Research Journal of Chemical Sciences ISSN 2231-606X
Vol. **11(3),** 24-32, October **(2021)** *Res. J. Chem. Sci.*

Physical, proximate and pasting properties of flours from selected clones of low postharvest physiological deterioration cassava

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Available online at: www.isca.in, www.isca.me
Received 17th May 2021, revised 3rd July 2021, accepted 10th August 2021

Abstract

Pasting properties of food depicts various uses of starch based food ingredients in food production processes. The physical, proximate and pasting properties of high quality cassava flours produced from low postharvest physiological deterioration (PPD) cassava was examined by this study. Wholesome four varieties of yellow-fleshed Low PPD cassava and one variety of high PPD cassava were, washed, grated, pressed, pulverized, flash dried at 120°C for 8 minutes, milled with cyclone hammer mill to which a screen having aperture size of 250 was affixed, subsequently cooled and packaged into high density polyethylene bag. The flours were subjected to analysis such asphysical, proximate and pasting. SPSS 25.0 was used to analyze pertinent data generated, means that were significant was separated applying Duncan multiple range test. Lightness of the flour (L), redness to greenness (a*), blueness to yellowness (b*), hue and chroma had values ranging from 97.96-99.01, -0.07-1.05, 6.42-15.28 and 90.62-95.93 and 6.43-15.32. Moisture, protein, ash, fat, carbohydrate, dry matter and energy value ranged from 6.84-8.73%, 0.17-0.34%, 0.23-0.63%, 0.23-0.63%, 90.08-92.14%, 91.27-93.16% and 1521.68-1558.96KJ/kg. Pasting parameter such as peak, trough, breakdown, final, setback viscosity, peak time and pasting temperature had values ranging from 552.25-716.79RVU, 68.29-234.67RVU, 361.13-517.38RVU, 291.09-380.09RVU, 85.67-265.21RVU, 3.53-4.13min and 71.93-73.55°C respectively. The high gel strength, starch granule stability to heating and low peak time revealed that low PPD cassava flours are suitable for use in the baking and confectionery industry.*

Keywords: Confectionery, Pasting properties, Pulverization, Screening, Supplementation, baking.

Introduction

Cassava (*Manihot esculenta Crantz*) is a crop that people eat in the tropical regions[1]. Notably, cassava production rose from 132,200,764 tons to exactly 157,271,697 tons in 2010 to 2016, respectively, which was about 18.9%[2]. Also, the production share of cassava by region: Africa (60.7%), Americas (9.9%), Asia (29.3%) and oceania (0.1%) from 2017 to 2018[3]. The total production of cassava in Africa in 2018 was 169,673,737[3]. Cassava is known to suffer a physiological disorder that takes effect in about 24-72 hours after the roots have been harvested which impairs its palatability even though it has propensity for increased productivity[4].

Cassava (*Manihot esculenta Crantz*) characteristically has short postharvest life and this is as a result of a phenomenon known as postharvest physiological deterioration (PPD, which consequently reduce its market potential and makes the stakeholders in its value chain loose enthusiasm. This challenge requires that cassava is quickly transported to the point of processing and this has led to the screening of cassava varieties for extended shelf life, improvement in the nutritional composition and yield, thereby overcoming the major challenge confronting cassava value chain.

In countries and regions where wheat grain production is not supported due to unfavorable soil and climatic conditions required for optimum growth of wheat, such countries would largely depend on importation of wheat. In Nigeria, crops such as cassava, cowpea etc. and their flour has been explored and prospected for use in replacing wheat flour up to 30% so as to reduce the over-dependence on wheat importation for use as food and industrial application[5,6]. Replacement of wheat with high quality cassava flour (HQCF) in making composite flour for baking purpose attracted the attention of the Nigerian Government, which necessitate that Nigerian flour mills should replace wheat flour with cassava flour up to 10%.

Development (screening) of some low PPD cassava varieties targeted at extending the shelf life of cassava root from two days (48hrs) to 5 days (120hrs) and enhancement of nutritional value with vitamin A or β-carotene is very important. Authors had established that varietal difference goes a long way to affect the quality parameters such as physical, functional and chemical properties of high quality cassava flour[7]. This consequently implies that the flour making properties of such roots and their food uses would also vary[5].

Physical quality such as color is an important organoleptic quality attribute of consideration when talking about acceptability of food products to the consumer. The proximate components in food are essential to the consumers in order to be informed on the nutritional benefits derivable in a food so as to guide them in making knowledgeable decisions about their diet. Pasting properties of food depicts various uses of starch based food ingredients in food production processes[8-10]. This study therefore examined the physical, proximate and pasting characteristics of flours made from selected screened cassava varieties for delayed or low postharvest physiological deterioration (PPD).

