

Production and characterization of cassava peel flour from three varieties (*Manihot Esculenta Crantz*) to combat food insecurity

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Abstract

Background: Cassava peels usually discharged as wastes during cassava processing were found to have good nutritional properties, but their high anti-nutrients contents limit their utilization. However, fermentation process has greatly contributed to reduce these anti-nutrients and also to enhance the nutritional composition. This study explored the nutritional upgrading of three Cameroonian cassava peels, which are usually discarded since they have high antinutrients.

Materials and Methods: Cassava peels of three Cameroonian varieties (Mbongdoux, TME-693 and 01/17/97) were naturally fermented for 1,2,3,4 and 7 days, then milled into flour. The resultant flour samples were analyzed for their physico-chemical properties. The anti-nutritional, proximate and techno-functional analyses were performed using AOAC methods and minerals by atomic absorption spectrophotometry.

Results: The results showed that fermentation significantly reduced ($P<0.05$) the hydrogen cyanide and oxalate contents of the different flours samples. Proximate analysis showed a decrease in fat, protein and ash contents, and an increase in crude fibre with increase in fermentation periods while carbohydrate content was not significantly ($P<0.05$) affected. TME-693 recorded the highest crude fibre content when fermented for 4 days ($16.89\pm0.06\%$) and 7 days ($17.37\pm0.11\%$) respectively. Concerning minerals, the variety TME-693 recorded the highest calcium, magnesium and zinc contents when fermented for 4 days while the highest potassium, sodium and phosphorous contents were recorded by the variety 01/17/97 in the non-fermented flour. For techno-functional properties, TME-693 showed the highest water absorption capacity and oil absorption capacity when fermented for 4 days ($454.71\pm29.10\%$) and 7 days ($433.77\pm49.86\%$).

Conclusion: However, the improvement in the nutritional composition and reduction in cyanide content of cassava peels flour occurred with increase in fermentation time making the flour samples edible.

Key words: Cassava peels, Anti-nutrients, Natural fermentation, By-product, Edible flour

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I. Introduction

Cassava (*Manihot esculenta* Crantz) is a root crop rich in starch widely cultivated and consumed as a staple food by more than 800 million people in tropical countries¹. The annual production of cassava is estimated at 330.33 million tonnes (Mt) in the World, 208.77 Mt in Africa and 6.5 Mt in Cameroon.² Due to its high starch content, tolerance to drought and poor soil conditions, availability throughout the year and suitability for diverse smallholder farming, cassava plays a major role in efforts to eradicate famine in Africa³. Furthermore, cassava acts as a food storage due to its perennial characteristics and greatly contributes to food diary⁴.

Cassava represents the second most important food crop in Cameroon after maize and is cultivated in the five agro-ecological zones. Generally, cassava is classified based on its hydrogen cyanide (HCN) content as sweet and bitter cultivars¹. The cultivation of cassava is primarily aimed at human consumption, starting from boiling the tubers to flour processing, which are essential sources of carbohydrates. The leaves are eaten as vegetables and are sources of proteins and vitamins⁴. A study by Youchahou et al. (2019) revealed that each Cameroonian household consumes about 75kg of cassava annually, and the commonly consumed by-products include: *garri*, *fufu*, *miondo* and flour. However, the cultivation of cassava is limited due to the presence of cyanogenic glycosides where the most abundant are linamarin and lotaustralin. This toxicity can cause health issues in populations that consume large quantities improperly treated cassava such as: goitre, cretinism, ataxic neuropathy⁶.

During the processing of cassava, a high quantity of cassava peels is generated as wastes. These peels constitute 35% of the tuber weight and are the first by-products derived from cassava processing⁷. They are often discharged

or dumped as wastes into the environment, leading to cassava wastes disposal problem and environmental pollution⁸. Furthermore, they can be used, fermented or no for animal feed formulations due to the fact that they were found to have appreciable food compositions which is as follows: total protein 6.24g/100g, crude fibre 10.88g/100g, crude fat 1.39g/100g and carbohydrate 75.20g/100g^{9,10, 11}) showed that cassava peels flour have good minerals composition. This composition relates to that of cassava flour which is also a crude fibre and carbohydrate rich product already consumed through bakery products formulations in the food industry. Despite the above appreciable compositions, their high concentrations of HCN limits their utilization. Nevertheless, fermentation could be an efficient approach to reducing the HCN content for both industrial and domestic use as reported by Adeleke et al., (2017). The biodegradation of peels through fermentation processes might be an adequate method of improving the shelf life, texture, aroma, nutritional quality, digestibility and reduce their anti-nutrients¹². Despite this potential, studies made on cassava peels to our knowledge are limited. This study aims at valorizing cassava peels through the production of an edible flour from peels of three cassava varieties from Cameroon having acceptable anti-nutrients contents and appreciable nutritional compositions for food formulations.

