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EFFECTS OF HERMETIC AND NON-HERMETIC PACKAGING MATERIALS ON THE PROXIMATE, FUNCTIONAL AND PASTING PROPERTIES OF FERMENTED CASSAVA FLOUR (LAFUN) DURING 6-MONTH STORAGE

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ABSTRACT
This research evaluated the effects of packaging materials on the proximate, functional, and pasting attributes of fermented cassava flour (Lafun) in storage. The study involved the storage of cassava flour in PICS bags, plastic containers and polypropylene bags for six (6) months. Storage was done at an average room temperature of 26.2 °C and relative humidity of 78.2%. Samples were taken from each packaging material every two months for analysis. The proximate analysis of cassava flour stored in the three packaging materials showed a significant decrease in ash content, crude fibre, and crude protein. In comparison, a significant increase was observed in moisture content and carbohydrates in cassava flour stored in the different packaging materials upon completion of the study. The results from the functional properties indicate a significant decrease in the swelling capacity, oil absorption capacity, water absorption capacity and bulk density of cassava flour stored in PICS bags, plastic containers and polypropylene bags, respectively. Results of the pasting properties also indicate that peak viscosity, trough viscosity and breakdown viscosity of cassava flour stored in the polypropylene bag decrease significantly, while a significant increase was observed in the pasting temperature of flour stored in a plastic container and PPICS bag. In conclusion, PPICS bags serve as a better packaging material for fermented cassava flour than plastic containers and polypropylene bags.

Keywords: PICS, Polypropylene, Cassava flour, Proximate composition, Functional Properties

INTRODUCTION
Cassava (*Manihot esculenta*) is a tropical root crop grown with a low-cost vegetative propagation. About 600 million people rely on it as their main source of nutrition, making it the third most significant source of food in the tropical region after maize and rice. Because cassava produces well even on poor soil without the use of fertiliser, is resistant to drought, and its roots may be left in the soil for close to three years as a food reserve, its use as a source of food is growing, especially in Africa (Nhassico et al., 2008). Cassava is essential for income generation, guaranteed food security and poverty reduction especially in sub-Saharan Africa where it serves as a staple for thousands of households (Ekwe et al., 2025). Due to the high postharvest deterioration of cassava, which begins within the first two days after harvesting, there is limited use of cassava root as raw material for industries and as food (Sanchez et al., 2006; Iyer et al., 2010). Various food varieties and raw materials, including fufu, gari, tapioca, flour, chips, pellets, and biofuel, are being made from cassava roots to extend their shelf life, ease commerce, and encourage industrial use, packing, and storage (Taiwo, 2006).
Fermented cassava flour (lafun) is a product of the fermentation process of cassava by lactic acid bacteria (Purwadi et al., 2021). Improper packaging materials during storage are seen as one of the postharvest challenges limiting the quality and shelf life of cassava flour (lafun) (Opara et al., 2016). Research has demonstrated that the microbial load and other quality characteristics of flour products, including their proximate, functional, and pasting qualities, are influenced by both moisture and packing materials (Robertson, 2012). Hermetic packaging materials such as PICS and polypropylene bags have been reported as an effective storage material for flour, thereby preserving the physicochemical and microbial quality, such as the storage of Teff flour, as against the non-hermetic storage material that exposes stored flour to several deteriorating agents (Awol et al., 2023).
Fermented cassava flour (lafun) must be stored and packaged optimally to minimise postharvest losses, increase shelf life, preserve quality, raise market requirements, and ensure food safety (Opara et al., 2010). Inadequate findings on the effects of packaging materials on the functional, pasting and proximate attributes of fermented cassava flour (lafun) made it imperative for this study. Three packaging materials, namely plastic container (PPC), polypropylene (PPP) and PICS bag (PPIC), which are commonly used by vendors, were selected for the six-month storage period of this study. The finding was poised to provide remarkable insights into the best packaging materials with the potential of retaining the nutritional and functional properties of fermented cassava flour (lafun). The aim of the study, therefore, was to evaluate the effects of packaging materials on the proximate, functional, and pasting properties of fermented cassava flour (lafun).

MATERIALS AND METHODS
Description of Study Site
The study was conducted at the Research Outreach Department laboratory of the Nigerian Stored Product Research Institute between 2023 and 2024. A Temtop data logger (Elitech, USA) with device code TemLog 20H was placed within the storage area to monitor the temperature and relative humidity. The average room temperature of the study area was 26.2 °C while the average relative humidity was 78.2%.

Sample Procurement and Processing

Cassava (TME 419 variety) was procured from the Stop Hunger Cooperative Society. The roots were conveyed from the sales outlet to the processing unit of the Nigerian Stored Products Research Institute, Ibadan Zonal Office.

The process developed by Falade and Akingbala (2010) and Lagnika et al. (2019) was followed for producing fermented cassava flour. Firstly, extraneous materials and other contaminants were removed from the cassava roots. This was followed by sorting to separate the samples into wholesome and unwholesome lots. The wholesome lots free of defects, evident rot, mechanical damage, and any indications of physiological degradation were used in this study. After sorting, the roots were rinsed, peeled with a peeler, and cleaned in potable water. The clean samples were submerged in water and allowed to undergo fermentation for three days, drained and put into sacs. To ensure the complete removal of water, the sac-filled cassava was dewatered mechanically using a 30-ton hydraulic jack. Further processing was then carried out to ensure the roots were dried by placing the moist cassava chips in the NSPRI-Parabolic Shaped Solar-Tent Dryer (PSSD). The chips of the dried cassava were ground into fine flour.

Packaging and Storage of Cassava Flour

The resulting cassava flour was packaged and stored over a period of 6 months for the shelf life study. The cassava flour was packaged in PICS bags, plastic containers, and polypropylene bags.