Materials and methods

Materials: Flours from five (5) varieties were used for the study. Four yellow fleshed varieties screened for low postharvest physiological deterioration are: IITA-TMS-IBA011368 (yellow), IITA-TMS-IBA070596 (yellow), IITA-TMS-IBA011412 (yellow), IITA-TMS-IBA011371 (yellow) and one variety of high postharvest physiological deterioration: TMEB419 (white) were provided by International Institute of Tropical Agriculture (IITA), Ibadan while the refined wheat flour was gotten from Nigerian Eagle Flour Mills of Nigeria, Ibadan.

Production of cassava flour used in the study: Wholesome cassava used for this study were provided by International Institute of Tropical Agriculture (IITA) which was processed into HQCF. The wholesome cassava roots were subjected to unit operations such as peeling, washing in a clean water so as to remove dirts and extraneous material that could be adhered to the roots. The washed roots were then grated and pressed with screw jack press to remove water from the mash. The cake was reduced to very small particles (pulverizing) and subsequently dried with the aid of flash dryer at 120°C. The flour that was dried using a flash dryer was reduced (milled) to flour using cyclone hammer mill to which a mesh size of 250 µm was attached, the cooled flour was then packaged using high density polyethylene bag and sealed for subsequent analysis. Chemical analysis such as (sugar, starch, amylose, cyanogenic potential, total titratable acidity, total carotenoids and pH) was carried out while functional (flour ability to absorb water, oil, swelling power, degree of flour being soluble in water, starch damaged, gelation capacity and bulk density) properties were determined.

The proximate analysis: The proximate parameters (moisture content, protein, ash, and fat content) of the HQCF produced from the varieties of the low postharvest physiological deterioration (PPD) cassava tubers were determined following the AOAC methods[11]. Carbohydrate content in percentage was estimated employing difference Equation (1)[12]. An equation which was a factor was used in calculating the energy value expressed in Kcal/kg or KJ/kg (2)[13]. The dry matter of the HQCF was estimated using Equation (3)[14].

Carbohydrate (%) = 100 - % (protein + fat + moisture + ash) (1)
Energy value Kcal/kg = (Protein content x 4 + fat content x 9 + carbohydrate content x 4) (2)
Dry matter (%) = (100 – Moisture content) (3)

Color determination (CIE L* a* b*): The surface color of the low PPD cassava flours were determined objectively with the aid of a Colorimeter (Color Tec PCM™ Color Tec Associates, Inc., Clinton, NJ, USA). At five different point was the reading taken for the value of L*, a*, and b*, averages of the readings were computed and reported.

The pasting properties of the flours: The pasting profile of HQCF from low PPD cassava was studied with the aid of a Rapid Visco Analyzer (Model RVA-4C, Newport Scientific, Warriewood, Australia). Exactly 3g of the HQCF was measured, transferred into a canister that was dry to which 25 ml of de-ionized water was added. The resulting mixture was stirred with the aid of a stirrer and the canister was then fixed into the RVA (equipment) as stipulate by the manufacturers' handbook (instructional manual). Heat was then applied to the slurry with temperature regime of 50 to 95°C for 2min and subsequently cooled to 50°C after the holding the sample heated for 2min. The rate at which heat was applied and subsequent cooling was at a steady rate of 11.25°C $min^{-}1$. The pasting behavior of the HQCF from low PPD cassava was characterized being aided by Thermocline for Windows Software connected to a computer.

Statistical analysis: SPSS 25.0 (SPSS Inc. USA) was used to analyze pertinent data (physical, proximate and pasting) generated, means that were significant was separated applying Duncan multiple range test.

Results and discussion

The physical properties of the flour produced from four (4) low PPD (yellow fleshed) and one (1) high PPD (white fleshed) cassava as affected by the variety are presented in Table-1**.** Color is a very critical quality parameter that is rated or adjudged by eye (organ of the body) i.e. organoleptic or instrumental with the aid of a colorimeter. It determines the acceptance and preference for a food product[15]. The degree of lightness, redness-greenness and yellowness-blueness of a food material is measured or estimated by L*, a* and b* values. The l, a b, hue and chroma values which ranged from (97.96-99.01), (-0.07-1.05), (6.42-15.28), (90.62-95.93), and (6.43-15.32), respectively, were significantly different ($p < 0.05$) from each other except the flour lightness. In terms of lightness, both low and high PPD cassava flour were not significantly different ($p>0.05$). Expectedly, cassava variety TMEB 419 gave the most whitish flour (L=99.01) simply because it was the only white variant examined while other variants were yellow fleshed, whereas IITA-TMS-IBA-011371 was least in terms of lightness. The range of values for (L^*), (a^*) and (b^*) in low PPD cassava flour investigated was 97.96-98.73, (-0.71) to (-1.05) and 9.70-15.28, respectively. The most yellowish flour was obtained from cassava variety IITA-TMS-IBA-011412 (b=15.28). The Hue angles greater than 90° denote a yellowish color, whereas those lower than 90° suggest a slightly yellow to orange color.

