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# Effect of packaging and storage conditions on the pasting and functional properties of pretreated yellow-fleshed cassava flour

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ABSTRACT

Cassava is highly susceptible to post harvest physiological deterioration which makes it necessary to initiate processing so as to extend the shelf life. In order to improve and enhance the nutritional characteristics of the processed cassava flour, this research was carried out so as to evaluate the adequate packaging materials and storage conditions necessary for safe storage and good flour quality. Pasting properties of food/flour is an indication of the different applicability of starch-based food ingredients in product development. The effect of packaging materials (cylindric polyvinyl containers and aluminum ziplock pouch bags) on quality attributes of pretreated yellow-fleshed cassava flour (YFCF) samples stored in two storage conditions a (cooling chamber at 5 °C and 30 % relative humidity and; in a climate chamber at 30 °C and 50 % relative humidity) was investigated for 8 weeks. Flour samples from each package type were evaluated for water absorption capacity, pasting and oil absorption capacity fortnightly. The treated initial flour sample before storage-sulfured (BSS) had the highest peak viscosity (891 RVU). The low peak time at the end of storage in non-sulfured flours packed in aluminum pouch bags and stored at 5 °C is an evidence of time and energy saving capacity. The water absorption capacity of non-sulfured flour samples packed in cylindric polyvinyl containers and the sulfured flour sample packed in an aluminum pouch bag at 30 °C increased with storage duration. The aluminum ziplock pouch bags showed excellent storage quality and retained better pasting property. The climatic storage condition revealed better keeping quality. The use of sodium metabisulphite revealed its suitability as a pretreatment tool.

## 1. Introduction

Cassava flour is gaining wide acceptance in the food and non-food industry (Chisenga et al., 2019). The diversity of cassava genotypes is responsible for the different characteristics of the final products and makes it necessary to characterize cassava varieties in terms of their suitability for consumption and processing (Ugo Chijioke et al., 2016). Cassava flour is a fine, white powdery flour that has a shelf life of about one year under adequate storage conditions. It is widely used as a staple food and for the small-scale production of a variety of fried, baked and confectionery products (Aristizábal et al., 2017; Opara et al., 2016; Ugo Chijioke et al., 2016). It is a fact that the storage stability of food products depends on the packaging materials and storage conditions (Inyang et al., 2006; Opara & Mditshwa, 2013). In particular, flour is a hygroscopic product, which could deteriorate under high humidity during storage and exportation.

Packaging is essential in the food system, as it helps to reduce losses, increase value, extend shelf life, maintain quality; wholesomeness of a product, improve market standards and food safety (Inyang et al., 2006; Opara & Mditshwa, 2013). Packaging materials used for household storage of floury products include high-density polyethylene (HDPE), polypropylene (PP) woven sacks and polyvinyl chloride containers (PVC) (Teniola, 2003). The packaging materials are usually clear, glossy films with good optical properties and high tensile strength. Some packaging materials are resistant to gasses and moisture, hence moisture as well as environmental gasses such as oxygen is trapped inside with the flour. The use of packaging material is an easy and cheap way to prevent food contamination (Opara & Mditshwa, 2013). However, the type of package used and the characteristic features of the packaging material can influence the product quality and shelf life (Opara & Mditshwa, 2013). A number of deteriorative reactions that affect the nutritional and functional properties of flour are initiated during processing, and these reactions continue during storage to an extent proportional to variations in the storage conditions.

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Processing of root tubers into high quality flour passes through a series of processes to improve flour quality and process efficiency. These processes include blanching, sulfating to prevent enzymatic reaction, and/or browning, drying and milling to obtain shelf stable flour. Sulphite inhibits enzymatic browning by reducing o-quinones to colorless diphenol (Grotheer et al., 2005; Sgroppo et al., 2010). Sulfur dioxide and its derivatives (sulphite, bisulfite and metabisulphite) are oxidizing agents that act as preservatives and stabilizers in some products and are commonly used for preservation of food and beverages (Sgroppo et al., 2010).

To enhance the shelf life of tuber crops, it is essential to inactivate the enzymes present as well as reduce the water activity using these pretreatment techniques (Sgroppo et al., 2010). Flour's storability and shelf life depends on several factors. Intrinsic factors like water content and extrinsic factors such as temperature, packaging material, gasses or vapors that affect physical, chemical, and biochemical changes in stored flour (Li et al., 2017). Generally, the stability of a food product is a function of the processing techniques and storage conditions (Li et al., 2017).

The aluminum ziplock bags are one of the most utilized packaging materials and are cost-effective. These packaging materials are made up of different material compositions that ensure the products inside stay fresh and hygienic. They are shelf stable for 18–24 months depending on the conditions where they are stored. The first layer (external layer) of an aluminum foil bag is made of polyethylene (PE) and offers mechanical strength against various levels of temperatures. The second layer, made mostly from aluminum foil. It shields the contents in the aluminum foil bags from moisture and other aggressive components (TED, Packaging Bags & Pouches, 2024). While the third layer, which is a polyethylene of low density. It is used to make the laminate acquire heat-sealing abilities without destroying the outer polyester film. The materials used in manufacturing the aluminum foil bags serve different purposes towards ensuring food safety and long shelf life. These barriers function against the migration of moisture, gasses and other volatile aroma as well as against the impact of light (TED, Packaging Bags & Pouches, 2024).

Packaging materials attribute includes heat sealable, odorless and have low permeability with regard to water vapor and gas (Kadam et al., 2008). The oxygen transmission rate (mL/100 $cm^2$ in 24 h and 25 °C) of Polyvinyl chloride (PVC), PolyEthylene (PE) and Polypropylene (PP) is 8–160, 500 and 160 respectively, while the percentage water absorption is rated PP > PE > PVC (Allahvaisi, 2012). The sunlight-resistance of PE, PP and PVC is ranked as moderate-good, moderate and good, respectively. In general, the stability of starchy products is a function of the processing techniques and the storage conditions. Reports from different studies on the processing and storage of various cereal and tuber flours have shown nutrient losses due to packaging, storage temperature, relative humidity and storage time (Forsido et al., 2021). Studies have been conducted on flour stored at temperatures < 25 °C and RH < 70 % but none have been performed on the effect caused by different packaging on the stability of pretreated yellow-fleshed cassava flour in Nigeria. The rapid visco analyzer (RVA) is a widely used procedure to assess the pasting properties of flour or starch. However, it is vital to highlight its versatility, being able to analyze the viscosity in heating-cooling cycles. Therefore, the aim of this study was to evaluate the flour quality and stability of pretreated yellow-fleshed cassava flour stored at controlled storage conditions of 5 °C and 30 °C with variations in packaging (aluminum Ziplock pouch bags and cylindric polyvinyl containers) for 8 weeks, as well as the effect of packaging/packaging material and storage conditions on shelf life quality, pasting and functional properties.

## 2. Materials and methods

### 2.1. Packaging materials

Two packaging materials were used in the experimental study: (i) aluminum ziplock pouch bags and, (ii) Cylindric polyvinyl containers.

The aluminum ziplock pouch bags (ALPE) as a state-of-the-art method with a Thickness of 7 μm, oxygen transmission rate (< 0.5 cc/$m^2$, 24 h. 0.1 mpa) and moisture vapor transmission rate (g/$m^2$) and size dimension of 10 cm W x 187 cm H x 6 cm bottom gusset, were purchased from Mop/Silver, Midland Resource Company, Jos, Nigeria while the cylindric polyvinyl containers with a size dimension of 6 cm H x 13 cm D, and with a lid cover, were purchased from the local market in Lagos, Nigeria and are frequently used packaging methods in Nigeria. (Fig. 1). The PVC has thickness (0.45 μm), oxygen transmission rate (80 mm /100 $cm^2$, 24 h @ 26 °C) and moisture vapor transmission rate (8 mm /100 $cm^2$, 24 h @ 37.8 °C

### 2.2. Sample preparation

Fresh roots of yellow-fleshed cassava variety (TMS 01/1368) were collected from the experimental fields of the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria. The method described by Ekeledo et al. (2023) was used to process the cassava flour. Briefly explained as follows, wet cassava chips were divided into two portions; one portion was pretreated with sodium metabisulphite (0.3 % w/v) solution for 7 min and the other portion was non-sulfured. The samples were drained, dried and milled into yellow-fleshed cassava flour (YFCF).