PICS Bag

A 100 kg PICS bag was modified to hold 3 kg of cassava flour. The PICS bag was cut into 4 equal parts and were re-sewn using a sewing machine, while the embedded nylon was sealed with a sealing machine at the side and bottom end after cutting them into four equal parts. Packaging in PICS bag was done in triplicate. After placing 3 kg of cassava flour into each PICS bag, the top was securely tied with a rope to prevent air penetration, and the bags were stored in a cool, dry environment for the shelf-life study. The modified storage bags were labelled as PPICS.

Plastic Container

Three kilograms of cassava flour were placed into a 5-litre plastic container, sealed with a lid to prevent air penetration, and stored in a dry, cool location for the storage study. Packaging in plastic container was done in triplicate. The container was labelled as PPC.

Polypropylene Bag

Packaging was done in triplicate using a 50 kg-capacity polypropylene bag that was recycled and resized to hold 3 kg of cassava flour. 3kg of cassava flour was placed inside each bag. The end was fastened with a rope to prevent air from leaking out. The PPP label was attached to the storage bags.

Figure 1: Cassava Flour Stored in Plastic Container (PPC)

Figure 2: Cassava Flour Stored in PICS bag (PPIC)

Figure 3: Cassava Flour Stored in Polypropelene bag (PPP)

Proximate Analysis

Moisture Content Determination

The method described by AOAC (2010) was used to determine the moisture content. Washed crucibles were dried in an oven. The weight was recorded after cooling in the desiccator. Samples of a known weight were then put into the crucibles and allowed to dry at a temperature of 103-105 °C. After cooling in a desiccator, the weight of the dry samples was recorded. The dried samples were returned to the oven, and drying continued until a constant weight was achieved.

Calculation: $Moisture\ Content\ \% = \frac{(Weight\ loss)}{(Weight\ of\ Sample)} \times 100 \quad (1)$

Determination of Ash Content

The method described by AOAC (2010) was used to determine the ASH content. A crucible with a lid (W1) that had been previously weighed and cleaned, and dried was filled with a known weight of the finely powdered material. After removing the cover, the sample, over a low flame, was lit to char the organic content. After that, the crucible was heated in a muffle furnace at a temperature of 600 °C for 3 hours until the samples were totally reduced to ashes. After that, it was weighed after cooling in a desiccator (W2).

$$Ash\ \% = \frac{(W2-W1)}{(Weight\ of\ Sample)} \times 100 \quad (2)$$

Crude Fat Determination

The Soxhlet extraction process described by AOAC (2010) was used to determine the percentage of crude fat. A filter paper of a known weight was filled with a known-weight sample, which was then neatly folded. This was then put inside a thimble (W1) that had been previously weighed. After inserting the thimble containing the sample (W2) into the Soxhlet apparatus, the extraction under reflux was conducted for six hours using n-hexane at a boiling range of 40 to 60 °C. At the end of the extraction process, the thimble was cooled in a desiccator, dried in an oven for 30 minutes at 100 °C and weighed (W3). The calculation of the fat extracted from a given quantity of sample is:

$$\%\ Fat\ (w/w) = \frac{(Loss\ in\ weight\ of\ sample\ (w2-w3))}{weight\ of\ sample\ (w2-w1))} \times 100 \quad (3)$$

Crude Protein Determination

The Kjeldahl method, described by AOAC (2010), was used to determine crude protein content. 2 g of sample was weighed into a Kjeldahl flask. One Kjeldahl tablet, which was to serve as a catalyst, was added to the sample, and 25 ml of concentrated H_2SO_4 was later added and then swirled. The flask was clamped and heated to digest the sample in a fume cupboard until a clear solution was obtained. The resulting clear solution was allowed to cool and was poured into a 100 ml measuring cylinder. Distilled water was then added to make up to 100 ml. 10ml of the solution was measured into a distillation set with a funnel. 5ml of Boric acid was measured into a conical flask, and two drops of methyl orange, serving as an indicator, were added. Ammonia was liberated from the solution with 40 % NaOH, which was added to the 10ml of the solution. Steam generated from the distillation set was let down into the boric acid solution, trapping the ammonia liberated from the digested sample solution until about 50 ml of solution was obtained. The process ceased when a colour change was seen in the boric acid used to trap the ammonia. The resulting solution in the conical flask was titrated against 0.1 M HCl a colour change was observed.

$$\%\ N = \frac{(Molarity\ of\ HCl \times Sample\ titre - Blank\ titre)}{(Weight\ of\ Sample\ used) \times 100} \times 0.014 \times DF \quad (4)$$

Multiplying the % N by 6.25 converts it to percentage crude protein. DF is the dilution factor, % N is the percentage nitrogen, and the nitrogen: protein conversion factor is 6.25.

Crude Fibre Determination

The method described by AOAC (2010) was used to determine the crude fibre. 100 ml of freshly prepared 0.1 M H_2SO_4 was added to 5 g of the sample in a round-bottom flask, and boiled over a heating mantle for 30 minutes. The boiled mixture was filtered using a muslin cloth. The residue was washed with distilled water to obtain an acid-free residue. The residue was returned to the round-bottom flask, and 100 ml of freshly prepared 0.1M NaOH was added, and was boiled over a heating mantle for 30 minutes. The mixture was filtered with a muslin cloth after boiling and washed with distilled water to obtain a NaOH-free residue. The residue was placed in a crucible and oven-dried for 3 hours at 105 °C. The crucible was cooled in a dessicator and weighed (W1). The crucible was then ignited in a muffle furnace for 30 minutes at 600 °C. The crucible was then cooled in a dessicator and weighed (W2). The percentage crude fibre is calculated as:

$$Crude\ fibre\ \% = \frac{(Weight\ after\ oven\ drying - Weight\ after\ igniting)}{(Weight\ of\ Sample)} \times 100 \quad (5)$$

Carbohydrate Estimation

The percentage of carbohydrate in the sample was calculated by difference.