The cassava flour or cassava that is yellow in color appeal more to consumer than the ones having white color from aesthetic and preference perspective. In addition to the β-carotene that was present is another carotenoid, referred to as lutein, which has been found to improve and intensify the general appearance of cassava that is colored[15]. Worth pointing out is the fact that high quality cassava flour produced from cassava root has propensity to retain the specific native color of the flesh of the root. The aforementioned point may not be unconnected with the fact that carotenoids characteristically possess active compounds that are color-sensitive which are soluble in lipids and observed color retention could be attributed to the complex being formed which include but not limited to interaction between mucilage-latex, lipid-starch, lipid-fiber and lipid-protein[16].

The variation in color parameter of the flour in this study may be attributed to the difference in the variety of the cassava under examination. The Lightness of the flour (L^*) correlated significantly with both redness (a^*) and ash content of the low PPD cassava flours ($r=0.664$, $p<0.05$; $r=0.717$, $p<0.05$) Table-4.

The proximate properties of the flour produced from four low PPD (yellow fleshed) and one high PPD (white fleshed) cassava as affected by the variety is presented in Table-2. The amount of moisture in a food gives an idea of the dry matter in such food. In terms of the flour moisture, the values ranged from 6.84 to 8.73%, with IITA-TMS-IBA-011368 having the lowest while IITA-TMS-IBA-011412 had the highest. It was observed that the moisture content of IITA-TMS-IBA-011412 was significantly higher than all other cassava flours (both high and low PPD). However, the moisture content recorded in this study in all cultivars falls within the recommended moisture range (12%) for flour products[17-19]. The changes or variation observed in the flour moisture in this study may be due to inherent attribute such as the dry matter and the relative humidity of the environment where the flour is stored, the higher the moisture content of the cassava flour, the lower the dry matter in the flour and vice-versa. The moisture of the cassava flour correlated significantly with protein content but had negative significant correlation with carbohydrate, energy value, and dry matter of the flour ($r=0.894$, $p\leq0.01$; -0.966, $p\geq0.01$; $r=-0.842$, $p\geq0.01$; $r=-1.000$, $p\geq0.01$) (Table-4).

The storage stability of a food product is majorly dependent on the moisture content present in food. Generally, food with lower moisture content is more shelf stable as posited by authors such as Sanni *et al.* Higher moisture content about 12% has propensity to enhance growth of microbes and subsequent spoilage of food[7]. It is therefore a critical requirement that food material intended to be stored must be at safe moisture level (below 12%). Hence, low moisture ensures higher shelf stability in dried products, from the foregoing, IITA-TMS-IBA-011368 is expected to be more shelf stable provided the storage conditions are kept constant i.e. there is no gaseous exchange between the product and the environment where the product is being stored via the packaging material.

Cassava in particular have low protein content (1-3%) on a dry basis which is low when compared with other roots and tubers [21]. The low PPD cassava investigated had protein content which ranged from 0.17 to 0.34% with IITA-TMS-IBA-011412 having the highest while other had the same lowest value of 0.17%. Maziya-Dixon *et al*. reported protein content value of (0.56-0.96%) which was relatively higher than the range of value (0.17 to 0.34%) observed in this present study[22]. This could be due to the screening effect (genetic factor) that the variant under investigation were subjected to in order to achieve delayed PPD.

Also, there was insignificant difference in the protein content of low and high PPD cassava under investigation, the same observation was made by Ukenye *et al*. who reported that the protein content was not significantly different between variants (yellow and white fleshed)[23]. Protein may be lost during processing of cassava root into flour and starch. Hence, protein content in cassava may be dependent on the variety. Protein content of the cassava flours had negative significant correlation with the carbohydrate content, energy value and the dry matter of the cassava flours (-0.871, $p\geq0.01$; $r=-0.868$, $p\geq0.01$; $r=-0.894$, $p\geq0.01$), respectively (Table-4).