### 2.3. Storage conditions

The storage study was conducted in two different conditions: (i) in a cooling chamber (a typical cold room storage chamber) at 5 °C and 30 % relative humidity and (ii) in a climate chamber (22 cubic foot capacity SG 22 Single Controlled Environment Chamber stainless steel, Hoffman Manufacturing Inc. Albany, OR USA. Specifications: temperature range: 2–40 °C, magnetic door, 1280 lbs W, 220 V/50 Hz 1Ph 7 amp) at 30 °C and 45–50 % relative humidity. A portion (160 g) of the YFCF was properly weighed using a weighing scale, packed and sealed in each of the packaging materials. The packed flour was stored for eight weeks, during which samples were collected from each package fortnightly for analysis. The ambient temperature and relative humidity of each storage condition were measured with a digital wireless thermo-hygrometer (Max-Min, HTC-1, LCD, Shanghai, China) prior to each batch of sample collection (Table 1).

### 2.4. Analysis of pasting properties

The pasting properties of the pretreated cassava flour samples were determined using the Rapid Visco Analyser Perten instrument (Model RVA Super 3D+, Newport Scientific, Newport, Australia). Three grams of YFCF sample was weighed into the test canister and 25 mL distilled water was added and stirred. The suspension was thoroughly mixed and the canister was fitted into the Rapid Visco Analyser. Each suspension was kept at 50 °C for 1 min, then heated up to 95 °C with a holding time of 2 min, followed by cooling to 50 °C with 2 min holding time. The rate of heating and cooling were at a constant rate of 11.85 °C per min. The experiment was performed with the computer connected, which automatically records the measured values.

The parameters for analysis were peak viscosity, setback viscosity, final viscosity, peak time and pasting temperature. The viscosity is expressed as rapid viscosity units (RVU).

### 2.5. Water absorption capacity

The water absorption capacity (WAC) was determined using the

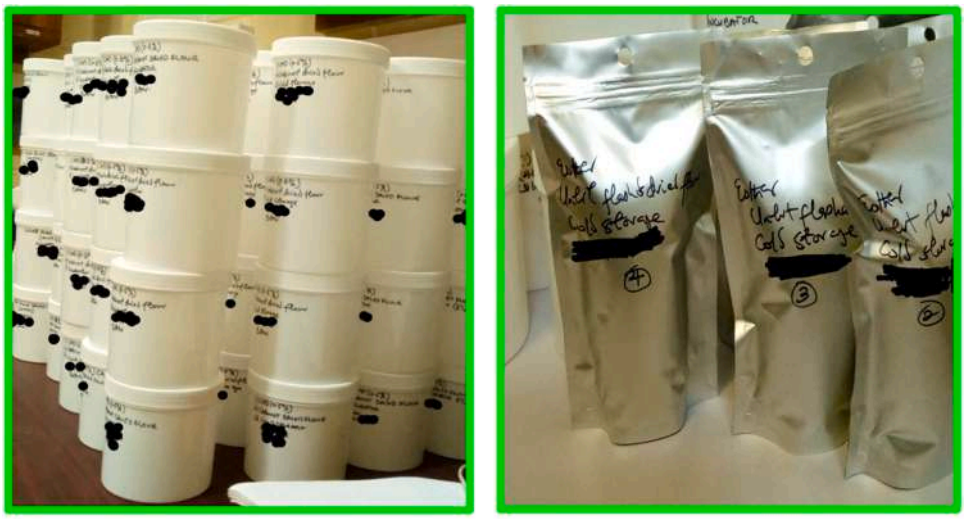

**Fig. 1.** Packaging materials. *A* = PVC containers and *B* = Aluminum ziplock pouch bags.

**Table 1**
Temperature and relative humidity of each of the storage conditions.

| Storage period | 4-week | | 8-week | |
|---|---|---|---|---|
| Conditions | Temperature (°C) | Relative Humidity (%) | Temperature (°C) | Relative Humidity (%) |
| Cold storage (cooling chamber) | 5.0 | 30.0 | 5.0 | 30.0 |
| Warm storage (climatic chamber) | 31.2 | 45.0 | 30.9 | 50.0 |

method described by Sosulski (1962). One g of the flour sample was weighed into a 25 mL pre-weighed centrifuge tube and mixed with 15 mL of distilled water. The mixture was allowed to stand for 30 min at 28 °C room temperature. The mixture was then agitated on a vortex mixer (IKA Vortex mixer 2, 4 mm orbit, 120 W x 138 D x 140 H, VWR International GmbH, Darmstadt, Germany) for 2 min and centrifuged (Table top cold centrifuge. Z326K Hermle Labortechnik GmbH, Wehingen, Germany) at a maximum speed of 4000 rpm (maximum relative centrifugal force: 2647 xg, maximum radius: 14.8 cm) for 20 min. The clear supernatant was discarded and the centrifuge tube was weighed with the sediment. The amount of water absorbed by the sample was calculated and expressed as percentage WAC.

### 2.6. Oil absorption capacity

Oil absorption capacity (OAC) was determined using the method described by Sosulski (1962). One gram of the flour sample was weighed into a 25 mL pre-weighed centrifuge tube and mixed with 15 mL of vegetable oil (refined cooking oil). The mixture was left to stand for 30 min at 28 °C room temperature. The mixture was then agitated in the vortex mixer (IKA Vortex mixer 2, 4 mm orbit, 120 W x 138 D x 140 H, VWR International GmbH, Darmstadt, Germany) for 2 min and centrifuged (Table top cold centrifuge. Z326K Hermle Labortechnik GmbH, Wehingen, Germany) at a maximum speed of 4000 rpm (maximum relative centrifugal force: 2647 xg, maximum radius: 14.8 cm) for 20 min. The clear supernatant was discarded and the centrifuge tube was weighed with the sediment. The amount of oil absorbed by the sample was calculated and expressed as the percentage OAC.

### 2.7. Dispersibility

Dispersibility was determined by using the method described by Kulkarni et al. (1991). 10 g of the sample was weighed into a 100 mL falcon tube. Distilled water was added up to mark and the mixture was stirred with a vortex mixer (IKA Vortex mixer 2, 4 mm orbit, 120 W x 138 D x 140 H, VWR International GmbH, Darmstadt, Germany) for 2 min and allowed to settle for 3 h. The volume of the settled particles was recorded after the supernatant was gently decanted and subtracted from 100 % to obtain the volume of the displaced supernatant, and expressed as the percentage dispersibility.

### 2.8. Statistical analysis

Analysis of variance was used to determine the effect of storage conditions (categoric), packaging materials (categoric) and storage time (numeric) on the pasting and functional properties. The results of the analyses carried out in duplicates were expressed as mean ± standard error (SE). The means were analyzed by analysis of variance (ANOVA) test and an error probability value of $p < 0.05$ was considered to denote a statistically significant difference between the tested parameters (pasting and functional properties) and the effect of storage conditions, packaging and storage time on them. Duncan test was used to compare the means using the SPSS package for Windows (ver. 16.1).

#### 2.8.1. Limitations

There are limitations but duplicate samples are also used in assessing variance in sampling as well as in analysis. Duplicates as well as triplicates increase reliability of the analysis and allow the averaging of results when there is considerable innate variability. Assaying samples in triplicate or duplicate is done to reduce experimental error and by replicating the measurements, more reliable and accurate results can be obtained. This therefore, helps in identifying any random or systematic errors that may occur during the experiment. Determining samples in triplicate or duplicate also increases the precision of the experiment by allowing comparisons between the measurements.