II. Materials and Methods

Biological material

Fifty kilograms of cassava roots of three varieties were harvested in March 2024 from a nearby farm in Yaoundé town and transported to National Herbarium for identification. The plant material consisted of peels of three cassava varieties: two improved varieties (01/17/97) and TME-693 and a local variety Mbongdoux. Of the three varieties, (01/1797) and Mbongdoux are sweet varieties while TME-693 is a bitter variety These roots were then transported to the Laboratory for Food Science and Metabolism (LabSAM) of the University of Yaoundé 1 where they were hand peeled. The peels obtained were washed and processed into flour as follows:

Flour production

The tubers of each cassava variety were peeled by hand using a table knife to remove the two outer layers. The skins were collected and the cortex (skin) was separated from the periderm (bark) and washed thoroughly several times with distilled water to remove dirt particles and sand. Each variety of cleaned peels was segmented into 6 portions. The first portions were non-fermented (Day0), washed, oven (Memmert) dried for 24 hours at 50 °C then ground with use of a grinder (Blend-X BLP41.A0WH). The remaining 5 portions were fermented for 1 day, 2 days, 3 days, 4 days and 7 days respectively. The fermentation process was done by introducing 5Kg of washed peels into a container, followed by addition 10L of distilled water at room temperature. After, the fermentation period completed, the peels were washed, oven dried for 24h at 50°C. The dried samples were ground using a blender to obtain homogeneous samples with a particle size of 250 µm. The production yield was calculated and the flours obtained were packaged in polythene plastics to prevent flour rancidity and kept for analysis notably the anti-nutrient, proximate, mineral and techno-functional properties.

Anti-nutrients analysis

The cyanogenic glycosides content was determined daily using the titrimetric method described by Horwitz *et al.*¹³ which is based on the hydrolysis of glycosides by orthophosphoric acid with the liberation of hydrogen cyanide. Total oxalate content was performed by the oxidation of oxalic acid by KMnO₄ in the presence of sulphuric acid¹⁴. Phytate content was determined by titration with an iron III solution after acid digestion¹⁵. The Saponin content was determined by the difference in weight after solvent extraction. Tannins were analyzed using a ferric reagent in an acidic alcoholic medium with gallic acid as a standard¹⁶.

Proximate Analysis

The moisture content was determined by drying 1g of the flour sample in an electric oven at 105°C to constant mass¹⁷. Crude fibre was detected by the successive digestion of 2g of the flour sample with strong acid and strong alkaline. The residue obtained was incinerated at 550°C for 2h in a muffle furnace, cooled in a desiccator and the difference in weight calculated¹⁷. Crude Protein was determined by the Kjeldahl method to obtain the percentage of nitrogen. The formula: protein content = 6.25 × nitrogen (g/100g) in accordance with A.O.A.C.¹⁸ was used to calculate the total protein content. The ash content was determined by the method described by A.O.A.C.¹⁸ which lies on the complete incineration of organic matter contained in the flour sample at 550°C for 6h in a muffle furnace. The lipid content was done by extraction according to the Russian method described by Bourelly¹⁹. The difference in weight before and after extraction gave the lipid content in the flour samples. Carbohydrate content was determined by the differential method of A.O.A.C.¹⁸ which was done by summing percentages of the different contents (total protein, total lipid, water content, crude fibre, ash and moisture content) and deducted from 100%.

Mineral Analysis

The determination of the minerals (Na, K, Ca, Mg, Fe, Zn, P) was done by atomic absorption spectrometry as described by Benton and Vernon ²⁰.

Analysis of techno-functional properties

The Water Absorption Capacity (WAC) and Oil Absorption Capacity (OAC) were determined as described by Sosulski *et al.* ²¹. 1g of flour sample was mixed with 10ml of distilled water or soybean oil, kept at ambient temperature for 30 minutes and centrifuged for 10 minutes at 2000 g. The value obtained was expressed as % water and oil bound per gram of the sample. The bulk density (BD) was determined according to the method of Okaka and Potter ²². 50g of flour sample was placed into 100 mL graduated measuring cylinder and tapped 20 to 30 times, until no observable change in volume. The bulk density was determined as weight per unit volume of the sample. Swelling capacity was determined by the method described by Okaka and Potter ²². 5 mL of flour sample of known mass was introduced into a measuring cylinder and the volume recorded (V1). Then, 25ml of distilled water was added and the mixture homogenised. The mixture was left to stand at room temperature for 2 hours and the final volume (V2) was recorded.

Statistical analysis

The data were analysed using IBM/SPSS 20.0 software for Windows and one-way analysis of variance (ANOVA) followed by post Hoc *Tukey* test for flours of the varieties 01/17/97 and Mbongdoux and one sample t test for flours of the variety TME-693 to compare averages at 5% threshold level of significance. Data was consistently reported based on dry weight (DW) basis of 100g (nutrients). The results of the various tests were presented in the form of means $\pm$ standard deviation. Microsoft Excel 2016 software was used for calculations and graphical representations.

III. Results and Discussion

Moisture content of flours from peels of three cassava varieties

The moisture content of our flour samples is presented in Table 1 below. The moisture content ranged from $6.44 \pm 0.25\%$ to $9.24 \pm 0.65\%$; $7.14 \pm 0.75\%$ to $9.57 \pm 0.09\%$ and $6.32 \pm 0.33\%$ to $7.86 \pm 0.00\%$ respectively for Mbongdoux, TME-693 and 01/17/97. Relatively higher moisture contents were registered by the varieties Mbongdoux and TME-693 on day1 ($9.24 \pm 0.65\%$) and day7 ($9.57 \pm 0.09\%$) respectively.