% CHO = 100 - (Sum of the percentages of moisture, ash, fat, protein and crude fibre)

Functional Properties

Bulk Density

The bulk determination was done using the method described by Oladele and Aina (2007). Fifty grams (50 g) of the flour sample was put into a 100 ml measuring cylinder. The measuring cylinder was continuously tapped until the flour compacted and a constant volume was obtained. Bulk density (g/cm^3) was calculated using the formula:

$$\text{Bulk Density} = \frac{weight\ of\ sample}{volume\ of\ sample\ after\ tapping} (\text{g/ml or g/cm}^3) \quad (6)$$

Water Absorption Capacity/Oil Absorption Capacity

The method of Sosulski et al. (1976) was used to determine the water /oil absorption capacity of the flour samples. One gram of the sample was placed into a centrifuge tube and mixed with 10 ml of distilled water/oil and allowed to stand for 30 minutes at an ambient temperature of (30 ± 2°C). The tubes were then centrifuged for 30 minutes at 3000 rpm. The water/oil was carefully decanted and placed at a 45° angle for 10 minutes to allow complete draining of oil/water, and then weighed. Water/Oil absorption was expressed as a percentage increase of the sample weight.

Water Absorption Capacity/Oil Absorption Capacity (%) =

$$\frac{\text{Initial Weight} - \text{Final Weight}}{\text{initial Weight}} X100 \quad (7)$$

Swelling Capacity

The method described by Okaka and Potter (1977) was used to determine the swelling capacity. Flour sample was poured into a 100 ml graduated cylinder until it reached the 10 ml mark. Distilled water was then added until the 50 ml mark. Mixing was done by inverting the cylinder with the top tightly covered. The cylinder was left to rest for 8 minutes. The increase in volume by the swelled sample after the 8th minute was taken.

$$\text{Swelling Capacity (\%)} = \frac{\text{Initial Weight} - \text{Final Weight}}{\text{initial Weight}} X100 \quad (8)$$

Pasting Properties

The method described by Maziya-Dixon et al. (2005) was used to determine the pasting temperature, Peak time and viscosity of the fermented cassava flour. Rapid Visco Analyser (RVA) (model RVA 3D+, Network Scientific, Australia) was used to determine the pasting characteristics. 2.5g of sample was weighed into a canister, after which 25ml of distilled water was added to form a solution. The solution was mixed carefully until a slurry was formed. The resulting slurry was heated with a holding time of 2 minutes from a temperature of 50°C to 95 °C and was subsequently cooled to 50 °C with a 2-minute holding time. Heating and cooling were carried out at a constant rate of 11.25 °C / min. The pasting profile with the aid of a thermocline for Windows software (Newport Scientific, 1998) was read to give the peak viscosity, final viscosity, trough, breakdown, peak time, setback, and pasting temperature.

Statistical Analysis

One-way analysis of variance (ANOVA) using IBM SPSS Statistics version 23 (IBM Corporation, USA) was used to analyse the results. Duncan's multiple range tests were used to estimate the statistical differences among mean values of the various treatments with a 95 % significance level.

RESULTS AND DISCUSSION

Effects of Packaging Material on the Proximate Analysis of Cassava Flour

The quality retention of fermented cassava flour (lafun) during storage is influenced by the properties of the packaging material used. The observed proximate and functional properties, ranging from moisture content to swelling capacity, varied markedly across the three tested packaging materials: PPIC (PICS bag), PPP (polypropylene bag), and PPC (plastic container).

Among all parameters, moisture content (Figure 4) was most notably impacted by packaging type. Lafun stored in PPIC (PICS bag) consistently exhibited the lowest moisture uptake throughout storage. This reflects the superior hermetic sealing properties of PICS bags, which significantly reduce water vapour transmission. In contrast, samples stored in PPP (polypropylene bags) showed the highest moisture gain, followed by those in PPC (plastic containers). Elevated moisture levels are perceived to be causing microbial activity and biochemical degradation in cassava flour stored in PPP (Omodara et al., 2021). According to Adepoju et al. (2019), cassava flour is susceptible to spoilage when the moisture content is above 12%, a threat that the use of PPIC prevents. It is in agreement with Iwuoha et al. (2022) in illustrating that hermetic packages, for example, PICS bags, act to keep low moisture environments.

In terms of ash content (Figure 5), indicative of mineral composition, samples in PPIC retained significantly more ash compared to PPP and PPC. This suggests that the PICS bag's reduced oxygen permeability helps prevent mineral loss via oxidative processes. Ash levels declined most in PPP, highlighting its limited protection against environmental factors. Akinyele et al. (2020) emphasised that ash content in flour is highly sensitive to oxygen exposure, while Osei-Agyemang et al. (2023) found that mineral degradation is aggravated by humidity conditions likely encountered in the more porous PPP packaging. Oluwafemi et al. (2022) further confirmed the role of hermetic packaging in mineral preservation.

The crude fibre content (Figure 6) of lafun showed moderate reductions in all packaging types, but was best preserved in PPIC. Fibre degradation, often linked to microbial or enzymatic activity under humid conditions, was severe in PPP stored flour. These findings are aligned with Adegunwa et al. (2019), who observed dietary fibre loss in cassava flours exposed to moisture-laden environments. Udofia and Ogbodo (2021) also supported the use of modified atmosphere or hermetic packaging in preserving fibre fractions. Ogunmoyela et al. (2020) corroborated that microbial fermentation accelerates fibre breakdown, especially under poorly sealed conditions like those found in polypropylene bags.