## 3. Results

### 3.1. Pasting properties

The pasting results in Fig. 2 shows the peak viscosity values ranging from 708 RVU to 881 RVU for all PVC samples for both storage

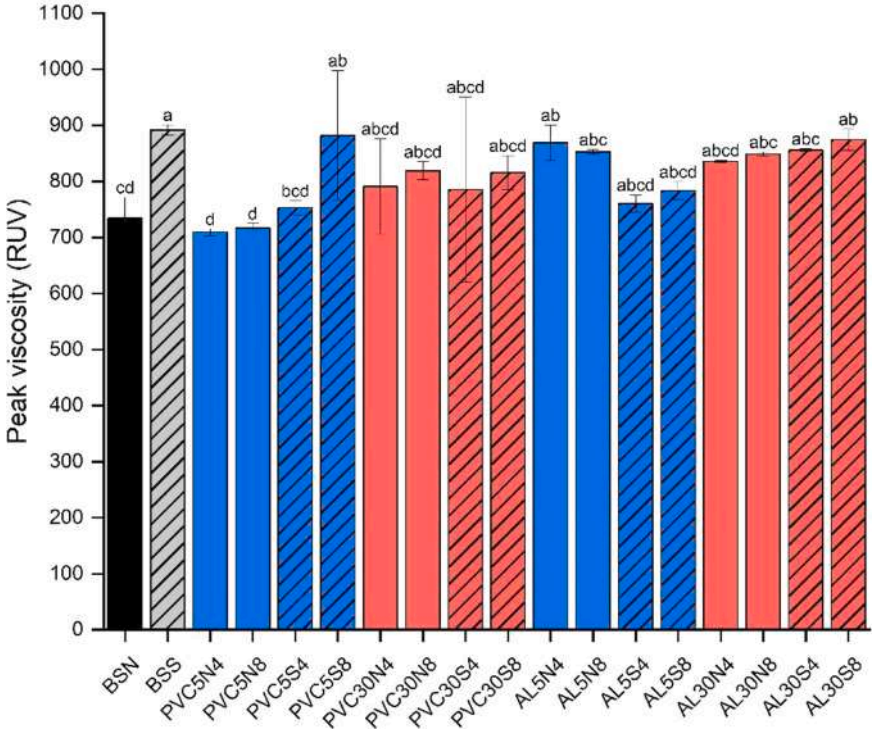


**Fig. 2.** Peak viscosity (PV) of non-sulfured and sulfured YFCF before storage (BSN;BSS), at 4-week and after 8-weeks storage at 5 °C and 30 °C. Different letters indicate significant differences. PVC = cylindric polyvinyl container, AL = aluminum ziplock pouch bag.

conditions while the peak viscosity for the aluminum ziplock pouch (AL) samples ranges from 760 RVU to 874 RVU for both storage conditions.

The peak viscosity value of the BSS sample was significantly higher (891 RVU) than BSN sample (734 RVU). No significant difference was observed in the peak viscosity of the PVC non-sulfured and sulfured samples stored at 5 °C except for the PVC5S8 sample at the end of storage (8-week), that had a peak viscosity value of 881 RVU significantly ($p < 0.05$) higher than the PVC non-sulfured samples at weeks 4 and 8. No significant ($p < 0.05$) difference was also observed in the peak viscosity of both the PVC non-sulfured and sulfured samples stored at 30

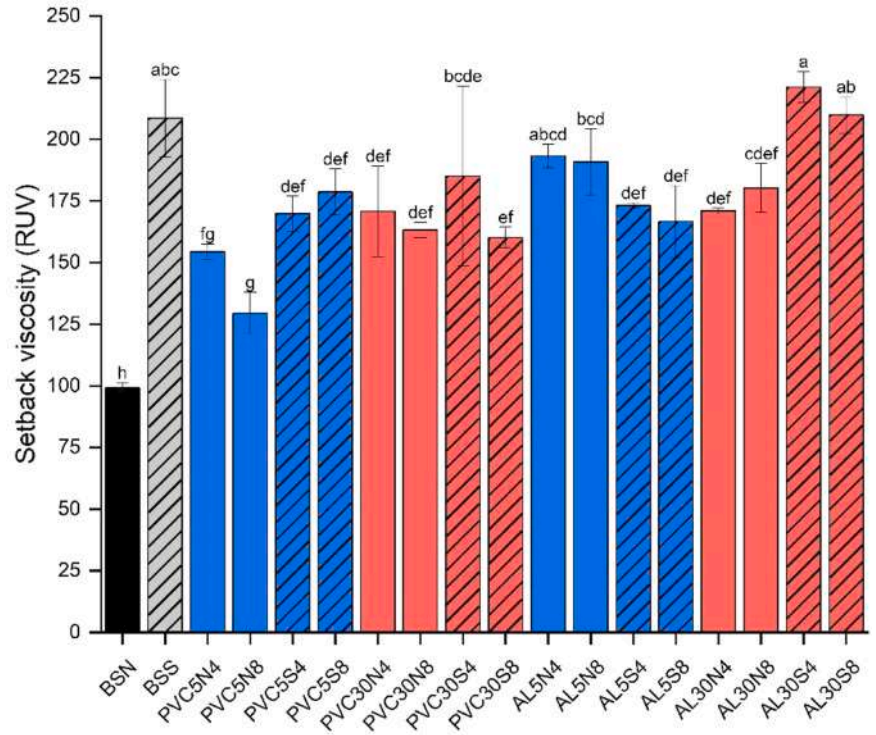


**Fig. 3.** Setback viscosity (SV) of non-sulfured and sulfured-YFCF before storage (BSN;BSS), at 4-week and 8-weeks storage at 5 °C and 30 °C. Significant differences are indicated by different letters. PVC = cylindric polyvinyl container, AL = aluminum ziplock pouch bag.

°C. The peak viscosity of the samples stored at both storage conditions showed no significant differences, otherwise signifying no treatment, packaging and storage effect on the yellow-fleshed cassava flour quality.

Comparing the peak viscosity of the BSN sample to that of the PVC samples at both storage periods and conditions, no difference ($p < 0.05$) was observed statistically, while comparing that of BSS sample's peak viscosity to the PVC sulfured samples, a significant difference was observed for PVC5S4. The peak viscosity was lower (752 RVU) than that of BSS (891 RVU). Similarly, while comparing the peak viscosity of BSN and BSS samples to the peak viscosity of the AL samples, no significant difference ($p < 0.05$) was observed. Comparing the effect of treatment over storage time, no significant differences ($p < 0.05$) were observed in the peak viscosity of the samples packed in PVC and AL for both storage conditions.

The setback viscosity shows the setback viscosity for the PVC samples ranging from 129 to 185 RVU respectively while, for the AL samples, the setback viscosity ranges from 166 to 221 RVU respectively (Fig. 3). The setback viscosity of the BSS sample was significantly higher (208 RVU) than the BSN sample (99 RVU). This is an indication of the effect of pretreatment on the yellow-fleshed cassava flour quality. The setback viscosity of the PVC30S4 sample was significantly different and higher (185 RVU) than the PVC5N4 and PVC5N8 (154 & 129 RVU) samples respectively. No difference was observed amongst samples stored at 30 °C at week 4 and 8. The non-sulfured samples stored at 5 °C had significantly lower setback viscosity value of 129 RVU, than the sulfured samples stored at the same condition with the same packaging material.

Comparing the setback viscosity of the BSN sample to the non-sulfured PVC samples at both storage conditions, the BSN sample was significantly different and had the lowest setback viscosity value of 99 RVU. While comparing the BSS sample to the sulfured samples, it was observed that the BSS sample had a significantly different and higher setback viscosity value of 208 RVU than the PVC sulfured samples at both storage conditions except for the PVC30S4 sample. The setback viscosity of the AL samples were significantly different. The AL30S4 sample had a significantly different and higher setback viscosity value of 221 RVU than other samples except for the AL30S8 and AL5N4 samples that had viscosity values of 209 and 193 RVU respectively. Although, no difference was observed in the setback viscosities between the samples stored at 5 °C, irrespective of treatment; the sulfured samples stored at 30 °C had a significantly different and higher setback viscosity than the non-sulfured samples.

Comparing the effect of treatment on storage time and storage condition, the samples packed in PVC showed no significant difference in their setback viscosity while; significant difference was observed in the setback viscosity of the sulfured AL samples at both storage periods. In comparing the setback viscosity of the BSN sample to that of the non-sulfured samples stored at 5 °C and 30 °C, it was observed that BSN had the lowest value of 99 RVU and was statistically different. The BSS sample had a setback viscosity significantly different and higher than the samples stored at 5 °C.