Table 1: Moisture content of flour from peels of three cassava varieties (%)

	Day0	Day1	Day2	Day3	Day4	Day7
Mbongdoux	6.87 ± 0.49^a	9.24 ± 0.65^b	6.44 ± 0.25^a	7.16 ± 0.39^a	7.62 ± 0.35^{ab}	6.39 ± 0.12^a
TME-693	7.14 ± 0.75^a	8.9 ± 0.4^{bc}	8.57 ± 0.50^{bc}	8.79 ± 0.59^{bc}	7.67 ± 0.19^{ab}	9.57 ± 0.09^c
01/17/97	6.32 ± 0.33^a	6.77 ± 0.01^{ab}	7.52 ± 0.15^{cd}	7.28 ± 0.29^c	7.86 ± 0.00^d	7.56 ± 0.09^{cd}

The values with different letters subscripts in the same row of the same variety are significantly different ($p < 0.05$). Day0: non-fermented peel, Day1: peels fermented for one day, Day2: peels fermented for two days, Day3: peels fermented for three days, Day4: peels fermented for four days, Day7: peels fermented for seven days

Anti-nutrient

The effect of fermentation on the HCN contents of the different flour samples in g/100g dry weight are showed in Table 2.

It could be seen that fermentation significantly affected the HCN contents of flours of different varieties. In general, the total HCN content decreased as fermentation time increased. The HCN content ranged from 24.35 ± 0.00 to 6.05 ± 0.28 mg/kg; 44.19 ± 0.58 to 8.36 ± 0.00 mg/kg and 6.62 ± 0.28 to 2.04 ± 0.29 mg/kg for the varieties Mbongdoux, TME-693 and 01/17/97 respectively. Cyanide content is a limiting factor for the utilization of the cassava plant, necessitating thorough processing before consumption. Fermentation contributes to the reduction in HCN content in food. The decrease in the HCN content might be related to the fact that during fermentation, the cyanogenic glucoside linamarin is hydrolyzed under the action of the enzyme linamarase into HCN and acetone which are soluble and volatile compounds ²³. Youchahou *et al.* ⁵ in their study obtained similar results when spontaneously fermented cassava for the production of traditional products. These values are online with WHO legislation who recommends the level of safety of HCN in cassava flour at 10mg/Kg making our flour samples suitable for consumption ²⁴. It is on this basis that flours samples whose cyanide contents were above this limit were put aside and the rest kept for further analysis. These flour samples were named Day3, Day4 and Day7 for the variety Mbongdoux, Day4 and Day7 for TME-693 and Day0, Day1, Day2, Day3, Day4 and Day7 for TME-693.

Table 2: effect of fermentation on the HCN content of flour from peels of three cassava varieties (mg/kg) expressed in g/100g dry weight

Cyanide (mg/kg DM)						
	Day0	Day1	Day2	Day3	Day4	Day7
Mbongdoux	24.35 ± 0.0 ^f	22.9 ± 0.29 ^e	12.12 ± 0.00 ^d	8.43 ± 0.29 ^b	7.2 ± 0.29 ^c	6.05 ± 0.28 ^a
TME-693	44.19 ± 0.58 ^c	32.89 ± 2.07 ^d	26.28 ± 0.88 ^c	15.09 ± 0.29 ^b	8.77 ± 0.00 ^a	8.36 ± 0.00 ^a
01/17/97	6.62 ± 0.28 ^d	6.08 ± 0.28 ^d	4.96 ± 0.29 ^c	3.78 ± 0.29 ^b	3.22 ± 0.29 ^b	2.04 ± 0.29 ^a

The values with different letters subscripts in the same row of the same variety are significantly different ($P < 0.05$). Day0: non-fermented peel, Day1: peels fermented for one day, Day2: peels fermented for two days, Day3: peels fermented for three days, Day4: peels fermented for four days, Day7: peels fermented for seven days.

The oxalate, phytic acid, tannin and saponin contents of flours produced from the peels of three cassava varieties expressed in mg/100g of dry weight (Table 3).

The results obtained showed that fermentation significantly affected the contents of these anti-nutrients ($P < 0.05$) with the exception of phytic acid. For the variety Mbongdoux, oxalates significantly decreased from Day3 to Day4 (0.17 ± 0.01 to 0.09 ± 0.02 g/100g) with no significant decrease observed in Day7. Saponins content ranged from 0.2 ± 0.00 to 0.29 ± 0.00 g/100g from Day3 to Day7 while the tannins significantly reduced ($P < 0.05$) at early fermentation when we leave from Day3 to Day4: (15.38 ± 0.08 to 9.76 ± 0.03 mg/100g), but later doubles when fermentation was prolonged to Day7 (17.32 ± 0.10 mg/100g). For the variety TME-693, there was no significant difference observed in oxalates, phytic acid and saponins contents while tannins significantly increased ($P < 0.05$) from Day4 to Day7; 23.34 ± 0.10 to 40.70 ± 0.05 mg/100g. Concerning the variety 01/17/97, oxalate content significantly reduced from Day0 to Day7; 0.47 ± 0.03 to 0.13 ± 0.00 g/100g. No significant difference was registered for phytic acid, while saponins content reduced from Day0 to Day7; (0.24 ± 0.04 to 0.01 ± 0.00 g/100g) and the tannins contents significantly reduced ($P < 0.05$) from Day0 to Day7; (32.67 ± 0.07 to 21.10 ± 0.04 mg/100g). There was a significant decrease in oxalate content among flour samples from different varieties, possibly due to leaching losses in the fermentation medium during steeping. High ingestion of oxalate can hinder the absorption of soluble divalent ions such as Ca^{2+} , Zn^{2+} , and Fe^{2+} , as oxalate binds to these ions to form insoluble complexes, thereby reducing their bioavailability and potentially leading to mineral deficiencies ^{25,26}. The physiological tolerance level for oxalate being 2 to 5g/day ²⁷. The oxalate contents of our flour samples were well below these values, indicating their safety for consumption. There was no significant difference among flours of different varieties regarding phytate content. Phytic acid can bind to divalent ions such as magnesium, calcium, iron, zinc, and molybdenum, leading to micronutrient deficiencies. It also forms stable bonds with proteins and inhibits the activity of certain enzymes such as amylases and proteases ²⁸. The daily recommended intake for phytate is fixed at 2000 to 2600 mg/day ²⁹. The phytic acid content of our flour samples was well below these values, ensuring their safety for consumption. Saponin content ranged from 0.01 ± 0.00 to 0.34 ± 0.04 g/100g. This is primarily because saponins are soluble in water and therefore leach into the liquid medium (water) during the fermentation process ³⁰. The tannin content was found to decrease at early fermentation and significantly increase at longer fermentation periods. This increase may be attributed to the hydrolysis of phenolic compounds into simpler forms by the enzyme polyphenol oxidase during fermentation, thereby releasing free nutrients ³¹. The safety limit of consumption for tannins being 560 mg/day, the tannins contents of the flour samples are well below this value. This makes the flour samples safe for consumption ³².