The ash content of a food sample reveals the mineral element available in that food sample[24]. The ash content of the cassava flours ranged from 0.23 to 0.63% with IITA-TMS-IBA-070593 having the lowest while the highest value was found in IITA-TMS-IBA-011412. Several authors reported similarity in the ash content of cassava with white flesh and that with yellow flesh[23]. Processing to which cassava is subjected also contribute to the observed low ash content of theroots[24]. Difference in variety could also be responsible for the variation in the ash content of the low PPD cassava flour. The range of value for fat content was from 0.23 to 0.63% with IITA-TMS-IBA-011412 having the lowest while TMEB 419 had the highest (Table-2). Insignificant difference ($p>0.05$) in fat content was observed for flours from cassava variety IITA-TMS-IBA-011368, IITA-TMS-IBA-011412 and TMEB 419, the same was also observed for IITA-TMS-IBA-070593 and IITA-TMS-IBA-011371. Getu *et al*. reported an increase in fat content and total fatty acid by two to threefold due to the accumulation of carotenoid in cassava with yellow flesh in comparison with the one of white flesh, whereas the value of fat content of these low PPD cassava flour in this study did not increase but decreased marginally when compared with the high PPD (TMEB 419) cassava flour[25].

This variation may not be unconnected with the fact that the variants under investigation were different.

Carbohydrate provides the body with energy to do work and subsequently helps in the regulation of blood glucose. The carbohydrate content ranged from 90.08-92.14% with IITA-TMS-IBA-011412 having the lowest while IITA-TMS-IBA-011368 had the highest (Table-2). In terms of carbohydrate content, flour from IITA-TMS-IBA-011371 and TMEB419 were insignificantly different ($p>0.05$). The flour prepared with IITA-TMS-IBA-011368, IITA-TMS-IBA-070593 and IITA-TMS-IBA-011412 (low PPD) had significantly higher carbohydrate content than TMEB 419 (high PPD) cassava flour. The carbohydrate content of the flours correlated significantly with energy value and the dry matter of the cassava flour ($r=0.838$, $p<0.01$; $r=0.966$, $p<0.01$) (Table-4). The relatively higher carbohydrate content of flours from the varieties of cassava studied is an indication that these cassava tubers are good sources of carbohydrate which could be composited with other flour such as wheat for baking purposes especially bread.

The value for the dry matter ranged from 91.27-93.16% with IITA-TMS-IBA-011412 having the lowest while IITA-TMS-IBA-011368 had the highest. The flour from IITA-TMS-IBA-070593, IITA-TMS-IBA-011371 and TMEB419 cassava roots were insignificantly different ($p>0.05$). The observed significant increase in the dry matter of the low PPD cassava flour (IITA-TMS-IBA-011368, IITA-TMS-IBA-070593 and IITA-TMS-IBA-011412) when compared with high PPD (TMEB 419) was desirable and could be as a result of the screening treatment the low PPD cassava variants were subjected to. The energy value of the flours ranged from 1521.68-1558.96KJ/kg with flour from IITA-TMS-IBA-011412 having the least while IITA-TMS-IBA-070593 had the highest. The energy value of the flour from IITA-TMS-IBA-011412 cassava root was significantly lower when compared with other flours (Table-2). The energy value correlated significantly with the dry matter of the cassava flours ($r=0.842$, $p\leq0.01$) Table-4.

The pasting behaviour of the flour prepared with four low PPD cassava that were yellow in color and one high PPD that was white in flesh color as affected by their variety are presented in Table-3**.** Cassava starch behaviour and quality could be better studied with the aid of rapid visco analyzer (RVA) which provides the pasting profile when subjected to and held at regulated heating regimes with subsequent cooling interval.

The peak viscosity is the quantification of the highest viscosity reached when the flour is subjected to the heating and cooling regimes. It takes place after substantial fraction of the granules that swells had stopped.

The peak viscosity gives a clear picture of activity of enzymes such as alpha amylase and the degree of susceptibility of starch to amylase. The cassava gel strength is depicted and described by the peak viscosity[26,27].

It therefore means that, a reduced (lower) diastatic activity correspond to an increased (higher) value of peak viscosity and vice versa[28]. The maximum (peak) viscosity of the cassava flour ranged from 552.25-716.79RVU, with IITA-TMS-IBA-070593 having the lowest while IITA-TMS-IBA-011412 had the highest (Table-3). The peak viscosity value 716.79RVU and 694.58 RVU was found to be significantly higher for flours from both IITA-TMS-IBA-011412 and IITA-TMS-IBA-011371, implying that these two flours had a lower diastatic activity and increased (higher) gel strength relatively in comparison with other flour investigated (both high and low PPD). The range of peak viscosity value (552.25-716.79RVU) of the low PPD (yellow fleshed) cassava flours gotten for this study was higher than the values (271.85–471.29RVU) reported in previous study by other researchers[22].