The final viscosity values range from 398 to 492 RVU for the PVC samples and from 455 to 565 RVU for the AL samples (Fig. 4). The viscosity of the BSS sample was significantly different and higher (513 RVU) than the BSN sample (416 RVU). The BSS sample had significantly different and higher final viscosity value to that of PVC5N4, PVC5N8 and PVC30S8 samples. The final viscosity of the BSS sample was not significantly different from all non-sulfured and sulfured AL samples at both storage periods and storage conditions. The BSN sample had a significantly different but lower final viscosity value from that of PVC5S8 and all AL non-sulfured samples stored at 5 °C at both storage periods. The final viscosity of the BSN sample was significantly different and lower than that of AL30N4, AL30S4 and AL30S8 samples but not different from the all the PVC non-sulfured and sulfured samples. The final viscosity of the non-sulfured PVC samples stored at 5 °C at both storage periods were not significantly different from each other. The same trend was observed for the sulfured PVC samples. The sulfured PVC5S8 sample had a significantly different and higher final viscosity value of 492 RVU from the non-sulfured PVC5N4 and PVC5N8 samples. The PVC5S4 sample had a final viscosity value significantly different

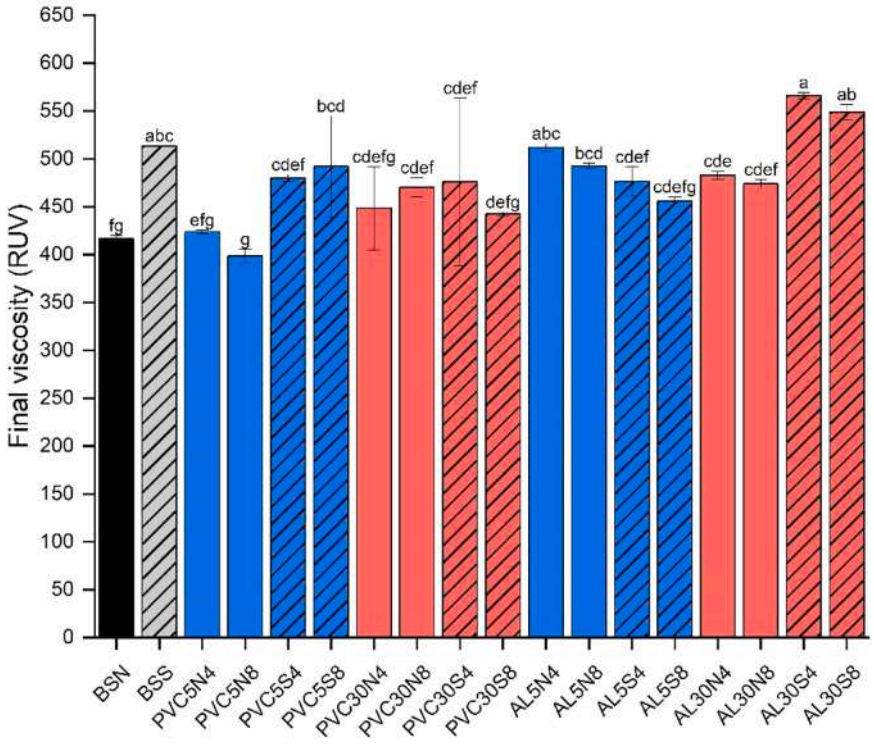


**Fig. 4.** Final viscosity (FV) of non-sulfured and sulfured YFCF before storage (BSN;BSS), at 4-week and after 8-weeks storage at 5 °C and 30 °C. Different letters indicate significant differences. PVC = cylindric polyvinyl container, AL = aluminum Ziplock pouch bag.

and higher to the PVC5N8. No significant difference was observed in the final viscosity of both sulfured and non-sulfured AL samples stored at 5 °C, respectively. The final viscosity of the PVC sulfured and non-sulfured samples stored at 30 °C were not significantly different while, for the AL30S4 and AL30S8 samples had significantly different and higher viscosity (565 RVU and 548 RVU) to the non-sulfured samples.

Between the storage periods and treatment, no significant difference was observed in the final viscosity except for PVC5N8 and PVC5S8 samples.

Peak time for the PVC samples ranges from 3.47 to 3.90 min while for the AL samples range from 3.50 to 3.77 min Fig. 5. There was no significant difference observed between the peak time of both the non-sulfured and sulfured PVC samples stored at 5 °C for both storage periods. Although the peak time value of non-sulfured PVC samples at 8 weeks was significantly different from the sulfured samples. Similarly, no significant difference was observed in the peak time between the non-sulfured and sulfured PVC samples stored at 30 °C at 4-week.

For the AL samples, no significant difference was observed amongst the non-sulfured and sulfured samples at both storage periods and conditions. However, the AL5S8 sample had a significantly higher peak time than the AL30S8 sample. In addition, the AL30S4 sample had significantly higher peak time than the AL30N8 sample. The peak time value of the AL5N8 sample was significantly lower than the other samples stored at the same condition. In comparing the peak time of the BSN sample to the peak time of the non-sulfured PVC samples, it was observed that the peak time of the PVC30N4 sample had a significantly lower value to that of BSN sample. In addition, the peak time of the BSN sample was significantly different and higher than that of the samples stored at 5 °C and 30 °C respectively.

While for the BSS sample, the peak time was significantly different and lower than that of the PVC samples stored at 5 °C. The same trend was observed for the AL samples stored at both conditions except for AL5N4, AL5S4, AL5S8 and AL30S4.

The pasting temperatures ranged from 72 to 74 °C for PVC samples and from 74 to 75 °C for AL samples (Fig. 6). No significant difference was observed in the pasting temperatures amongst all the samples except for samples PVC5N4 and AL30S4 samples that had the lowest and highest pasting temperatures (72 °C and 75 °C) respectively.

### 3.2. Results of the functional properties

The water absorption capacity (WAC) ranges from 202 to 427 % for the PVC samples and from 216 to 431 % for the AL samples. The significant differences ($p < 0.05$) observed in the WAC of both the non-sulfured and sulfured PVC samples stored at 5 °C shows that the sulfured PVC samples had significantly different and higher WAC values than the non-sulfured PVC samples at both storage periods. The WAC of the PVC30N8 sample stored at 30 °C was significantly different and higher than the other samples. Significant differences were observed when the WAC of the BSN sample was compared to that of the PVC5N8 and PVC30N8 samples. While for the BSS samples, no significant difference was observed in the WAC.

The WAC of both the non-sulfured and sulfured AL samples stored at 5 °C were significantly different, with the WAC values of the AL5N4 sample significantly higher than the others. The WAC of the AL30S8 sample stored at 30 °C was also significantly different and higher. Comparing the WAC of the non-sulfured AL5 samples, it was observed that the AL5N4 sample had a significantly higher WAC value (356 %) than the AL5N8 sample (265 %). While, for the sulfured AL5 samples, the WAC of the AL5S4 sample was significantly different and higher (273 %) than the AL5S8 sample (216 %). No significant difference ($p < 0.05$) was observed in the WAC of the non-sulfured AL30 samples, while the sulfured AL30S8 sample had a significantly different and higher WAC value (431 %) to that of the AL30S4 sample (322 %).