The crude protein content (Figure) declined across all samples, though retention was highest in PPIC, followed by PPC, and lowest in PPP. This pattern reinforces the protective effect of PICS bags, which minimise both oxygen and moisture ingress. Protein degradation, often driven by microbial proteases and oxidative reactions, was particularly evident in the less protected PPP group (Eke-Okoro et al., 2021). Ajayi and Fadeyibi (2019) linked protein loss in cassava flour to enzymatic activity exacerbated by high humidity. In contrast, Nwosu et al. (2023) demonstrated that nitrogen loss can be significantly curtailed using multilayered, hermetically sealed packaging like PICS bags.

Crude fat content (Figure 8) decreased significantly in all storage conditions, yet again, the PPIC stored samples retained the highest fat levels, while the PPP stored samples experienced the greatest losses. Lipid oxidation, which accelerates under oxygen and light exposure, is most prevalent in the transparent and permeable PPP. Bakare et al. (2020) document similar trends in cassava flour, associating the loss of fat with oxidation during open storage. Adebayo et al. (2023) observe that packaging such as PPIC that is opaque and impermeable to oxygen greatly reduces lipid degradation. Obadina et al. (2018) highlight the usefulness of vacuum or hermetic sealing in preserving lipid content; that is in corroboration with the present findings.

Carbohydrate content (Figure 9) was relatively stable across the three packaging types, though slight declines were noted in PPP stored samples. This suggests some level of starch hydrolysis due to microbial or enzymatic action in humid environments. The PPIC stored flour showed the highest carbohydrate stability, indicating that hermetic conditions limited enzymatic activity. According to Ogunlade and Adegoke (2022), carbohydrates, albeit more stable than either proteins or fats, still sometimes become vulnerable in the presence of high moisture. Afolabi et al. (2020) deliberate that moisture control needs to be in place to prevent the breakdown of starch. Iwuagwu et al. (2021) went further to assert that carbohydrate preservation can be achieved by inhibiting microbial activity via the use of sealed packaging.

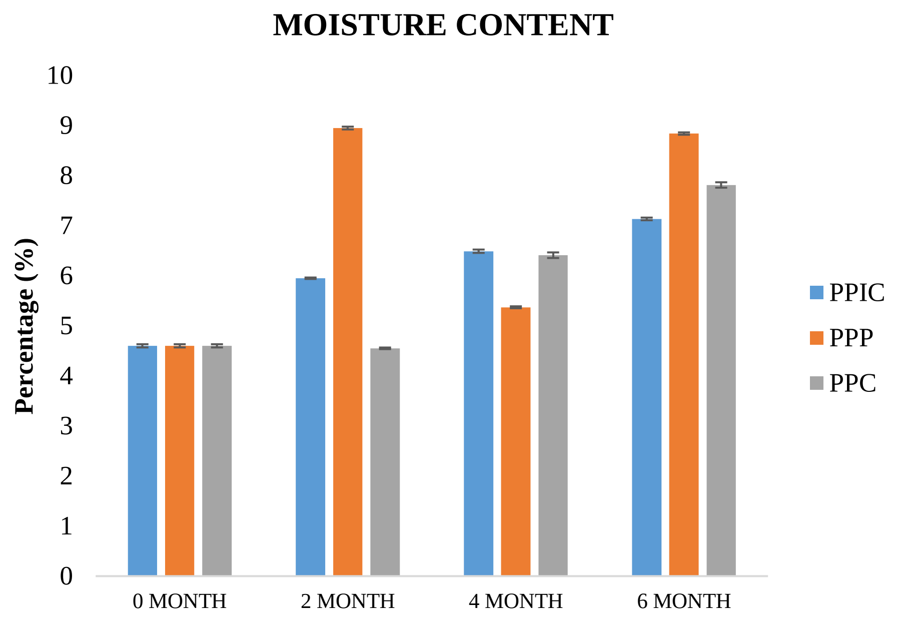

Figure 4: Moisture Content of Stored Cassava Flour
Mean ± Standard Error of Mean (n=3) is used to Express Values, and $P<0.05$

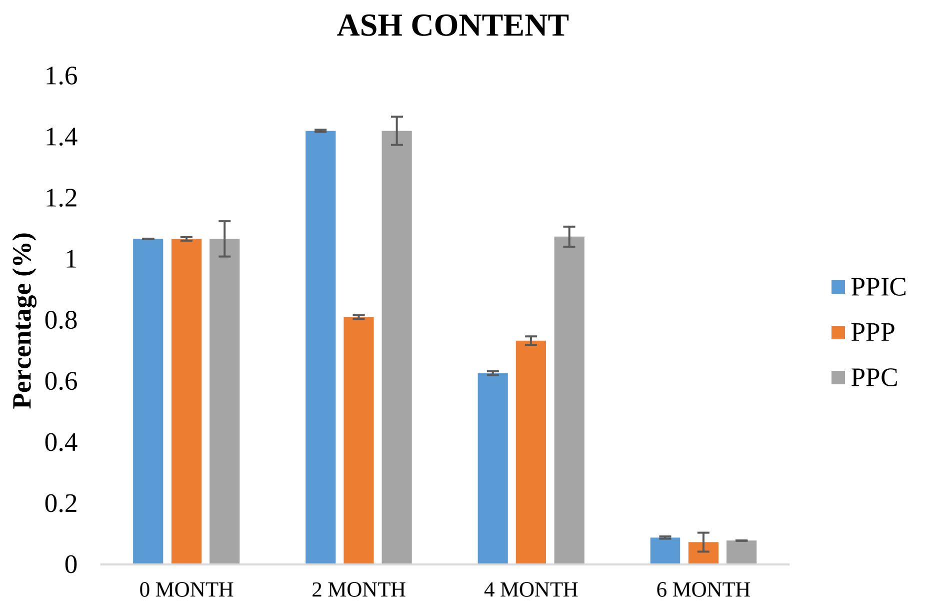

Figure 5: Ash Content of Stored Cassava Flour
Mean ± Standard Error of Mean (n=3) is used to Express Values, and $P<0.05$