The difference in variety and the screening effect to which the low PPD cassava under investigation were subjected to are the possible reasons that could be adduced for the variation that was observed in the peak viscosity. It necessary to point out that starch viscosity is dependent on a number of factors which include but not limited to the quantity of amylose present, concentration of the paste formed, and time of the year (season) when the crop is harvested. Nuwamanya *et al*. reported that starch from cassava with yellow (color) flesh was higher in comparism with starches gotten from cassava that has white (color) flesh[29]. The maximum (peak) viscosity of the cassava flours had significant correlation with final viscosity, yellowness, flour moisture and protein of the flour but had negative significant correlation with the peak time, carbohydrate and dry matter ($r=0.657$, $p\leq0.05$; $r=0.888$, $p\leq0.01$; $r=0.762$, $p\leq0.05$; $r=0.676$, $p\leq0.05$; $r=-0.793$, $p\geq0.01$; $r=-0.681$, $p\geq0.05$; $r=-0.762$, $p\geq0.05$) (Table-5). The relatively high peak viscosity values (716.79 RVU and 694.58 RVU) of cassava flours from IITA-TMS-IBA-011412 and IITA-TMS-IBA-011371 cassava varieties informed that they could be considered promising for use for production of food products that requires gel strength and elasticity that is high.

Stability of starch granules to heating is referred to as the holding strength or trough. The trough viscosity (TV) of the cassava flour ranged from 68.29-234.67 RVU, with IITA-TMS-IBA-011368 having the lowest while IITA-TMS-IBA-011412 had the highest (Table-3). The range of value for trough viscosity of the low PPD cassava flour was 68.29-234.67 RVU. The finding of this work established the fact that the value of trough viscosity of flours produced with high PPD (white) cassava and that produced with low PPD cassava (yellow) falls within the same range, this finding is in agreement with that of Maziya-Dixon *et al*.[22]. The trough viscosity of the flours had negative significant correlation with setback viscosity, carbohydrate and dry matter but correlated significantly with moisture content of the cassava flours ($r=-0.901$, $p\geq0.01$; $r=-0.838$, $p\geq0.01$; $r=-0.789$, $p\geq0.01$; $r=0.789$, $p\leq0.01$), respectively (Table-5). Notably, the trough viscosity value (234.67 RVU) for IITA-TMS-IBA-011412 was significantly higher, indicating that its starch granules had the highest ability to maintain gelatinized structure than all other low and high PPD cassava flours studied. The order of their holding strength follows this order IITA-TMS-IBA-011412>TMEB419>IITA-TMS-IBA-011371>IITA-TMS-IBA-070593>IITA-TMS-IBA-011368.

The degree of starch disintegration is depicted by breakdown viscosity value. It reveals the hot paste stability of the starch. Therefore, the higher the paste stability, the smaller the breakdown viscosity value and vice versa[30,31]. The breakdown viscosity of the cassava flour ranged from 361.13-517.38 RVU, with TMEB 419 having the lowest while IITA-TMS-IBA-011368 had the highest (Table-4). Noteworthy is the fact that TMEB 419 had the lowest breakdown viscosity value 361.13 RVU, indicating a tendency to form a stable hot paste when compared with other flours under investigation. The tendency of the cassava flours to form a stable hot paste is variant dependent and follows the order: TMEB 419>IITA-TMS-IBA-070593> IITA-TMS-IBA-011412>IITA-TMS-IBA-011371>IITA-TMS-IBA-011368. The breakdown viscosity of the flours had significant correlation with final and setback viscosity but had a negative significant correlation with both peak time and fat content ($r=0.733$, $p \leq 0.05$; $r=0.671$, $p \leq 0.05$; $r=-0.718$, $p \geq 0.05$; $r=-0.641$, $p \geq 0.05$), respectively (Table-5).