Table 3: Effect of fermentation on the anti-nutritional factors (oxalates, phytic acid, tannins and saponins) of flours from peels of three different varieties expressed in mg/100g dry weight

Variety	Time (days)	Oxalates (mg/100g)	Phytates (mg/100g)	Saponins (mg/100g)	Tannin (mg/100g)
Mbongdoux	Day3	0.17 ± 0.01 ^a	0.04 ± 0.00 ^a	0.2 ± 0.00 ^a	15.38 ± 0.08 ^b
	Day4	0.09 ± 0.02 ^b	0.19 ± 0.05 ^a	0.25 ± 0.04 ^{ab}	9.76 ± 0.03 ^a
	Day7	0.09 ± 0.00 ^b	0.04 ± 0.00 ^a	0.29 ± 0.00 ^c	17.32 ± 0.10 ^c
TME-693	Day4	0.27 ± 0.01 ^a	0.06 ± 0.02 ^a	0.01 ± 0.00 ^a	23.34 ± 0.10 ^b
	Day7	0.25 ± 0.01 ^a	0.05 ± 0.01 ^a	0.02 ± 0.00 ^a	40.70 ± 0.05 ^a
01/17/97	Day0	0.47 ± 0.03 ^a	0.04 ± 0.00 ^a	0.2 ± 0.00 ^b	32.67 ± 0.07 ^f
	Day1	0.33 ± 0.00 ^b	0.04 ± 0.00 ^a	0.24 ± 0.04 ^{bc}	31.19 ± 0.04 ^e

	Day2	0.19 ± 0.00 ^c	0.04±0.00 ^a	0.34±0.04 ^c	30.75±0.05 ^d
	Day3	0.18 ± 0.00 ^c	0.04±0.00 ^a	0.34±0.04 ^c	24.31±0.00 ^b
	Day4	0.16 ± 0.00 ^{cd}	0.06±0.02 ^a	0.01±0.00 ^a	28.22±0.04 ^c
	Day7	0.13 ± 0.00 ^d	0.04±0.00 ^a	0.01±0.00 ^a	21.10±0.04 ^a

The values with different letters subscripts in the same row of the same variety are significantly different ($P<0.05$). Day0: non-fermented peel, Day1: peels fermented for one day, Day2: peels fermented for two days, Day3: peels fermented for three days, Day4: peels fermented for four days, Day7: peels fermented for seven days.

Proximate analysis

The following Table 4 represents the proximate analysis of flours produced from the peels of three cassava varieties. The moisture, protein, lipid, crude fibre, ash and carbohydrate contents of the different fermented flours expressed in g/100g dry weight.

Fermentation significantly affected these different contents amongst flours of different varieties. The highest moisture content was recorded in the variety TME-693 when fermented for 7 days ($9.57\pm0.09\%$). The protein content reduced from Day3 to Day4; 1.14 ± 0.19 to 0.84 ± 0.01 g/100g then after wards increased when fermentation is prolonged to Day7; 1.18 ± 0.02 . The lipid content reduced with an increase in fermentation time from Day3 to Day7; 2.7 ± 0.00 to 1.27 ± 0.09 g/100g. As for crude fibre, a significant increase ($P<0.05$) was registered as fermentation increased from Day3 to Day4; 4.58 ± 0.05 to 4.8 ± 0.05 g/100g then later on decreased to 2.76 ± 0.03 g/100g in Day7. There was no significant difference in the ash contents of flour samples. Carbohydrates on the other hand, significantly increased as fermentation time increased from Day3 to Day7; 83.13 ± 0.18 to 87.17 ± 0.17 g/100g. The energy value ranged from 356.40 to 363.82 kcal.

For the variety TME-693, protein content showed no significant difference ($P<0.05$) between the flour samples. Lipid, ash and carbohydrate contents significantly reduced ($P<0.05$) as fermentation increased from Day4 to Day7 2.34 ± 0.01 to 1.69 ± 0.29 g/100g; 1.90 ± 0.12 to 1.57 ± 0.06 g/100g; and 68.69 ± 0.18 to 66.10 ± 0.35 g/100g respectively. The energy level reduced as fermentation periods increased from Day4 to Day7 300.29 to 284.09 kcal.