The WAC of non-sulfured AL samples was compared to the BSN sample, and it was revealed that except for the AL5N4 sample that had a significantly different and higher WAC, no difference was observed amongst the other samples. Subsequently, when the WAC of the BSS sample and that of the sulfured AL samples was compared, it was observed that the WAC of the AL5S8, AL30S8 and BSS samples were

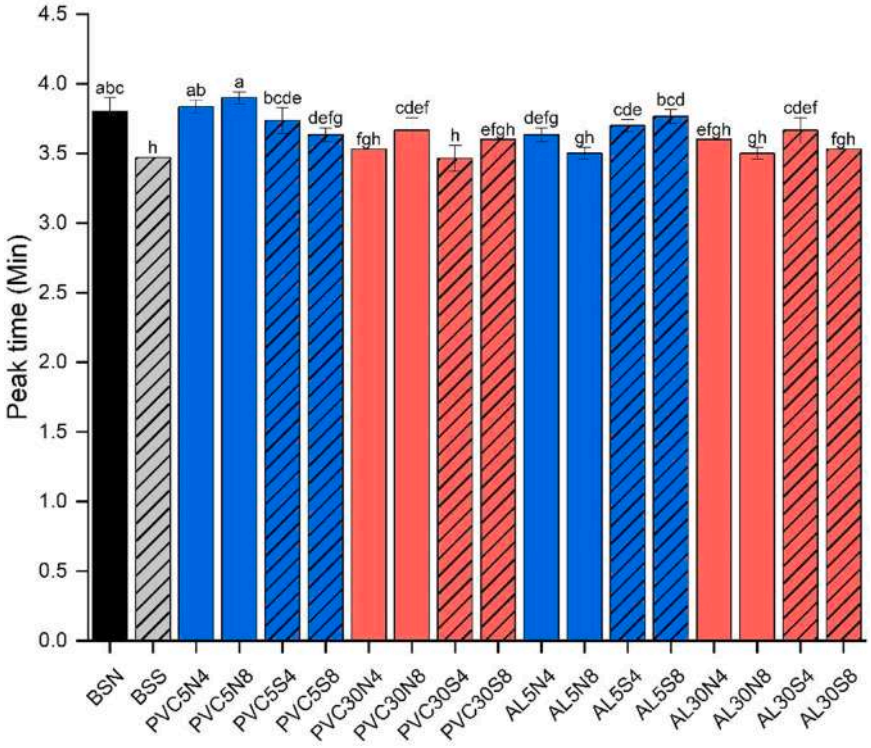


**Fig. 5.** Peak time of non-sulfured and sulfured YFCF before storage (BSN;BSS), at 4-week and after 8-weeks storage at 5 °C and 30 °C. Different letters indicate significant differences. PVC = cylindric polyvinyl container, AL = aluminum ziplock pouch bag.

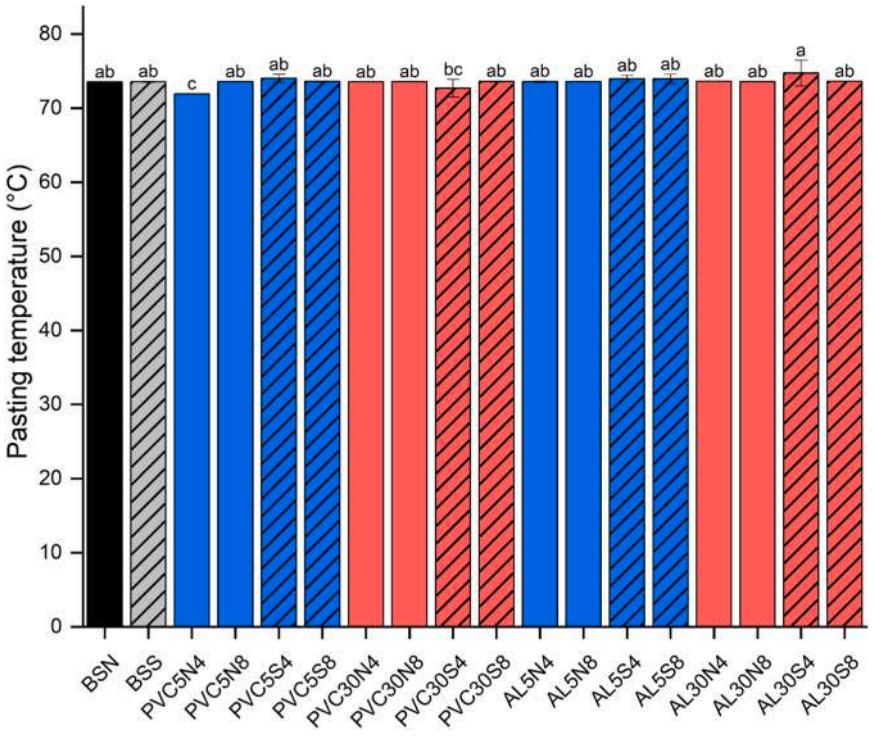


**Fig. 6.** Pasting temperature of non-sulfured and sulfured YFCF before storage (BSN;BSS), at 4-week and after 8-weeks storage at 5 °C and 30 °C. Different letters indicate significant differences. PVC = cylindric polyvinyl container, AL = aluminum Ziplock pouch bag.

significantly different and it was recorded in the following order AL30S8 > BSS > AL5S8 (431 %, 312 % & 216 %) respectively (Fig. 7).

The oil absorption capacity (OAC) values range from 127 % to 162 % for the PVC samples and from 117 % to 181 % for the AL samples (Fig. 8). The OAC of non-sulfured PVC samples were significantly different for samples stored 5 °C while no difference was observed in the OAC of the non-sulfured PVC samples stored at 30 °C. For the sulfured PVC samples, no difference was observed in the OAC at both storage conditions. In comparing the OAC of BSN samples to the non-sulfured PVC samples, except for PVC5N4, no significant difference was

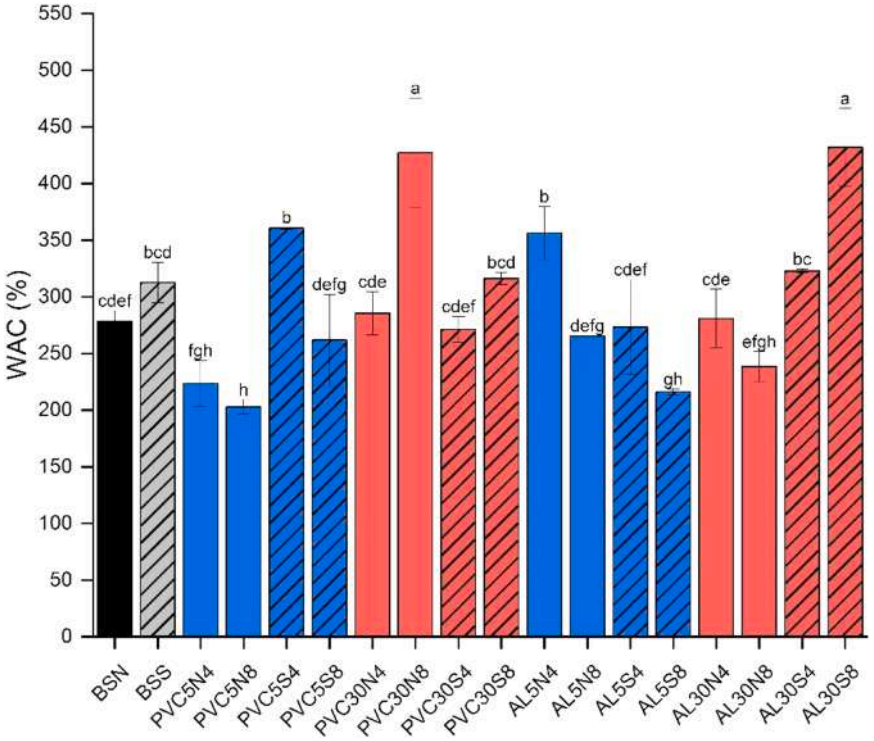


**Fig. 7.** Water absorption capacity (WAC) of non-sulfured and sulfured YFCF before storage (BSN;BSS), at 4-week and after 8-weeks storage at 5 °C and 30 °C. Different letters indicate significant differences. PVC = cylindric polyvinyl container, AL = aluminum ziplock pouch bag.