The final viscosity (FV) is a major pasting parameter that determines the final product quality of starch-based foods. The final viscosity of the cassava flours differed significantly ($p<0.05$) from each other, the range was 291.09-380.09 RVU, with flour from TMEB 419 having the lowest while flour from IITA-TMS-IBA-011371 had the highest (Table-3). The FV value for the low PPD (yellow fleshed) cassava flours ranged from 315.29-380.09 RVU, amongst all the flours, TMEB 419 which was the only high PPD (white fleshed) flours had significantly lower final viscosity value 291.09 RVU, indicating greater propensity to form a paste or gel that is not firm (i.e. loose paste). The finding of this work is in consonance with that of Awoyale *et al*. who noted that the final viscosity of starch of three cassava variants having yellow (color) flesh was greater than those that had white (color) flesh variants[32]. Notably, the difference in final viscosity of the flours was majorly due to the genetic make-up of each variety that was investigated. The final viscosity had a negative significant correlation with peak time and pasting temperature ($r=-0.920$, $p \geq 0.01$; $r=-0.730$, $p \geq 0.05$). The ability of the low PPD flours to form a relatively firmer gel or paste is: IITA-TMS-IBA-011371>IITA-TMS-IBA-011368> IITA-TMS-IBA-011412>IITA-TMS-IBA-070593.

The setback viscosity when measured has been used to describe the retogradation tendency of starch or starch-based food product. The setback viscosity of the cassava flours differed significantly ($p<0.05$) from each other, with value range of 85.67-265.21RVU, with TMEB 419 having the lowest while IITA-TMS-IBA-011368 had the highest. The setback viscosity of the low PPD cassava flours ranged from 93.63-265.21 RVU (Table-3). The higher the SV, the greater the disposition to undergo a process known as retrogradation of starch. The flour from 1IITA-TMS-IBA-011368 had significantly higher setback viscosity value 265.21 RVU, indicating high tendency towards retrogradation of starch than all others (high and low PPD flours). Notably, TMEB 419 had significantly lower setback viscosity value 85.67 RVU, indicating high stability of its starch molecule, with relatively low tendency for retrogradation of starch. It therefore implies that bread baked with flours from TMEB 419, IITA-TMS-IBA-011412, IITA-TMS-IBA-070593 and IITA-TMS-IBA-011371 have relatively low tendency for staling. The finding in this study for SV agreed with the findings of Awoyale *et al*. who noted that SV of starches inherent in variety of cassava with yellow flesh was higher than white varieties of cassava[32].

Time to reach maximum (peak) viscosity is referred to as the peak time. The requisite time for starch portion of food material to cook is referred to as the peak time. The range of time taken for the flour starch to cook was 3.53-4.13 min, with IITA-TMS-IBA-011371 having the minimum while TMEB 419 had the maximum (Table-3). The lower the peak (cooking) time, the better, from energy conservation point of view. The IITA-TMS-IBA-011371 flour had significantly lower peak time value 3.53 min, indicating a lower energy requirement to achieve cooking of the starch. In baking industry, this delights a baker as it reduces the down time, giving rise to optimum bread production in a given time. The mean peak time (PT) value (3.83min) recorded in this present study for low PPD (yellow fleshed) cassava flour is relatively lower than mean value (4.60min) reported by Awoyale *et al*. and this could be due to the difference in variant under investigation[32]. The cooking time for flour starch from cassava variants investigated followed the order: IITA-TMS-IBA-011371>IITA-TMS-IBA-011412>IITA-TMS-IBA-011368>IITA-TMS-IBA-070593>TMEB419.
Notably, TMEB 419 flour starch took the longest time to cook, requiring more energy consumption. The low PPD cassava flour took relatively low cooking time when compared with high PPD (TMEB419) cassava flour. Peak time correlated significantly with pasting temperature but had negative correlation with flour yellowness ($r=0.817$, $p \leq 0.01$; $r=-0.786$, $p \geq 0.01$), respectively (Table-5).

The temperature at which a notable increase in viscosity of starch or flour is first observed with simultaneous swelling is known as pasting temperature. It gives information on the minimum temperature and energy costs involved in such a production process. The pasting temperatures of the cassava flours ranged from 71.93-73.55°C with IITA-TMS-IBA-011371 having the lowest while TMEB 419 and IITA-TMS-IBA-070593 had the highest, respectively (Table-3). The range of value for pasting temperature of low PPD cassava flour recorded in this study is in consonance with the findings of Nuwamanya *et al*. for yellow fleshed and white fleshed cassava variants. There is a relationship that exists between water binding, pasting and gelatinization temperature which is positive. A restricted (resistance to) swelling ability when the pasting temperature is high[33]. A phenomenon that results into a disruption and loss of structural integrity happens when cassava starch is heated in solution. The flour from IITA-TMS-IBA-011371 attained gelatinization at the significantly lower temperature of 71.93°C when compared with other flours. It was noted in the previous works by authors that when starch gelatinization occurred at a lower temperature, bread making quality is enhanced (improved) when such a flour is used for bread baking purpose[8]. It is advantageous economically with characteristic relatively low pasting temperature (71.93°C) of IITA-TMS-IBA-011371 starch simply because it saves energy and ultimately production cost is reduced. Generally, factors responsible for significant differences in pasting properties of cassava include but not limited to varietal differences, location, and cultivation conditions.