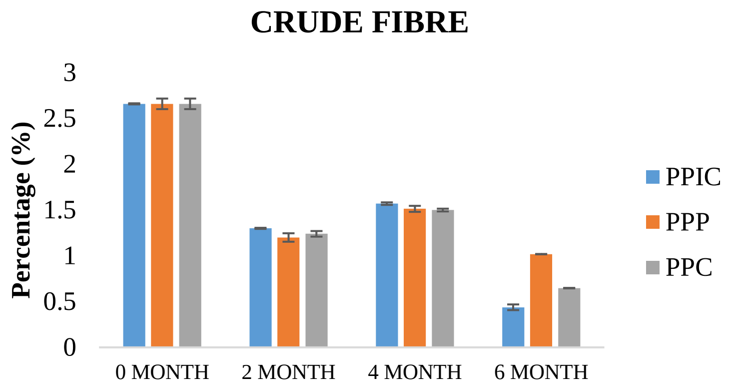

Figure 6: Crude Fibre of Stored Cassava Flour
Mean ± Standard Error of mean (n=3) is used to Express Values, and $P<0.05$

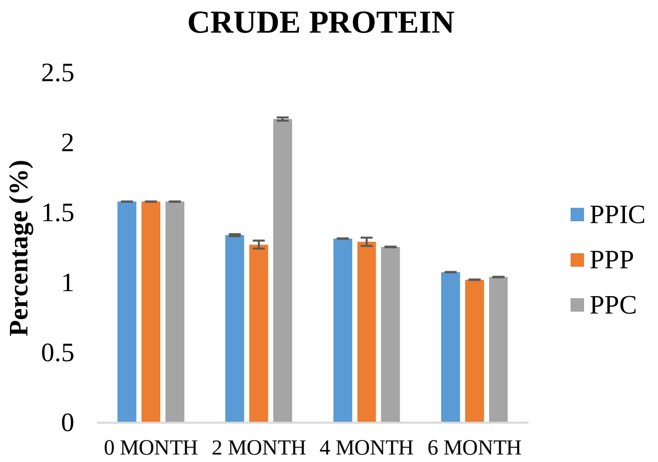

Figure 7: Crude Protein of Stored Cassava Flour
Mean ± Standard Error of Mean (n=3) is used to Express Values, and $P<0.05$

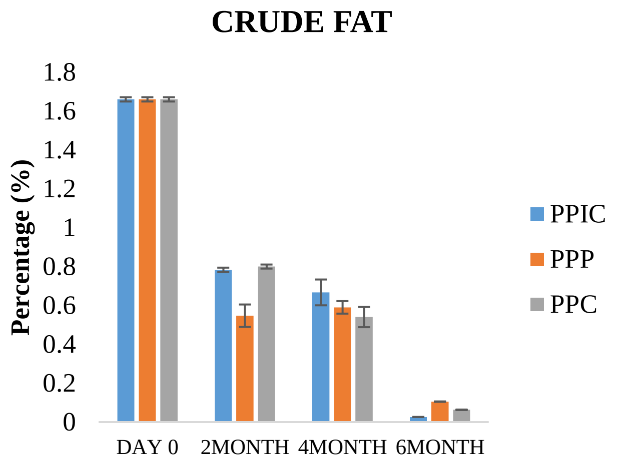

Figure 8: Crude Fat of Stored Cassava Flour
Mean ± Standard Error of Mean (n=3) is used to Express Values, and $P<0.05$

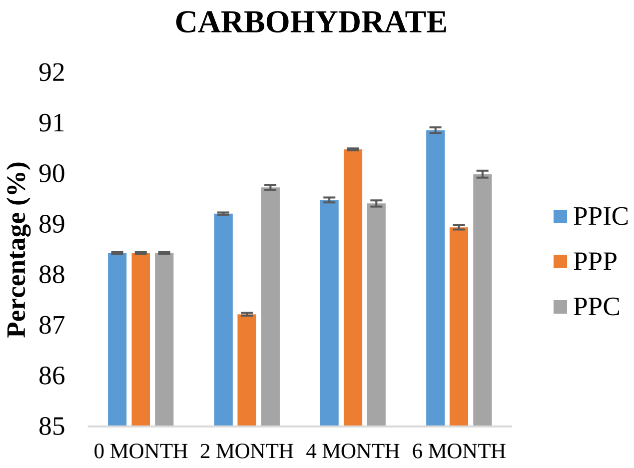

Figure 9: Carbohydrate of Stored Cassava Flour
Mean± Standard Error of Mean (n=3) is used to Express Values, and P<0.05

Effects of Packaging Material on the Functional Properties of Cassava Flour

The functional properties of the flour, bulk density, water and oil absorption capacities, and swelling capacity also displayed packaging-dependent variations. Among functional properties, bulk density (Figure 10) declined slightly in all packaging types but remained highest in PPIC. The denser structure is likely a result of better moisture control, which prevents clumping or degradation of flour granules. PPP stored samples exhibited the lowest bulk density, likely due to moisture-induced swelling and particle softening (Oyedeji et al., 2019). Alamu et al. (2021) reported that barrier packaging helps retain the structural integrity of flour particles. Bello et al. (2023) noted similar findings in cassava products stored in foil-lined pouches.