For the variety 01/17/97, the protein content significantly ($P<0.05$) reduced from non-fermented flour (Day0); 1.88 ± 0.02 g/100g to flour fermented for 4 days (Day4); 1.06 ± 0.00 g/100g then afterwards increased when fermentation was prolonged to day 7 (Day7); 1.80 ± 0.01 g/100g. On the other hand, the lipid content significantly decreased ($P<0.05$) from non-fermented flour (Day0); 3.55 ± 0.00 g/100g to fermented flour (Day7); 0.39 ± 0.00 g/100g respectively. Crude fibre on its own tends to increase as fermentation increased, that is from Day0 to Day7 crude fibre content ranged from 5.10 ± 0.04 g/100g to 6.19 ± 0.03 g/100g respectively. The ash content also decreased with increase in fermentation time from Day0 to Day7; 4.03 ± 0.03 to 1.22 ± 0.17 g/100g respectively. Carbohydrates on the other hand increased from non-fermented flour to fermented flours with values ranging from 80.45 ± 0.06 to 83.02 ± 0.12 g/100g respectively. The energy value for this variety ranged from 360.86 to 342.36 kcal respectively for non-fermented to fermented (Day7) flours. The moisture content is a measure of the quantity of water present in a material. The moisture content in our flours samples ranged from 6.39 ± 0.12 to 7.62 ± 0.35 %; 7.67 ± 0.19 to 9.57 ± 0.09 % and 6.32 ± 0.33 to 7.86 ± 0.00 respectively for Mbongdoux, TME-693 and 01/17/97. Low moisture content of flour is very important as regard its shelf life, storage ability through the reduction in the development of microorganisms³³. The analysis revealed that the protein content, expressed in g/100g dry matter (DM), decreased from 1.14 to 0.84 g/100g from Day3 to Day4, then increased to 0.96 g/100g in Day7 for the Mbongdoux variety. A similar trend was observed for the variety 01/17/97, where the protein content decreased from 1.88 to 1.06 g/100g from Day0 to Day4, and then increased to 1.80 g/100g in Day7. The increase in protein content towards the end of fermentation may be due to an increase in microbial biomass involved in the fermentation process³⁴. Crude fibre content showed a general increase with longer fermentation times. TME-693 had the highest crude fibre content, registering 16.89 g/100g for flour samples fermented for 4 days and 17.37 g/100g for 7 days. Mbongdoux and 01/17/97 varieties showed slightly similar crude fibre values ranging from 4.58 to 4.80 and 5.10 to 6.19 g/100g, respectively. This increase could be explained by the fact that during fermentation there was hydrolysis of carbohydrates into fibres³⁴. Indeed, fibres are indigestible components of food, also known as roughage. Our flour samples, rich in fibre, can be recommended for patients with metabolic diseases such as diabetes. Karimu and Seyifunmi³⁵ obtained similar results for cassava flour. Ash content serves as a rough measure of the inorganic mineral content in samples. The ash content generally decreased with longer fermentation times for the variety 01/17/97, decreasing from 1.41 to 1.07 g/100g for Day3 and Day4, then increasing to 1.41 g/100g in Day7 for the Mbongdoux variety. For TME-693, ash content increased from 1.41 g/100g to 3.19 g/100g for Day4 and Day7, respectively. These findings align those of Touzou et al. (2018)²⁶ who also observed decreased ash content in their flour samples after fermentation. The decrease in ash content may be attributed to fermentation metabolites utilizing essential salts initially present in cassava peels for their metabolic activities²⁶. Additionally, during fermentation, some water-soluble minerals

may have leached into the fermentation medium ³¹. Fat content in flour samples from different cassava peel varieties decreased with longer fermentation times, with lipid content ranging from 2.7 to 1.27 g/100g DM for Mbongdoux, 2.34 to 1.69 g/100g DM for TME-693, and 3.55 to 0.39 g/100g DM for 01/17/97. The decrease in fat content may be due to lipid hydrolysis into fatty acids, as well as predigestion of lipids by various enzymes involved in digestion ³⁶. Moreover, this low-fat content could contribute to extending the shelf life of the flour samples by reducing the likelihood of rancidity. The hydrolysis of lipids contributes toward reducing the concentration of lipids susceptible to oxidation through the formation of free fatty acids, thus making the environment more acidic and reducing the effectiveness of pro-oxidation pathways due to the formation of free fatty acids that can largely be removed through fermentation ³⁷. The decrease in the carbohydrate content from 68.69 g/100g to 66.10 g/100g might be associated with the fact that they were used as substrate by micro-organisms during fermentation ³¹.