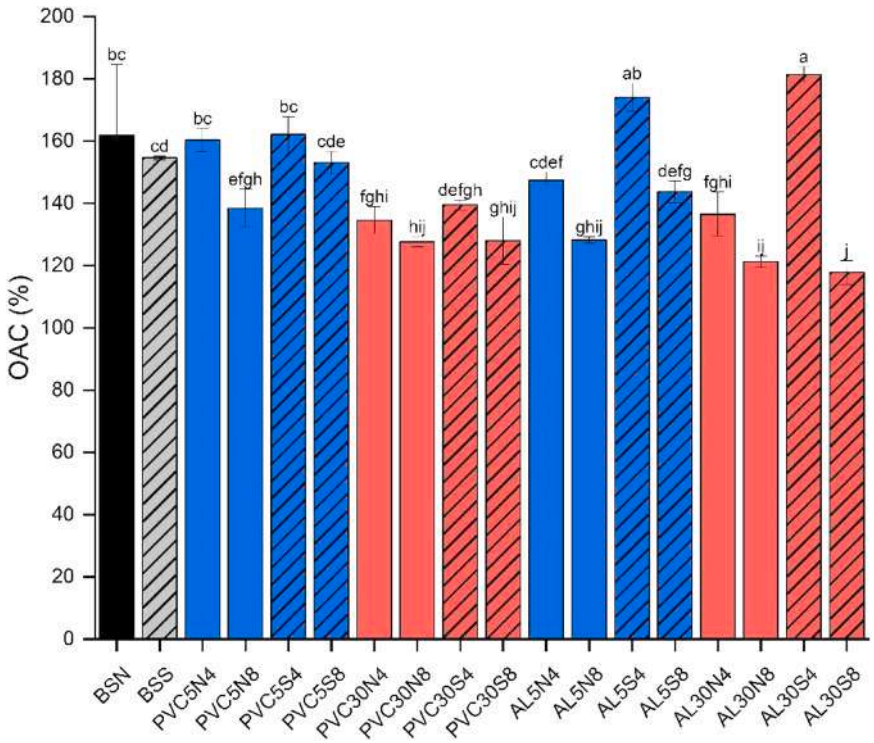


**Fig. 8.** Oil absorption capacity (OAC) of non-sulfured and sulfured YFCF before storage (BSN;BSS), at 4-week and after 8-weeks storage at 5 °C and 30 °C. Different letters indicate significant differences. PVC = cylindric polyvinyl container, AL = aluminum ziplock pouch bag.

observed.

The OAC of the non-sulfured AL samples were not significantly different for both storage conditions except for the AL5N4 sample that has a significantly different and higher WAC than the AL5N8. Both sulfured AL samples stored at both storage conditions at the 4 week period had significantly different and higher WAC than the other AL samples. The AL5S4 sample had OAC values significantly higher (174 %) to the AL5S8 sample (143 %), similarly, the AL30S4 sample had a

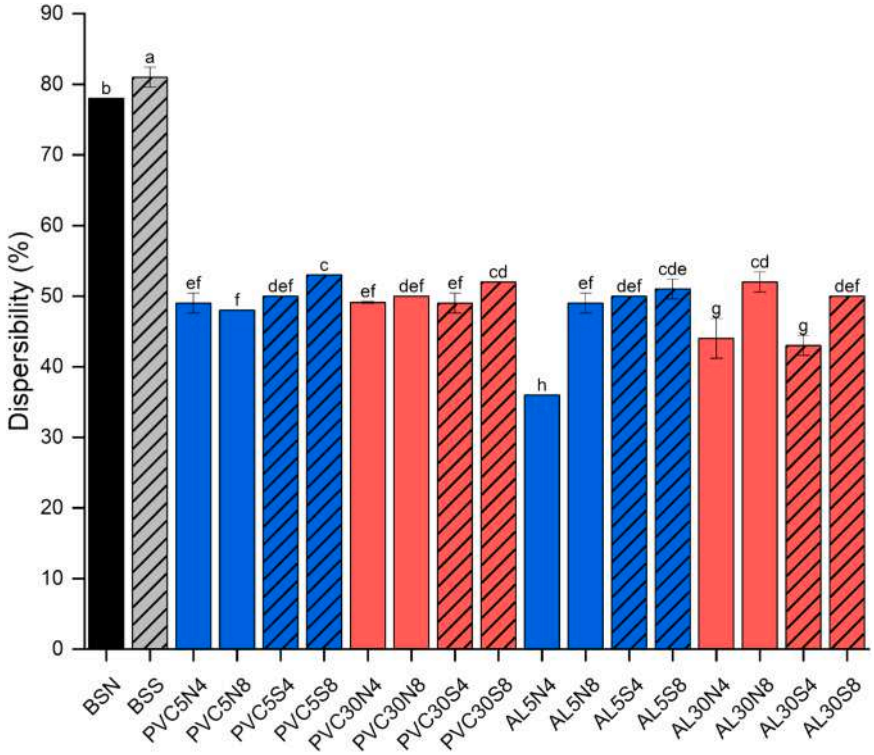


**Fig. 9.** Dispersibility percentage of non-sulfured and sulfured YFCF before storage (BSN;BSS), at 4 weeks and after 8 weeks storage at 5 °C and 30 °C. Different letters indicate significant differences. PVC = cylindric polyvinyl container, AL = aluminum ziplock pouch bag.

significantly higher OAC value (181 %) to that of the AL30S8 sample (117 %). Although no significant difference was observed in the OAC for sulfured AL5 and AL30 samples at 4 weeks, sulfured AL5S8 had OAC significantly higher than that of AL30S8 sample.

Comparing the OAC of BSN samples to the non-sulfured AL samples, except for the AL5N4 sample, the other non-sulfured AL samples had significantly different WAC for both storage conditions. While the OAC of the BSS and the sulfured AL5S8 sample were not significantly different. The AL30S8 sample had significantly lower OAC, and AL5S4 and AL30S4 samples had significantly higher OAC than that of BSS sample.

The percentage dispersibility ranges from 48 % to 53 % for the PVC samples and from 36 % to 52 % for the AL samples (Fig. 9).

No difference was observed in the percentage dispersibility of the PVC samples stored at 5 °C except for PVC5S8 that had a higher percentage dispersibility of 53 %. The same trend was observed for PVC samples stored at 30 °C, as PVC30S8 samples had a significantly different and higher percentage dispersibility of 52 % even though not significantly different from PVC30N8.

Comparing the percentage dispersibility of the BSN sample to that of the non-sulfured PVC samples, a significant difference was observed as the BSN sample had a higher percentage dispersibility (78 %) more than the other samples except for the PVC30S8 sample.

Significant difference ($p < 0.05$) was observed in the percentage dispersibility of the AL samples. The AL5N4 sample had significantly different and lower percentage dispersibility (36 %) to the other samples stored at 5 °C. While the AL samples stored at 30 °C showed significant difference in the percentage dispersibility.

The non-sulfured and sulfured AL samples had significantly different percentage dispersibility for both storage periods. The AL30N8 sample had a higher percentage dispersibility of 52 % than AL30N4 while the AL30S8 sample had a higher percentage dispersibility value of 50 % than the AL30S4 sample.

No difference was observed in the percentage dispersibility of both the non-sulfured and sulfured AL30 samples at week 4, also the percentage dispersibility of non-sulfured AL30 samples was not significantly different from that of sulfured AL30 at week 8.