Table-1: Physical properties of flours from low PPD cassava as affected by varieties.

Cassava. Var.	*L*	*a*	*b*	Hue	Chroma
IITA-1368	98.73±014^{a}	-0.71±0.01^{c}	9.70±0.45^{b}	94.35±0.04^{c}	9.72±0.45^{b}
IITA-0593	97.97±0.30^{a}	-1.05±0.01^{a}	10.08±0.09^{b}	95.93±0.02^{d}	10.13±0.13^{b}
IITA-1412	98.30±1.11^{a}	-1.05±0.04^{a}	15.28±0.21^{d}	93.92±0.20^{b}	15.32±0.21^{d}
IITA-1371	97.96±0.44^{a}	-1.00±0.01^{b}	13.88±0.62^{c}	94.11±0.14^{b}	13.78±0.80^{c}
TMEB419	99.01±0.12^{a}	-0.07±0.01^{d}	6.42±0.14^{a}	90.62±0.18^{a}	6.43±0.15^{a}

Results are expressed as mean ± standard deviation. Mean values followed by different superscript letter within a column are significantly different ($P \leq 0.05$). Cassava Var.: Cassava varieties; *L*: flour lightness; *a*: redness-greenness; *b*: yellowness-blueness; IITA-011368: IITA-TMS-IBA-011368; IITA-070593: IITA-TMS-IBA-070593; IITA-011412: IITA-TMS-IBA-011412; IITA-011371: IITA-TMS-IBA-011371.

Table-2: Proximate composition of low PPD cassava flours.

Cassava Variety	Moisture (%)	Protein (%)	Ash (%)	Fat (%)	CHO (%)	Dry matter (%)	Energy value (KJ/kg)
IITA-1368	6.84±0.01^{a}	0.17±0.00	0.58±0.09^{b}	0.27±0.03^{a}	92.14±0.07^{d}	93.16±0.01^{c}	1555.07±0.54^{b}
IITA-0593	7.35±0.01^{b}	0.17±0.00	0.23±0.02^{a}	0.58±0.09^{b}	91.69±0.08^{c}	92.66±0.01^{b}	1558.96±0.52^{b}
IITA-1412	8.73±0.33^{c}	0.34±0.00	0.63±0.18^{b}	0.23±0.02^{a}	90.08±0.16^{a}	91.27±0.33^{a}	1521.68±0.46^{a}
IITA-1371	7.63±0.01^{b}	0.17±0.00	0.27±0.03^{a}	0.58±0.09^{b}	91.36±0.05^{b}	92.36±0.01^{b}	1553.60±0.57^{b}
TMEB419	7.46±0.10^{b}	0.17±0.00	0.58±0.09^{b}	0.63±0.18^{b}	91.17±0.18^{b}	92.54±0.10^{b}	1543.94±3.78^{b}

Notes: Results are expressed as mean ± standard deviation. Mean values followed by different superscript letter. Within a column are significantly different ($P \leq 0.05$). CHO: Carbohydrate; IITA-011368: IITA-TMS-IBA-011368; IITA-070593: IITA-TMS-IBA-070593; IITA-011412: IITA-TMS-IBA-011412; IITA-011371: IITA-TMS-IBA-011371.

Table-3: Pasting properties of low and high PPD cassava flour.

C. Var.	Peak visc. (RVU)	Trough visc. (RVU)	Brkd visc. (RVU)	Fin. visc. (RVU)	Stbk visc. (RVU)	Pk. t. (min)	P. temp (°C)
1368	585.67±3.54^{a}	68.29±9.96^{a}	517.38±13.50^{b}	333.50±3.54^{c}	265.21± 6.42^{d}	3.90± 0.04^{b}	73.50± 1.20^{b}
0593	552.25±11.67^{a}	164.96±46.37^{b}	387.29±58.04^{a}	315.29±0.76^{b}	150.34± 47.14^{bc}	4.07± 0.00^{c}	73.55± 0.07^{b}
1412	716.79±29.05^{b}	234.67±6.36^{c}	482.13±22.69^{c}	328.30±12.20^{bc}	93.63± 5.83^{ab}	3.80± 0.10^{b}	73.18± 0.53^{ab}
1371	694.58±0.71^{b}	193.75±22.27^{bc}	500.83±21.57^{b}	380.09±3.06^{d}	186.34± 19.21^{c}	3.53± 0.00^{a}	71.93± 0.04^{a}
419	566.54±0.41^{a}	205.42±0.47^{bc}	361.13±0.88^{a}	291.09±2.95^{a}	85.67± 2.48^{a}	4.13± 0.00^{c}	73.55± 0.00^{b}