Table 4: Effect of fermentation on the proximate analysis of flours produced from peels of three cassava varieties (g/100g DW)

Variety	TIME (days)	Moisture (%)	Proteins (g/100g)	Lipids (g/100g)	Crude Fibres (g/100g)	Ash (g/100g)	Carbohydrates (g/100g)
Mbongdoux	DAY3	7.16±0.39 ^a	1.14 ± 0.19 ^c	2.7 ± 0.00 ^c	4.58 ± 0.05 ^b	1.00 ± 0.16 ^a	83.13 ± 0.18 ^a
	DAY4	7.62±0.35 ^{ab}	0.84 ± 0.01 ^a	2.1 ± 0.00 ^b	4.8 ± 0.05 ^c	1.10 ± 0.08 ^a	83.51 ± 0.16 ^a
	DAY7	6.39±0.12 ^a	0.96 ± 0.00 ^b	1.27 ± 0.09 ^a	2.76 ± 0.03 ^a	1.18 ± 0.00 ^a	87.17 ± 0.17 ^b
TME-693	DAY4	7.67±0.19 ^{ab}	1.18 ± 0.02 ^a	2.34 ± 0.01 ^a	16.89 ± 0.06 ^b	1.90 ± 0.12 ^b	68.69 ± 0.18 ^a
	DAY7	9.57±0.09 ^c	1.21 ± 0.01 ^a	1.69 ± 0.29 ^b	17.37 ± 0.11 ^a	1.57 ± 0.06 ^a	66.10 ± 0.35 ^b
01/17/97	DAY0	6.32±0.33 ^a	1.88 ± 0.02 ^c	3.55 ± 0.00 ^c	5.10 ± 0.04 ^a	2.67 ± 0.00 ^d	80.45 ± 0.06 ^a
	DAY1	6.77±0.01 ^{ab}	1.87 ± 0.00 ^c	2.73 ± 0.19 ^d	5.44 ± 0.03 ^b	4.03 ± 0.03	81.58 ± 0.11 ^b
	DAY2	7.52±0.15 ^{cd}	1.59 ± 0.00 ^c	1.39 ± 0.19 ^c	5.67 ± 0.05 ^c	3.19 ± 0.16	81.89 ± 0.05 ^c
	DAY3	7.28±0.29 ^c	1.00 ± 0.00 ^a	0.98 ± 0.00 ^b	5.92 ± 0.06 ^d	1.41 ± 0.11 ^b	83.61 ± 0.06 ^c
	DAY4	7.86±0.00 ^d	1.06 ± 0.00 ^b	0.58 ± 0.00 ^a	6.17 ± 0.00 ^c	1.07 ± 0.10 ^a	83.20 ± 0.08 ^d
	DAY7	7.56±0.09 ^{cd}	1.80 ± 0.01 ^d	0.39 ± 0.00 ^a	6.19 ± 0.03 ^c	1.22 ± 0.17 ^{ab}	83.02 ± 0.12 ^d

The values with different letters subscripts in the same row of the same variety are significantly different ($P<0.05$). Day0: non-fermented peel, Day1: peels fermented for one day, Day2: peels fermented for two days, Day3: peels fermented for three days, Day4: peels fermented for four days, Day7: peels fermented for seven days.

Mineral composition

Table 5 presents some minerals (Na, K, Ca, Mg, P, Fe, Zn) contents of the different flour samples expressed in mg/100g of dry weight.

The results obtained showed that different minerals of the different flour samples were significantly ($P<0.05$) affected by the fermentation process. The Na, K, Ca and Fe contents decreased with increase in fermentation time for flours of the three varieties. Furthermore, the variety TME-693 registered the highest Ca (144.65 ± 0.1 mg/100g), Mg (105.36 ± 5.97 mg/100g) when fermented for 4 days and Zn (3.92 ± 0.53 mg/100g), Fe (19.55 ± 0.19 mg/100g) contents when fermented for 7 days while the highest K (735.28 ± 0.02 mg/100g), Na (138.54 ± 0.04 mg/100g) and P (62.18 ± 0.00 mg/100g) contents was registered by the variety 01/17/97 for the non-fermented flour (Day0) on dry matter basis. The mineral content was significantly ($P<0.05$) affected by fermentation. We observed a general decrease in Na, K, and Ca contents as fermentation periods increased for flours of each variety. This reduction in mineral content may be due to leaching into the water used during processing and also because these minerals serve as nutrient sources for microbes during their growth ²⁶. Calcium, the most abundant mineral in the human body, contributes to the formation of strong bones and teeth. A diet rich in calcium strengthens the body and vital organs. Recommended daily calcium intakes are 200 to 300 mg for children and 1000 to 3000 mg for adults ³⁸. These values exceed the calcium content of flour samples, with the highest content being 144.65 ± 0.1 mg/100g DM recorded in Day4 of the variety TME-693. Potassium is essential for protein and carbohydrate metabolism. The recommended daily intake of potassium is 3.4g ³⁸. The highest potassium content registered was 735.28 mg/100g, which is lower than the recommended daily intake but still

makes the flour sample a moderate source of potassium. The non-fermented flour samples of the variety 01/17/97, registered the highest potassium content at 735.28 mg/100g. Sodium, relatively abundant and vital in the human body, participates in acid-base balance and the proper functioning of the neuromuscular system. Since the body does not synthesize sodium, its main source is dietary intake, typically as sodium chloride. The recommended daily intake of sodium for adults is 1500 mg³⁹. The highest sodium content we obtained was 138.54 mg/100g in the non-fermented flour samples of the variety 01/17/97. Moderate values of magnesium, ranging from 21.11 to 105.36 mg/100g, were recorded in our flour samples across the three varieties. Magnesium, abundant in human bones, regulates the nervous system's mental and emotional functions. Daily magnesium requirements are estimated at 350 mg³⁸. The highest content was recorded in variety TME-693 variety when fermented for 7 days (105.36 mg/100g). Iron content ranged from 9.53 to 19.55 mg/100g in our flour samples. Iron is crucial for producing hemoglobin in red blood cells, smooth muscle function, and cell-mediated immunity. The highest iron content, 19.55 mg/100g, was recorded in the variety TME-693 variety when fermented for 7 days. Zinc had the lowest content among all analyzed minerals. Generally, an increase in zinc content was observed with longer fermentation periods, possibly due to reduced phytate hydrolyzed during fermentation. Zinc content ranged from 1.45 to 3.92 mg/100g. It is an essential element absorbed from food, acting as an antioxidant to counteract the harmful effects of free radicals. The recommended dietary intake for zinc varies between 3-12mg/day⁴⁰. The highest zinc content recorded by the variety TME-693 when fermented for 7days (3.92 mg/100g). Phosphorus content in our flour samples ranged from 24.82 to 62.18 mg/100g. Phosphorus is vital for bone and teeth formation and is involved in metabolic pathways for ATP energy production and enzyme activation. The highest phosphorus content observed was 62.18 mg/100g in the variety 01-17-97 when no-fermented.