Water absorption capacity (WAC) (Figure 11) increased in most samples, with the highest values in PPP, followed by PPC, and the lowest in PPIC. This suggests greater starch disruption in the more permeable packaging. Increased WAC can be attributed to partial gelatinisation or granule rupture due to moisture uptake (Adetunji et al., 2020). Olatunde and Adelekan (2022) explained that high WAC often results from starch structural loosening during storage. The relative stability of WAC in PPIC stored flour indicates less damage to starch granules, as confirmed by Okorie et al. (2019).

In contrast, oil absorption capacity (OAC) (Figure 12) declined more noticeably in PPP stored flour, likely due to protein denaturation and lipid oxidation. PPIC preserved OAC the best, suggesting limited structural and oxidative damage. Ukoha et al. (2023) showed that OAC is sensitive to enzymatic changes during storage. Omodara and Adebayo (2020) observed that moisture-proof packaging helps retain the protein-lipid matrix necessary for high OAC. Ogunfowora et al. (2021) emphasised that maintaining this matrix under sealed conditions helps preserve OAC.

Finally, swelling capacity (Figure 13), an important functional attribute for lafun preparation, declined significantly in PPP stored flour. This is likely due to starch granule rupture or hydrolysis from high moisture exposure. Conversely, PPIC samples maintained higher swelling indices, indicating better starch integrity. Oyeleke et al. (2018) emphasised that swelling capacity correlates with granule structure, which is compromised in humid conditions. Ayinde et al. (2020) also noted reductions in swelling under poor storage. Adefila et al. (2023) showed that high-barrier materials like PPIC maintain the gelatinisation potential of starch granules.

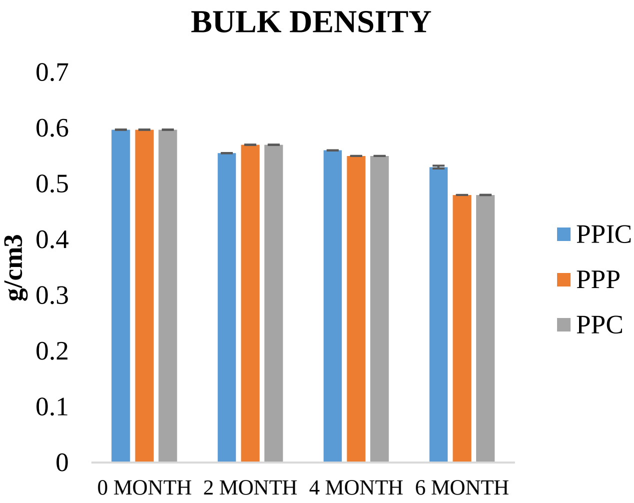

Figure 10: Bulk Density of Stored Cassava Flour
Mean ± Standard Error of Mean (n=3) is used to Express Values, and P<0.05

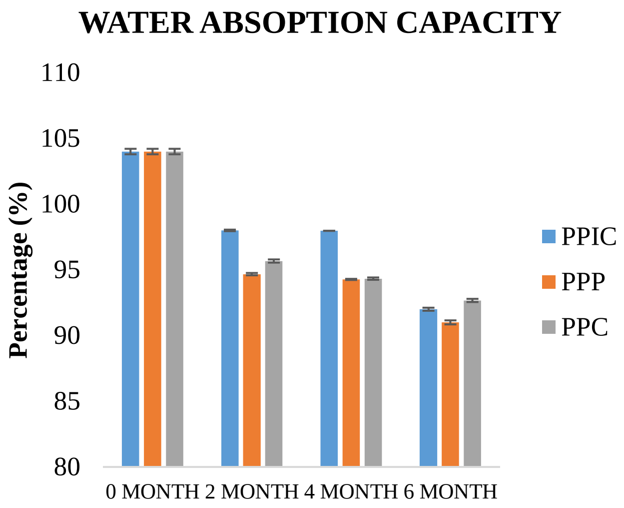

Figure 11: Water Absorbtion Capacity of Stored Cassava Flour
Mean ± standard Error of Mean (n=3) is used to Express Values, and P<0.05

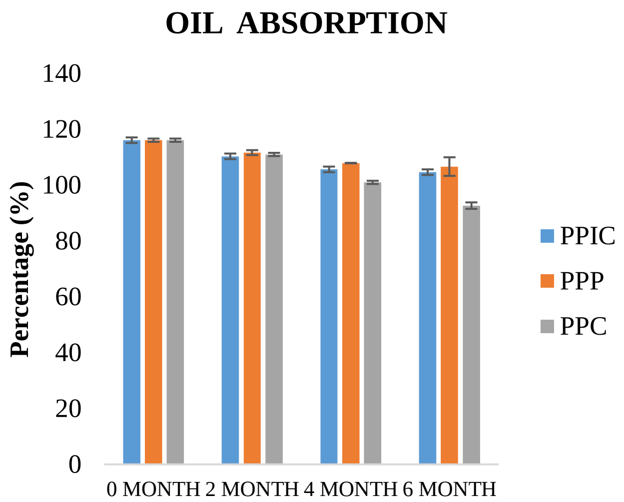

Figure 12: Oil Absorption Capacity of Stored Cassava Flour
Mean ± Standard Error of Mean (n=3) is used to Express Values, and P<0.05

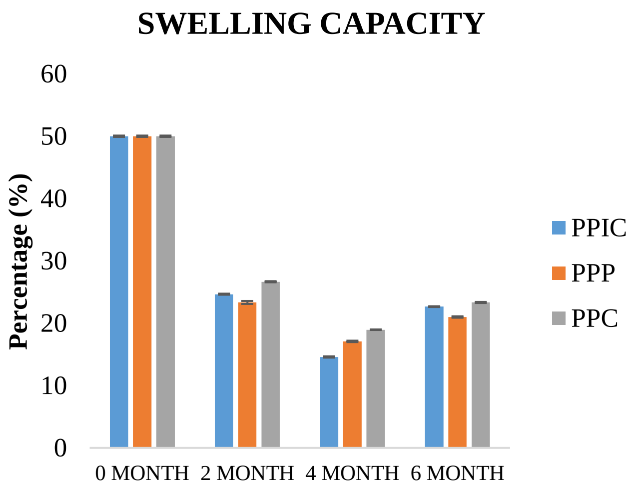

Figure 13: Swelling Capacity of Stored Cassava Flour
Mean ± Standard Error of Mean (n=3) is used to Express Values, and P<0.05