Results are expressed as mean ± standard deviation. Mean values followed by different superscript letter within a column are significantly different ($P \leq 0.05$). C. var.: Cassava variety; Peak visc.: Peak visc.: Trough viscosity; Brkd: Breakdown viscosity; Fin. Visc.: Final viscosity; Stbk visc.: Setback viscosity; Pk. T.: Peak Time; P. Time: Pasting temperature; 1368: IITA-TMS-IBA-011368; 0593: IITA-TMS-IBA-070593; 1412: IITA-TMS-IBA-011412;1371: IITA-TMS-IBA-011371

Table-4: Pearson's correlation matrix among the physical and proximate properties of high and low PPD cassava flour.

PARA.	*L*	*a*	*b*	M.C.	ASH	PROT.	FAT	CHO	E.V.	D.M.
L	1.000									
a	0.664*	1.000								
b	-0.500	-0.819**	1.000							
M. C.	-0.290	-0.339	0.671*	1.000						
ASH	0.717*	0.440	-0.097	0.181	1.000					
PROT.	-0.084	-0.366	0.663*	0.894**	0.468	1.000				
FAT	-0.127	0.325	-0.423	-0.301	-0.520	-0.621	1.000			
CHO	0.114	0.140	-0.536	-0.966**	-0.339	-0.871**	0.206	1.000		
E. V.	-0.118	0.027	-0.412	-0.842**	-0.523	-0.868**	0.577	0.838**	1.000	
D. M.	0.290	0.339	-0.671*	-1.000**	-0.181	-0.894**	0.301	0.966**	0.842**	1.000

* Correlation is significant at the 0.05 level (2-tailed). ** Correlation is significant at the 0.01 level (2-tailed). PARA.: Parameter; *L*: flour lightness; *a*: redness-greenness; *b*: yellowness-blueness; M. C.: Moisture content; PROT.: Protein content; CHO: Carbohydrate; E. V.: Energy value; D. M.: Dry matter.

Table-5: Pearson's correlation matrix among the pasting and the physical properties of the cassava flour.

PAR.	PV	TRGH	BRKD	FV	STBK	PTIM	PTEMP	*L*	*a*	*b*
PV	1.000									
TRGH	0.472	1.000								
BRKD	0.618	-0.402	1.000							
FV	0.657*	-0.057	0.733*	1.000						
STBK	-0.128	-0.901**	0.671*	0.484	1.000					
PTIM	-0.793**	-0.119	-0.718*	-0.920**	-0.296	1.000				
PTEMP	-0.539	-0.241	-0.344	-0.730*	-0.105	0.817**	1.000			
L	-0.379	-0.162	-0.249	-0.537	-0.091	0.290	0.167	1.000		
a	-0.501	-0.035	-0.489	-0.618	-0.237	0.553	0.326	0.664*	1.000	
b	0.888**	0.344	0.616	0.690*	-0.002	-0.786**	-0.493	-0.5	-0.819**	1.000

* Correlation is significant at the 0.05 level (2-tailed). ** Correlation is significant at the 0.01 level (2-tailed). PARA.: Parameter; *L*: flour lightness; *a*: redness-greenness; *b*: yellowness-blueness; PV: peak viscosity; TRGH: Trough viscosity; BRKD: Breakdown viscosity; FV: Final viscosity; STBK: Setback viscosity; PTIM: Peak time; PTEMP: Pasting temperature.

Conclusion

The high gel strength, starch granule stability to heating and low peak time revealed that low PPD cassava flour are suitable for use in the baking and confectionery industry. The relatively higher carbohydrate content of low PPD cassava flours from the varieties (IITA-TMS-IBA-011368, IITA-TMS-IBA-070593 and IITA-TMS-IBA-011371) is an indication that they could be composited with other flour such as wheat flour especially when the intended use is for baking. The pasting profile of the high quality cassava flours investigated revealed that flours from TMEB 419, IITA-TMS-IBA-011412, IITA-TMS-IBA-070593 and IITA-TMS-IBA-011371 have relatively low tendency for retrogradation (staling) if used for baking purpose especially bread.

Acknowledgement

The authors of the work sincerely acknowledge the Nigerian Stored Products Research Institute (NSPRI) for sponsorship, Centre for Food Technology and Research (CEFTER) Benue State University for scholarship, International Institute of Tropical Agriculture (IITA), for technical support and provision of low PPD cassava roots used for the research.

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