Table 5: Effect of fermentation on the mineral contents (Na, K, Ca, P, Zn Mg and Fe) of flours from peels of three cassava varieties at varied fermentation time (mg/100g) dry weight
The values with different letters subscripts in the same row of the same variety are significantly different ($P<0.05$).

VARIETY	TIME (days)	Na	K	Ca	Mg	Fe	Zn	P
Mbongdoux	Day3	114.39± 0.10 ^a	299.56± 0.20 ^c	18.45± 0.05 ^c	21.11±1.48 ^a	9.53±0.14 ^b	1.45±0.19 ^a	55.94±0.00 ^c
	Day4	120.15± 0.13 ^c	261.68 ± 0.03 ^b	14.96 ± 0.05 ^b	25.09±3.79 ^c	10.41±0.07 ^c	1.64±0.21 ^a	24.82±0.06 ^a
	Day7	116.23 ± 0.18 ^b	242.2 ± 0.05 ^a	2.68 ± 0.10 ^a	33.05±1.92 ^a	8.9 ± 0.06 ^a	1.76±0.22 ^a	34.35±0.00 ^b
TME-693	Day4	126.81 ± 0.03 ^a	360.46 ± 0.40 ^a	144.65 ± 0.1 ^a	105.36±5.97 ^a	19.16±0.15 ^a	3.45±0.44 ^a	57.53±0.00 ^a
	Day7	112.91± 0.01 ^b	261.34± 0.39 ^b	92.02 ± 0.02 ^b	88.49 ± 6.88 ^b	19.55±0.19 ^a	3.92±0.53 ^a	58.03±0.00 ^a
01/17/97	Day0	138.54± 0.04 ^f	735.28 ± 0.02 ^f	43.42 ± 0.07 ^f	60.82 ± 4.1 ^c	15.61±0.01 ^f	1.82±0.21 ^a	62.18±0.00 ^b
	Day1	123.12± 0.02 ^c	336.43 ± 0.11 ^c	42.94 ± 0.03 ^c	105.36 ± 4.5 ^b	11.58±0.09 ^c	1.49 ± 0.1 ^c	50.15±0.01 ^b
	Day2	120.16± 0.07 ^d	324.00 ± 0.01 ^d	40.91 ± 0.02 ^d	88.49 ± 5.58 ^b	9.04 ± 0.03 ^a	1.46±0.19 ^{bc}	50.55±0.00 ^b
	Day3	109.16± 0.0 ^c	165.78 ± 0.02 ^c	35.84 ± 0.04 ^c	56.14 ± 3.8 ^a	10.10±0.00 ^b	1.67± 0.21 ^c	34.57±0.01 ^a
	Day4	109.16± 0.0 ^c	158.39 ± 0.04 ^b	22.91 ± 0.01 ^b	66.00 ± 1.00 ^c	14.52±0.02 ^g	1.82± 0.24 ^b	28.30±0.00 ^a
	Day7	96.86± 0.24 ^a	134.67 ± 0.15 ^a	11.49 ± 0.01 ^a	63.31±1.63 ^{ab}	13.36±0.03 ^d	1.57± 0.21 ^b	50.48±0.00 ^b

Day0: non-fermented peel, Day1: peels fermented for one day, Day2: peels fermented for two days, Day3: peels fermented for three days, Day4: peels fermented for four days, Day7: peels fermented for seven days.

Techno-functional Properties

Results of some techno-functional properties (Water absorption capacity, Oil absorption capacity, swelling capacity and bulk density) of flour samples of different varieties at varied fermentation time are presented in table 6 below.

Concerning the variety Mbongdoux, the techno-functional properties were not significantly ($P > 0.05$) affected by fermentation with the exception of swelling capacity. The values ranged from 203.99 ± 8.00 to 220.9 ± 1.30 % and 194.03 ± 9.00 to 158.38 ± 37.45 % and 0.40 ± 0.01 to 0.42 ± 0.04 %. from Day3 to Day7 respectively. Concerning swelling capacity, a significant increase ($P<0.05$) was observed from Day3 to Day4: 1.34 ± 0.01 to 1.7 to 0.02 mg/L then significantly ($P<0.05$) drop to Day7: 1.42 ± 0.02 mg/L. The variety TME-693, registered the highest water and oil absorption capacities when fermented for 4 and 7 days respectively with values ranging

