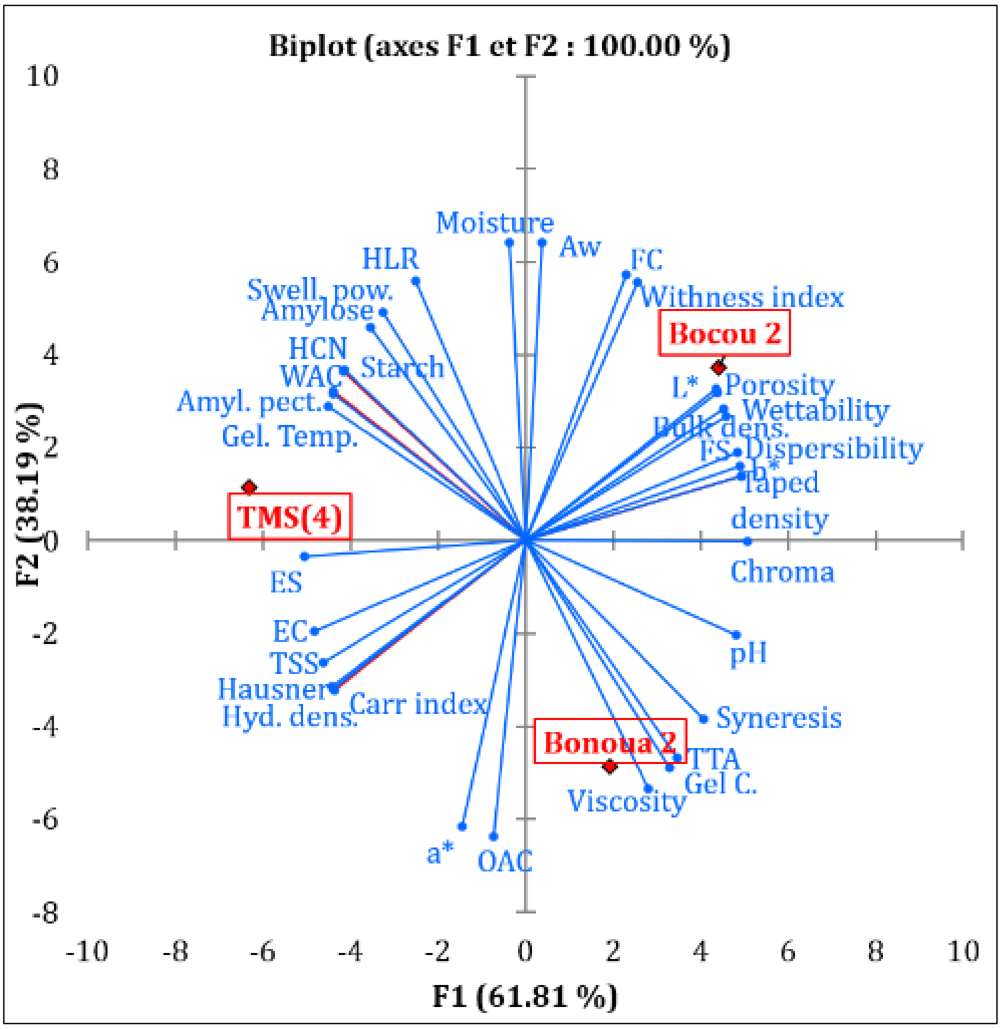


Figure 6: Principal component analysis score biplot among fermented flours from different cultivar (red) and physicochemical, functional properties (blue).

This suggests that fermented flour (TMS) would be more suitable for food products requiring the flour to absorb water, such as porridges, pasta and thickeners. Bonoua 2 fermented flour was classified according to its oil absorption capacity, viscosity, gel consistency, syneresis, pH, titratable acidity and chroma. This suggests that the fermented flour (Bonoua 2) would be more suitable for sausages, bakery products, meat substitutes, yoghurts, cheese, jam and gelatine-based desserts. Bocou 2 fermented flour correlates with water activity, foaming capacity, whiteness index, porosity, moisture content, dispersibility and bulk density. This suggests that fermented flour (Bocou 2) may be better suited to long-term storage, food safety, visual appeal and consumer acceptance.