Effects of Packaging Material on the Pasting Properties of Cassava Flour

Pasting property impacts texture, digestibility, and the final usage of starch-based food commodities, making them one of the most significant factors influencing quality and aesthetic considerations in the food industry (Ajanaku et al., 2012; Iwe et al., 2016). When forecasting the pasting behaviour during and after cooking, the flour's pasting qualities are a crucial indicator (Ogunlakin et al., 2012). The acceptability of using flour as a functional ingredient in food and other industrial products is determined by its pasting qualities. The maximal viscosity created during the sample's heating phase is known as the peak viscosity (PV). The strength of the pastes created during gelatinisation is indicated by peak viscosity (PV), which is also referred to as the starches' capacity to rise freely before their physical disintegration (Sanni et al., 2004).

In Table 1, the peak viscosity ranged from 307.00 to 386.67 RVU. PPP at month two had the lowest peak viscosity, while the value at the onset of storage had the highest peak viscosity. PV gives an indication of the viscous load that a mixing cooker is likely to encounter and correlates with the final product quality by indicating the WBC of the starch in a product (Awolu et al., 2017). The values recorded in this work are within the range reported by (Maziya-Dixon et al., 2005; Adegunwa et al., 2010 and Ajibola and Olapade, 2017). The values are, however, less than what was reported by Hasmadi et al. (2020). This might be a result of varietal differences and modifications adopted in the processing. The hold period, also known as the trough, is when the samples are exposed to a continuous temperature and mechanical shear stress (Kiin-Kabari et al., 2015). Trough viscosity, which typically occurs around the start of cooling, is the lowest viscosity following the peak. The granules can be kept intact by subjecting the starch paste to mechanical shear stress and a holding period of a constant high temperature of 95°C for two minutes and thirty seconds (Eke-Ejiofor and Friday, 2019). The trough viscosity ranged from 175.92 to 236.13m RVU. The lowest and highest trough viscosities are PPICS at month two and PPC at month four, respectively. The range reported in this work is higher than the range reported by Maziya-Dixon et al. (2005) and Ajibola and Olapade (2017), but is higher than that reported by Adegunwa et al. (2010). This could be due to varietal differences and processing methods.

The breakdown (BD) viscosity, which is linked to the disruption of gelatinised swelling granules, is the difference between PV and trough viscosity (T) or hot paste viscosity (HV) (Lumdubwong et al., 2022). Breakdown viscosity (BV) measures how easily the swollen granules are disintegrated. It is also a measure of cooked starch to disintegration (Eke-Ejiofor and Friday, 2019). The breakdown viscosity ranged from 102.04 to 163.88 RVU. PPP at month four had the lowest breakdown viscosity, while the value at the onset of storage had the highest breakdown viscosity. BV is an indication of how starch gel breaks down during cooking (Ragace et al., 2006). It is seen as a paste stability estimation (Kiin-Kabari et al., 2015). Generally, higher paste stability indicates lower breakdown viscosity. The range reported here is less than the range reported by Adegunwa et al. (2010) and Ajibola and Olapade (2017).

Table 1: Effects of Packaging Material on the Pasting Properties of Cassava Flour

	Month	PPC	PPP	PPICS
Peak viscosity (RVU)	0	386.67^{a} ± 5.77	386.67^{a} ± 5.77	386.67^{a} ± 5.77
	2	340.83^{a} ± 3.06	307.00^{c} ± 8.38	318.54^{b} ± 1.94
	4	360.08^{a} ± 3.42	319.88^{b} ± 1.24	367.17^{a} ± 1.41
	6	359.27^{a} ±3.24	326.29^{b} ± 0.77	360.38^{a} ± 19.39
Trough viscosity (RVU)	0	204.79^{a} ± 2.04	204.79^{a} ± 2.04	204.79^{a} ± 2.04
	2	197.79^{a} ± 3.36	188.08^{ab} ± 6.72	175.92^{b} ± 20.62
	4	236.13^{a} ± 12.32	217.83^{b} ± 13.67	235.04^{a} ± 2.06
	6	208.29^{a} ± 6.54	187.42^{b} ± 6.84	198.21^{a} ± 4.42
Breakdown viscosity (RVU)	0	163.88^{a} ± 2.89	163.88^{a} ± 2.89	163.88^{a} ± 2.89
	2	143.04^{a} ± 0.29	118.92^{b} ± 1.65	142.63^{a} ± 22.57
	4	123.96^{b} ± 8.90	102.04^{c} ± 14.91	132.13^{a} ± 3.48
	6	151.00^{b} ± 3.30	138.88^{c} ± 7.60	162.17^{a} ± 23.81
Final viscosity (RVU)	0	271.13^{a} ± 6.89	271.13^{a} ± 6.89	271.13^{a} ± 6.89
	2	279.04^{a} ± 2.53	265.17^{ab} ± 6.13	251.92^{b} ± 27.46
	4	321.29^{b} ± 14.79	311.58^{c} ± 0.82	335.29^{a} ± 0.41
	6	311.58^{a} ± 0.00	280.54^{b} ± 0.29	301.04^{a} ± 3.48
Setback viscosity (RVU)	0	66.33^{a} ± 4.01	66.33^{a} ± 4.01	66.33^{a} ± 4.01
	2	81.25a ± 0.82	77.08^{b} ± 0.59	76.00^{b} ± 6.84
	4	85.17^{c} ± 2.47	93.75^{b} ± 12.85	100.25^{a} ± 1.65
	6	103.29^{a} ± 6.54	93.12^{b} ± 6.54	102.83^{a} ± 7.90
Peak time (mins)	0	5.20^{a} ± 0.00	5.20^{a} ± 0.00	5.20^{a} ± 0.00
	2	5.33^{a} ± 0.00	5.33^{a} ± 0.00	5.17^{a} ± 0.05
	4	5.23^{b} ± 0.05	5.33^{a} ± 0.00	5.30^{a} ± 0.05
	6	5.13^{a} ± 0.09	5.27^{a} ± 0.00	5.23^{a} ± 0.14
Pasting temperature (^{o}C)	0	91.53^{a} ± 0.60	91.53^{a} ± 0.60	91.53^{a} ± 0.60
	2	93.63^{a} ± 0.04	94.00^{a} ± 0.64	92.78^{b} ± 1.03
	4	92.38^{b} ± 0.60	95.15^{a} ± 0.00	92.75^{b} ± 0.99
	6	91.55^{b} ± 1.63	94.00^{a} ± 0.64	92.03^{b} ± 2.16