## 4. Discussion

### 4.1. Changes in the pasting properties of YFCF during storage

The study samples exhibited significant differences in the peak viscosity which were high ranging from 716.58 RVU–852.58 RVU (Non-sulfured samples) to 783.42 RVU–881 RVU (Sulfured samples). The results for the sulfured flour samples shown in Fig. 2 indicate that the peak viscosity values of the samples apart from BSS sample were not significantly different from each other irrespective of the storage conditions and packaging although AL5 samples' peak viscosity (783.42 RVU) was not significantly different from BSS sample (642.08 RVU). Storage time significantly affected the peak viscosity towards the end of storage. The peak viscosity values recorded in this study for both non-sulfured and sulfured samples were significantly higher to those reported by Adebowale et al. (2017) on water yam flour. The variations observed in this study could be associated with the processing methods, pretreatment applied and the inherent properties of the study samples such as amylose content that ranges from 33.8–39.5 % (before storage) to 22.7–34.7 % (during storage) (data not presented here). According to Iwe and Agiriga (2014), variations observed in flour viscosity are due to varietal influences and harvest times. Zaidul et al. (2007) and Kaur et al. (2013) also reported that variations could be due to the degree of starch damage and the binding force between the flour particles that contribute to influence the peak viscosity. Adeyemi and Beckley (1986), reported that an increase in viscosity of gelatinized foods tends to be more dependent on the starch content of the product. Peak viscosity is the highest viscosity reached during heating or pasting and this occurs at the end of the heating stage when the high number of swollen starch granules results in pasting (Thomas & Atwell, 1999). Pasting is the combined effect of swelling and rate of disruption of the granules (Batey, 2007). The high peak viscosity observed in flour is linked to weak starch molecules and this is because the starch molecules penetrate easily into the granules leading to high viscosities and reduced resistance to heat and shear. In comparing the peak viscosity of the study samples with the report from Onitilo et al. (2007a), the study samples had a higher peak viscosity, possibly due to the different varieties, processing techniques and pretreatments used in both studies. Although high peak viscosity is related to starch hydration capacity, which occurs when the majority of starch granules swell. This is closely related to the degree of starch damage and the final product quality, as it provides an indication of the viscous load likely to be encountered during mixing. Nuwamanya et al. (2010a), stated that starches with low peak viscosity also exhibit better culinary properties (cooking time, cooking loss and cooking weight). The high viscosity and low resistance to shear in the study samples could be due to the weak starch molecules caused by the loose association between amylose and amylopectin in the native starch granules. According to Etudaiye et al. (2009), pastes produced from flours that have weak starch molecules are more prone to break down during cooking due to the weak associative force that maintains the structure of the granules. Similarly, Liu et al. (2006) affirmed that a high peak viscosity is indicative of the maximum swelling capacity of the starch granules before disintegration and this could be due to the water absorption capacity of the flour and the degradation of starch granules during storage. Sulfured (PVC5, PVC30 and AL30) and non-sulfured (PVC30, AL5 and AL30) flour samples with higher peak viscosities can be suitable for jelly production, thickener/binders and other products as they cannot withstand high temperatures during processing, while BSN and BSS samples, and non-sulfured PVC5 with lower peak viscosity would be recommended in making weaning food (Tsakama et al., 2010).

According to Shimelis et al. (2006) and Aviara et al. (2010), determination of the pasting (rheological) behavior of flour is important as it indicates its suitability and applicability in the food industry. It also affects the stability and texture of products during product development (Adebowale et al., 2017). Peak viscosity is linked to the ease of cooking and it is an indication of the water binding capacity of the starch flour to form a paste (Moorthy, 2002; Cozzolino, 2016; Mahasukhonthachat et al., 2010; Oduro et al., 2000; Kaur et al., 2013). Liu et al. (2006), reported that the peak viscosity of a flour correlates with the final product quality and other quality properties of the sample; as the temperature is increased, the starch granules swell, which increases the viscosity of the paste until the peak viscosity is achieved. Peak viscosity is measured as the highest value of viscosity attained by the slurry during the heating cycle (25–95 °C) (Moorthy, 2002; Mahasukhonthachat et al., 2010; Oduro et al., 2000). Peak viscosity is closely associated with the degree of starch damage (Ring et al., 1987).

Setback viscosity or the cooling phase describes the stability of flour paste after cooking (Sanni et al., 2006). The mean setback viscosity value of the BSN sample was 99.12 RVU, while for the BSS sample is 140.92 RVU. The study samples exhibited significant differences in the setback viscosity which were higher ranging from 129.46 RVU to 190.83 RVU (Non-sulfured samples); 160.17 RVU to 209.88 RVU (Sulfured samples) compared to the setback viscosity of water yam flour as reported by Adebowale et al. (2017), which was low range between 13.52 and 160.92 RVU. The setback viscosity from this study was significantly higher compared to the report by Etudaiye et al. (2009) on 43 cassava mosaic disease resistant (CMD) varieties which ranged from 28.17 RVU to 70.42 RVU respectively. Eke-Ejiofor and Owuno (2012) and Abiodun et al. (2013) also reported high setback values on *Dioscorea dumetorum* and this is associated with syneresis or weeping during freeze/thaw-cycles. Setback viscosity is an index of the tendency of the cooked flour to harden on cooling due to amylose retrogradation (Aribisala & Olorunfemi, 1989). It is the state at which retrogradation or re-ordering of starch molecules occurs. It measures the reassociation of

starch. The higher the setback value, the higher the retrogradation during cooling.

The setback viscosity helps to predict the storage life of a food product prepared from the flour (Zaidul et al., 2007b). The phase of the pasting curve commonly referred to as the setback region is the phase where the mixture cools down, a re-association between starch molecules occurs to a greater or lesser degree. It affects retrogradation or re-ordering of the starch molecules (IITA, 2001). Conversely, flour samples with low setback values may be useful for products like complementary foods (Oduro et al., 2001). According to Maziya et al. (2005), low setback viscosity value shows a low tendency to undergo retrogradation during freeze/thaw-cycles as the paste cools thereby indicating the stability of the cooked flour. A low setback viscosity value indicates that the flour has a high paste stability and resistance to retrogradation during cooling (Eke-Ejiofor & Owuno, 2012; Etudaiye et al., 2009).

The final viscosity is the ability of the flour to form a gel after cooking and cooling thereby signifying the stability of the flour paste quality (Shimelis et al., 2006). The mean final viscosity for BSN sample was 415.62 RVU while for BSS sample was 484.21 RVU respectively. The study samples exhibited significant differences in the final viscosity ranging from 398.33 RVU–492.46 RVU (Non-sulfured samples) to 442.46 RVU–548.88 RVU (Sulfured samples). The results obtained in this study indicates an increase in final viscosity of the flour samples with storage compared to the BS samples. The non-sulfured AL5, AL30 and PVC30 had higher final viscosities. Salman and Copeland (2007) also reported the increase in the final viscosity on wheat flour samples stored at 30 °C and 4 °C, and the highest final viscosity was seen in flour stored at 30 °C compared to samples at the lower temperature. The report was comparable to the AL30 sulfured samples. For the non-sulfured samples, the final viscosity of the AL5 samples was significantly higher from the other samples indicating that both packaging and storage conditions had a significant impact on the flour quality with respect to storage time. Iwe and Agrirga (2014) also recorded a significant difference in the final viscosity of cassava flour cultivars. The differences in the final viscosities were due to the kinetic effect of cooling and the reorganization of the starch molecules. High viscosities show that the associative forces between the starch molecules are relatively weak. The molecules are able to penetrate their starch granules much easier, and the granular swell enormously leading to weakening of associated forces, which in turn makes them susceptible to breakdown. The AL30 sulfured sample showed significantly higher final viscosity value to that of the PVC30 and AL5 samples but no difference to the final viscosity of the BS samples. This indicates that there was a minimal impact on the flour quality as regards to packaging and treatment over time. The final viscosity values obtained before storage (BS) were comparable to those reported by Adebowale et al. (2017) for water yam flour. Final viscosity also indicates the ability of the flour to form a firm, visco-elastic paste or gel after cooking and cooling due to reassociation of starch molecules (Newport Scientific, 1998). It is the common parameter used to determine the quality of starch-based samples and is the viscosity after cooling cooked paste to 50 °C.

The peak time and pasting temperature signify the set time when the paste reaches its peak viscosity and forms gel at a particular temperature (Etudaiye et al., 2009). Peak time is used to estimate the actual cooking time for flour-based products (Adebowale et al., 2005). The peak time for the cassava flour in this study was lower than that reported by Uchechukwu-Agua et al. (2015) for cassava flour. This could be attributed to the processing treatment and the cassava variety, however, cassava flour with shorter peak time could be expected to use lesser energy during processing thus reducing the production time and cost. Flour samples with short peak time, would show low resistance to shear (Iwe & Agrirga, 2014). In addition, Tsakama et al. (2010) reported that samples with short peak time would swell quickly which will lead to fast disassociation of the granules.

The temperature at which the first detectable viscosity was measured is the pasting temperature. It gives an indication of the gelatinization therefore it is the minimum temperature required to cook a sample (Singh et al., 2003) as well as the energy cost involved (Ikegwu et al., 2009). High pasting temperature can also indicate the starch resistance to swelling (Singh et al., 2003). The pasting temperature in this study were lower than the pasting temperatures reported by Uchechukwu-Agua et al. (2015) for Umucass 36 (88 °C) and TME 419 (85 °C) cassava flours but within the range reported by Etudaiye et al. (2009) and, Babajide and Olowe (2013) for cassava and water yam-cassava composite flour respectively. Consequently, indicating that the flour samples from this study would require less energy during cooking thus reducing cost of production.