4 CONCLUSION

In conclusion, solid-state fermentation has made it possible to reduce the HCN content relative to the recommended levels and to produce cassava flours fit for human consumption with ideal physicochemical and functional properties. This study revealed that physicochemical and functional properties of fermented cassava flours were significantly affected by the cassava 'Bonoua 2', 'TMS4' and 'Bocou 2' varieties grown in Côte d'Ivoire. Flours from all cassava varieties contained acceptable functional properties, demonstrating the suitability to be utilised as an ingredient/raw material in different food formulations. Further, flours of these cassava varieties can be combined with the flours from other grains and legumes to develop functional flours for modern nutrimental applications.

STATEMENTS ON COMPLIANCE WITH ETHICAL STANDARDS

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Disclosure of conflict of interest

No conflict of interest to be disclosed.

REFERENCES

[1] Mohidin SRNSP, Moshawih S, Hermansyah A, Asmuni MI, Shafqat N, Ming LC. Cassava (Manihot esculenta Crantz): A Systematic Review for the Pharmacological Activities, Traditional Uses, Nutritional Values, and Phytochemistry. J Evid Based Integr Med. 2023;28:2515690X231206227. doi:10.1177/2515690X231206227 PubMed PMID: 37822215; PubMed Central PMCID: PMC10571719.

[2] Assanvo JB, Agbo GN, Coulin P, Heuberger C, Farah Z. Etude comparée de 3 attiéké traditionnels et d'un attiéké commercial (Garba): Enquêtes sur les méthodes de production et caractéristiques physicochimiques du ferment de manioc et des différents produits finis. International Journal of Innovation and Applied Studies. 2019;26:1108-33.

[3] Nadjiam D, Ayessou NC, Guissé A. Physicochemical Characterization of Nine Cassava (Manihot esculenta Crantz) Cultivars from Chad. FNS. 2020;11:741-56. doi:10.4236/fns.2020.117053

[4] Kaur K, Ahluwalia P. Cassava as Potential Crop for the Food and Fermentation Industry: A review. Inte Jour of Food and Ferm Tech. 2017;7:1. doi:10.5958/2277-9396.2017.00001.0

[5] NZue B, Tanoh KE, N'zi JC, Essis B, Dibi K, Koffi A, et al. Agronomic and Culinary Evaluation of Cassava (Manihot Esculenta Crantz) Clones with Colored Flesh under Selection in Bouake (Cote d'Ivoire). International Journal of Science and Research (IJSR). 2022;11:824-32. doi:10.21275/SR22701220516

[6] Modeste KK, Adolphe M, Boni N, Edmond K, Camille K. Status of Cassava (Manihot Esculenta Crantz) in Côte d'Ivoire: From Production to Consumption and Evaluation of Technology Adoption. European Scientific Journal, ESJ. 2018;14:285-285. doi:10.19044/esj.2018.v14n9p285

[7] Mobio AJ, Fokou G, Aka S, Kouassi KB, Kreppel KS, Kouakou KP, et al. Exploring beyond the conjunctural rhetoric: sociocultural drivers for the "cassava crisis" in Côte d'Ivoire. Agric Econ. 2021;9:2. doi:10.1186/s40100-020-00174-0

[8] Niyibituronsa M, Shingiro JB, Nzamwita M, Ndilu L, Nyirahanganyamunsi G, Hagenimana G, et al. Chemical Characterization and Acceptability of Eight Cassava Varieties Introduced in Rwanda. Journal of Food Research. 2021;10. doi:10.5539/jfr.v10n3p1