Mean ± standard error of mean (n=3) is used to express values, and P<0.05

According to Sanni et al. (2006), the final viscosity is the pasting metric most frequently employed to assess a starchy product's quality since it shows how well the material gels after cooking. The ability of a viscous paste formation after cooking and cooling from starch is a measure of the final viscosity (Eke-Ejiofor and Friday, 2019). The final viscosity ranged from 271.13 to 335.29 RVU. The lowest and highest final viscosities are at the initial stage and PPICS at month four of storage, respectively. The final viscosity recorded in this work is higher than that reported by Adegunwa et al. (2010) but lower than the range reported by Ajibola and Olapade (2017). A decreased ultimate viscosity suggested that the sample's capacity to produce a viscous paste had diminished (Awolu et al., 2017). Generally, a better quality of flour is a result of higher final viscosity.

Setback is calculated as the difference between the trough and the final viscosity. This stage of the pasting curve occurs after the starches are cooled to 50°C. Setback viscosity involves retrogradation and re-association of starch molecules. In the trough and final viscosities at month two, there were no significant differences ($p > 0.05$). The retrogradation tendency of the starch in the flour sample after 50 °C is shown by the setback viscosity (SBV) (Fadimu et al., 2018). Setback viscosity is an index of the retrogradation tendency of a paste prepared from a starchy food (Sandhu et al., 2006). The setback viscosity ranged from 66.33 to 103.29 RVU. PPP shows the lowest setback viscosity at the onset of storage, while PPC at the sixth month of storage had the highest peak viscosity. The setback (SB) is the difference between trough (T) and final viscosity (FV) (Lumdubwong et al., 2022). The final viscosity recorded in this work is higher than that reported by Maziya-Dixon et al. (2005) and Adegunwa et al. (2010). This could be a result of different varieties of cassava used. The setback has a connection to the texture of different products (Eke-Ejiofor and Friday, 2019). Generally, the cohesiveness is a function of a higher setback value.

Pasting time is the duration of the occurrence of peak viscosity in minutes (Eke-Ejiofor and Friday, 2019). The peak time ranged from 5.13 to 5.33 minutes. The lowest peak time is seen in PPC and PPP at two months of storage, while PPC at month six of storage had the highest peak time. Pasting time shows the bare minimum amount of time needed to cook flour (Awolu et al., 2017). This study showed that the pasting time indicates that the fermented cassava flour dried with a parabolic dryer and packed inside a plastic container and polypropylene bag at month two will cook in a shorter time of 5.13 mins than that stored in a plastic container for six months, where pasting time occurred at 5.33 mins. Though the time change is minimal, thus only a marginal change in energy required to achieve cooking. The range of pasting time reported in his work is greater than that reported by (Maziya-Dixon et al., 2005; Adegunwa et al., 2010 and Ajibola and Olapade, 2017). The pasting temperature, which quantifies the lowest temperature needed to cook or gelatinise flour, affects the stability of other ingredients in a formulation and provides information on energy expenses (Adebowale et al., 2008; Awoyale et al., 2021). It also plays a significant role in controlling energy expenses and the stability of other food ingredients in a product (Kaur and Singh, 2005; Shimelis et al., 2006). The pasting temperature ranged from 91.53 to 94.00 °C. The lowest and highest pasting temperatures are PPC at the onset of storage and PPP at months two and six of storage, respectively. The pasting temperature reported in this work is higher than the reports of (Maziya-Dixon et al., 2005; Adegunwa et al., 2010; Ajibola and Olapade, 2017 and Hasmadi et al., 2020). This could be due to the type of RVA machine used. Generally, all pasting parameters decrease as storage time progresses.

CONCLUSION

This investigation was into how hermetic and non-hermetic packaging materials impact the proximate composition, functional properties, and pasting properties of the fermented cassava flour during storage. It showed that packing largely determines long-term retention of quality features. Those features, such as moisture content, nutrient composition, and functional properties, were generally retained by packing materials with relatively better barrier properties. Conversely, materials with less protection exhibited drastic decreases in these features, thereby highlighting the significance of packing into quality degradation with time. The PPICS bag could stand as a better packaging option for fermented cassava flour compared to plastic containers and polypropylene bags.

Recommendation

i. Further research on new hermetic multi-layer packaging materials should be explored if it gives better storage of cassava flour (Lafun)
ii. Economic feasibility and cost-benefit analysis should be conducted by creating instances of comparing the high cost of PICS bag or multi-layer bags to the value of spoilage reduction and prolonged shelf life.

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