### 4.2. *Changes in the functional properties of YFCF during storage*

The functional properties of flour determine their end use. The water absorption capacity is the ability of the starch or flour to absorb water and swell thereby improving the consistency, which is necessary in the food sector to improve yields and give body to food (Osundahunsi et al., 2003). The mean water absorption capacity for the BSN sample was 278.06 % while for the BSS sample was 312.70 %. The study samples exhibited significant differences in their water absorption capacity ranging from 202.76 %–427.34 % (Non-sulfured samples) to 216.02 %–431.87 % (Sulfured samples). The enhancement could be attributed to hydrophilic components such as polar or charged side chains of proteins and carbohydrates, which are key chemical components that boost water absorption ability (Ojo et al., 2017).

Water absorption capacity increased more with storage time for samples stored in the climatic chamber (30 °C), while a decrease in water absorption capacity was observed at the end of storage for samples stored in the cooling chamber (5 °C). The packaging materials and storage condition affected the water absorption capacity of the study samples. The increase in water absorption capacity of the non-sulfured sample (PVC30) and sulfured sample (AL30) is an indication of the loose structure of the starch polymer (Soni et al., 1985). The study samples had significantly higher water absorption capacity compared to the reports by Adebowale et al. (2008) for starches of 13 white cassava varieties ranging from 59.75 to 68.02 % and Onitilo et al. (2007a) for 39 white cassava varieties with water absorption capacity of 86.83–127.54 %. High water absorption capacity is attributed to the loose structure of the starch polymers while a low value indicates the compactness of the molecular structure (Eke-Ejiofor & Owuno, 2012). This implies that flour samples stored in an incubator condition (30 °C) have a loose starch polymer structure compared to those stored in a cold room storage condition (at 5 °C). The decrease in water absorption capacity values observed when the study samples were stored in the cold room storage (5 °C) is indicative of the compactness of the molecular structure (Soni et al., 1985). The decrease in water absorption capacity could be due to the loose association between amylose and amylopectin in the native starch granules and weaker associative forces maintaining the granules' structure (Newport Scientific, 1998; McWatters et al., 2003). The variations in the water absorption capacity of the flour could also be acclaimed to the degree of interaction with water and conformational characteristics (Adeleke & Odedeji, 2010). The relatively higher water absorption capacity values could be due to the pretreatment thus, the flour samples with highest water absorption capacity are considered more acceptable for baking purposes.

High oil absorption capacity is required to maintain flavor and improve palatability, whereas low oil absorbency is a desirable property in foods such as sausages, custard and dough as these foods are intended to absorb water without dissolving protein, resulting in thickening and viscosity. The mean oil absorption capacity of BSN samples was 161.95 % while for the BSS sample was 154.62 %. The study samples exhibited significant differences in their oil absorption capacity ranging from 121.24 %–138.42 % (non-sulfured samples) to 117.82 %–153.09 % (Sulfured samples). The non-sulfured samples were not significantly

different from each other except for the samples at the before storage, while for sulfured samples, all samples had high oil absorption values except for PVC30 and AL30. The reduction in oil absorption capacity with advancing storage could probably be due to the reduced ability of the flour to trap fat at its polar end of the protein chain due to the decrease in protein content (Adeola et al., 2020).

Dispersibility is a measure of the reconstitution of flours in water. The flour samples at the before storage had the highest value (78 % and 81 %) of dispersibility. This indicates that they reconstitute easily and give the dough a fine consistency when mixing (Adebowale et al., 2008). The dispersibility percentage of the study samples was within the same range as reported by Hidalgo and Brandolini (2008) for white and yellow cassava flour samples.

The water absorption capacity and dispersibility is also an added advantage for high peak viscosity. Temperature and type of packaging materials are important factors in controlling flour deterioration. According to Li et al. (2017), regulating these parameters can extend the shelf life of the flour. To realize the flour's full potential in food processing, either alone or together with other ingredients, understanding the effects of storage temperature and packaging materials on the rheological and functional properties of the stored flour is essential. Exposing flour to a certain temperature and relative humidity has led to caking of the flour. The use of improper packaging materials is a serious postharvest challenge, which affects the quality and shelf life of flour. Flour can readily take up and retain moisture during transportation and storage. Packaging materials differ in their permeability to oxygen and moisture and therefore, the choice of an appropriate packaging material is vital.

## 5. Conclusion

Packaging materials, storage conditions and time significantly affected the pasting and functional properties of yellow-fleshed cassava flour samples. Furthermore, higher water absorption capacity indicates easy handling of dough during product development. In addition, the use of sodium metabisulphite as a pretreatment tool may be recommended as it can improve the flour quality. Therefore, based on the overall quality and safety evaluation, the aluminum Ziplock pouch bag would be the most effective packaging material for long-term storage of cassava flour. The flour portrays a better storage quality and retains a better pasting property and this information could be useful in packaging, storage, exporting and commercialization of cassava flour and its products. The packaging performed well even at 30 °C. Therefore, cooling would not be required.

## Recommendation

Aluminum Ziplock pouch bags would be the most effective packaging material for long-term storage of cassava flour.

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Ethics approval was not required for this research.

## Ethical statement

The authors declare that no human nor animal was used in this study.

## CRediT authorship contribution statement

**Esther Ekeledo:** Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing, Visualization, Project administration, Funding acquisition. **Adebayo Abass:** Resources, Writing – review & editing. **Joachim Müller:** Data curation, Validation, Writing – review & editing, Supervision.

## Declaration of competing interest

The authors declare that this manuscript is original and has not been published nor is it under consideration for publication; elsewhere, we also declare that there are no conflicts of interest with respect to the work in this manuscript.

## Data availability

The authors are unable or have chosen not to specify which data has been used.

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## Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.afres.2024.100467.

## Appendix. Abbreviation code according to figure presentation

| Packaging materials | Storage conditions | Treatment | Period (weeks) | Remark |
|---|---|---|---|---|
| BSN | – | Non-sulfured | Baseline (control) | Before storage non-sulfured |
| BSS | – | Sulfured | Baseline (control) | Before storage sulfured |
| Cylindric polyvinyl containers | – | – | – | PVC |
| Aluminum ziplock pouch bags | – | – | – | AL |
| Cylindric polyvinyl containers | 5 °C | Non-sulfured | 4 weeks | PVC5N4 |
| Cylindric polyvinyl containers | 5 °C | Non-sulfured | 8 weeks | PVC5N8 |
| Cylindric polyvinyl containers | 5 °C | Sulfured | 4 weeks | PVC5S4 |
| Cylindric polyvinyl containers | 5 °C | Sulfured | 8 weeks | PVC5S8 |

(*continued on next page*)

(*continued*)

| Packaging materials | Storage conditions | Treatment | Period (weeks) | Remark |
|---|---|---|---|---|
| Cylindric polyvinyl containers | 30 °C | Non-sulfured | 4 weeks | PVC30N4 |
| Cylindric polyvinyl containers | 30 °C | Non-sulfured | 8 weeks | PVC30N8 |
| Cylindric polyvinyl containers | 30 °C | Sulfured | 4 weeks | PVC30S4 |
| Cylindric polyvinyl containers | 30 °C | Sulfured | 8 weeks | PVC30S8 |
| Aluminum ziplock pouch bag | 5 °C | Non-sulfured | 4 weeks | AL5N4 |
| Aluminum ziplock pouch bag | 5 °C | Non-sulfured | 8 weeks | AL5N8 |
| Aluminum ziplock pouch bag | 5 °C | Sulfured | 4 weeks | AL5S4 |
| Aluminum ziplock pouch bag | 5 °C | Sulfured | 8 weeks | AL5S8 |
| Aluminum ziplock pouch bag | 30 °C | Non-sulfured | 4 weeks | AL30N4 |
| Aluminum ziplock pouch bag | 30 °C | Non-sulfured | 8 weeks | AL30N8 |
| Aluminum ziplock pouch bag | 30 °C | Sulfured | 4 weeks | AL30S4 |
| Aluminum ziplock pouch bag | 30 °C | Sulfured | 8 weeks | AL30S8 |

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