[9] Sheela I, Jaganathan, D, Prakash P, Sethuraman S. Cassava for Food Security, Poverty Reduction and Climate Resilience: A Review. Indian Journal of Ecology. 2024;51:21-31. doi:10.55362/IJE/2024/4191

[10] Thaweewong P, Anuntagool J. Change in free cyanide content of bitter cassava during incubation and drying and physical properties of dry-milled cassava flour. Food and Bioproducts Processing. 2023;138:139-49. doi:10.1016/j.fbp.2023.01.009

[11] Widowati S, Misgiyarta, Setyawan N, Herawati H, Widaningrum, Suhirman S, et al. Physicochemical and functional properties of cassava flour produced by controlled fermentation using mixed culture from various bacteria and yeast. Journal of Agriculture and Food Research. 2025;19:101684. doi:10.1016/j.jafr.2025.101684

[12] Nilusha RAT, Jayasinghe JMJK, Perera ODAN, Perera PIP, Jayasinghe CVL. Proximate Composition, Physicochemical, Functional, and Antioxidant Properties of Flours from Selected Cassava (Manihot esculenta Crantz) Varieties. Int J Food Sci. 2021;2021:6064545. doi:10.1155/2021/6064545 PubMed PMID: 34926679; PubMed Central PMCID: PMC8674075.

[13] Du P, Liang J, Zhang H, Tan W, Liang G, Paul O, et al. Enhanced Cassava Flour Quality to Improve the Cassava Bread by Attibutes Yeast Fermentation. Food Science & Nutrition. 2025;13:e70581. doi:10.1002/fsn3.70581

[14] Kacou MA, Abbé YC, Aboa N, Boni N, Kouamé PL. Physicochemical Properties of Flours from Four Traditional Cassava (Manihot esculenta CRANTZ) Varieties Grown in Côte d'Ivoire | International Journal of Biochemistry Research & Review [Internet]. 2026 [cité 3 sept 2026]. Disponible sur: https://journalijbcrr.com/index.php/IJBCRR/article/view/1099

[15] Soro PL, Yao A, Kouadio MK, Koné FMT, Dabonné S, Kouamé PL. Comparative Effect of Cyanide Reduction Processes on the Techno-functional Properties of Cassava Flour. American Journal of Life Sciences. 2026;14:30-48. doi:10.11648/j.ajls.20261402.12

[16] Bolaniran T, Abubakar NS, Ocheme O, Hadiza LM. Nutritional and Techno-Functional Properties of Flours Processed from Dioscorea bulbifera Fermented with Edible Calocybe indica and Pleurotus ostreatus. International Journal of Chemical and Biochemical Sciences. 2025;27:302-8. doi:10.62877/41-IJCBS-25-27-21-41

[17] Tembo M, Alamu OE, Bwembya AP, Chitundu K, Emmanuel LL, David C. Cyanogenic content, moisture, and color of cassava products commonly consumed in Zambia. Afr J Food Sci. 2024;18:1-10. doi:10.5897/AJFS2023.2278

[18] Safi M, Jafari R, Taheri F. Quantifying whiteness tolerance for fluorescent textiles using color-difference formulas. Sci Rep. 2026;16:20625. doi:10.1038/s41598-026-50264-0 PubMed PMID: 42086646; PubMed Central PMCID: PMC13333985.

[19] Udoro EO, Anyasi TA, Jideani AIO. Process-Induced Modifications on Quality Attributes of Cassava (Manihot esculenta Crantz) Flour. Processes. 2021;9:1891. doi:10.3390/pr9111891

[20] Hawa LC, Ubaidillah U, Damayanti R, Hendrawan Y. Moisture sorption isotherms of modified cassava flour during drying and storage. Heat Mass Transfer. 2020;56:2389-96. doi:10.1007/s00231-020-02866-1