from 454.71 ± 29.10 to 433.77 ± 49.86 % and 236.83 ± 25.50 to 249.27 ± 25.50 % respectively. For the variety 01/17/97, water absorption capacity significantly reduced at early fermentation from Day0 to Day1; 253 ± 15.54 %. Then afterward significantly increased to Day3; 238.52 ± 1.77 %. No significant difference ($P < 0.05$) was observed from Day3 to Day7. On the other hand, there was no significance difference ($P < 0.05$) for the oil absorption capacity. The bulk density significantly decreased ($P < 0.05$) from 0.55 ± 0.00 to 0.38 ± 0.03 g/Cm³ as fermentation time increased from Day0 to Day7. Swelling capacity on the other hand significantly decreased ($P < 0.05$) from Day0 to Day1; 2.21 ± 0.07 to 1.84 ± 0.03 mg/L and afterwards increases when fermentation is prolonged to Day7; 2.15 ± 0.05 mg/L. Functional properties are essential physicochemical characteristics of foods that reflect interactions between structures, molecular conformation, composition, and physicochemical properties of food components with environmental conditions ⁴¹. Water Absorption Capacity (WAC) represents the ability of a product to associate with water under limited water conditions ⁴². The variety TME-693 recorded the highest WAC content 454.71 when fermented for 4 days. These values exceed those reported by Suresh and Smasher ⁴¹ who had values of 140 ± 12.25 and 192 ± 10.95 for wheat and rice flours respectively. The high WAC in TME-693 may be associated with its high crude fibre content, which has a strong binding capacity with water ⁴¹. The high WAC of our flour samples makes them useful ingredients in food preparations such as baked products ⁴³. Oil Absorption Capacity (OAC) was highest in flour sample of the variety TME-693 (249.27%) and lowest in flour sample of the variety 01/17/97 (155.83%) for flours fermented for 7 and 3 days, respectively. These values exceed those reported by Suresh and Smasher ⁴¹ for potato flour, which was 168 ± 10.95 %, in their study assessing the functional properties of different flours. Oil absorption capacity is primarily related to the physical capture and binding of fat to protein. The increase in oil absorption capacity of the flour samples may help maintain and improve the mouthfeel of bakery products ⁴³. Bulk density is a measure of heaviness of a flour sample ⁴⁴. The bulk density was significantly ($P < 0.05$) affected by fermentation. The highest and lowest values of bulk density was recorded by the non-fermented flour 0.55 (g/ml) and flour fermented at Day7 (0.38 g/ml) of the varieties 01/17/97 and TME-693 respectively. Variation in the bulk density of foods could be due to differences in starch content. Low bulk density of flour is suitable for food formulations and many bakery products. These values align with those reported by Yapi *et al.* ⁴⁵ who found a bulk density of 0.54 g/ml in nudsedge. Swelling capacity indicates the ability of starch to absorb water molecules and swell and is considered a quality measure in food products such as bakery products. Swelling capacity of flours depends on particle size, variety types, and processing methods or unit operations ⁴⁶.

Table 6: Effect of fermentation on techno-functional properties of flours produced from three cassava varieties.

Variety	Time (days)	WAC (%)	OAC (%)	BD (g/cm ³)	SC (mg/L)
Mbongdoux	DAY3	203.99 ± 8.00^a	194.03 ± 9.00^a	0.42 ± 0.04^a	1.34 ± 0.01^a
	DAY4	220.9 ± 1.30^a	167.3 ± 28.31^a	0.42 ± 0.01^a	1.7 ± 0.02^c
	DAY7	216.93 ± 17.83^a	158.38 ± 37.45^a	0.4 ± 0.01^a	1.42 ± 0.02^b
TME-693	DAY4	454.71 ± 29.10^a	236.83 ± 25.50^b	0.51 ± 0.00^a	1.64 ± 0.03^a
	DAY7	433.77 ± 49.86^a	249.27 ± 25.50^b	0.38 ± 0.00^b	0.53 ± 0.01^b
01/17/97	DAY0	253.97 ± 15.54^c	148.08 ± 32.31^a	0.55 ± 0.00^d	2.21 ± 0.07^b
	DAY1	207.16 ± 1.70^a	165.91 ± 26.74^a	0.5 ± 0.01^{cd}	2.15 ± 0.02^b
	DAY2	239.52 ± 1.77^{bc}	165.16 ± 26.74^a	0.46 ± 0.01^{bc}	1.76 ± 0.02^a
	DAY3	220.23 ± 4.79^{bc}	155.83 ± 6.84^a	0.41 ± 0.02^{ab}	1.84 ± 0.02^a
	DAY4	246.85 ± 9.37^c	174.2 ± 41.48^a	0.39 ± 0.00^a	1.84 ± 0.03^a
	DAY7	241.3 ± 3.33	214.39 ± 3.13^b	0.38 ± 0.03^a	2.15 ± 0.05^b

The values with different letters subscripts in the same row of the same variety are significantly different ($P < 0.05$). Day0: non-fermented peel, Day1: peels fermented for one day, Day2: peels fermented for two days, Day3: peels fermented for three days, Day4: peels fermented for four days, Day7: peels fermented for seven days. WAC: water absorption capacity; OAC: Oil absorption capacity; BD: Bulk density; SC: Swelling capacity

Conclusion

The results obtained revealed that fermentation process significantly reduces the anti-nutritional factors (HCN, Saponins and Oxalates) acceptable limits. Also, flour samples are rich in carbohydrates and crude fibre making them good energy sources, as well as containing some minerals like K, Mg and Na. Lastly the flour

samples exhibit good techno-functional properties (WAC and OAC) which makes them suitable for use in the food industry for food formulations.

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