[21] Meena KK, Taneja NK, Jain D, Ojha A, Badgujar P, Raigar RK. Physicochemical, Morphological, and Microbial Characterization of Spray-Dried Dairy–Cereal Grain-Based Probiotic Beverage (Raabadi) Powder. Future Postharvest and Food. 2025;2:372-80. doi:10.1002/fpf2.70011

[22] Akhtar MF, Wenqiong C, Umar M, Changfa W. Biochemical properties of lactic acid bacteria for efficient silage production: an update. Front Microbiol. 2025;16. doi:10.3389/fmicb.2025.1581430

[23] Bamidele OP. Effects of Natural Fermentation Time on Chemical Composition, Antioxidant Activities, and Phenolic Profile of Cassava Root Flour. Applied Sciences. 2025;15:8494. doi:10.3390/app15158494

[24] Chimphepo L, Alamu EO, Monjerezi M, Ntawuruhunga P, Saka JDK. Physicochemical parameters and functional properties of flours from advanced genotypes and improved cassava varieties for industrial applications. LWT. 2021;147:111592. doi:10.1016/j.lwt.2021.111592

[25] Akely PMT, Gnagne EH, To Lou GMT, Amani GN. Varietal influence of cassava on chemical composition and consumer acceptability of gari. Int J of Food Sci Tech. 2021;56:1239-46. doi:10.1111/ijfs.14610

[26] Nurhayati N, Jayus J, Fijriyah H. Physico-Chemical and Functional Characteristics of Fermented Cassava Flour by Lactobacillus Casei Using Submerged and Solid-State Fermentation. In: Proceedings of the International Conference on Food, Agriculture and Natural Resources (FANRes 2018) [Internet]. Yogyakarta, Indonesia: Atlantis Press; 2018 [cité 1 sept 2026]. Disponible sur: https://www.atlantis-press.com/article/25907138 doi:10.2991/fanres-18.2018.41

[27] Shankaraswamy J, Okechukwu-Ezike NC. The functional properties of four cassava varieties as affected by fermentation time. Journal of Applied Horticulture. 2024;26:394-9.

[28] Kıymaz BM, Ozturk E, Ozcan Y, Toker OS, Aric M. Modification of einkorn flours via lactic acid fermentation: changes in techno-functional and rheological properties. Journal of Food Measurement and Characterization. 2026;20. doi:10.1007/s11694-026-04510-8

[29] Tosin P, Adebisi WO, Okon OA. Evaluation of particle size, flowability and thermal properties of formulated composite wheat-sologold sweet potato flour for baked products. Int J Phys Sci. 2024;19:18-25. doi:10.5897/IJPS2023.5062

[30] Mudau M, Ramashia SE, Mashau ME. Mineral Content, Functional, Thermo-Pasting, and Microstructural Properties of Spontaneously Fermented Finger Millet Flours. Foods. 2022;11:2474. doi:10.3390/foods11162474

[31] Kizzie-Hayford N, Ampofo-Asiama J, Dadzie RG, Seidu-Larry S, Geraldo V, Gyimah CA, et al. Effects of Sprouting and Fermentation on the Physicochemical Properties and Nutritional Composition of Cowpea Flour, and Consumer Acceptability of Composite Doughnuts Made Thereof. Legume Science. 2025;7:e70045. doi:10.1002/leg3.70045

[32] Rashwan AK, Zhou F, El-Harairy A, Chen W. Structural, physicochemical, and gel properties of Wencheng yam (Dioscorea alata L.) starch and its application for enhancing set-type yogurt properties. Food Chemistry: X. 2025;32:103215. doi:10.1016/j.fochx.2025.103215

[33] Adekunle. OA, Ojo MA, Adebiyi Olabode AO, Adegbola GM, Ajani RichardA. Effects of Fermentation on the Functional Property, Physicochemical and Suitability of Cassava Starch/Flour for Food Production. IntJCurrMicrobiolAppSci. 2026;15:262-71. doi:10.20546/ijcmas.2026.1503.027