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Physicochemical characterization of starches from some Nigerian and Chinese roots and tubers

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Physicochemical properties of starches of two popular Nigerian sweet potato (NSP1 and 2) cultivars were studied using those from Chinese sweet potato (CSP), cassava (CC) and potato (CP) widely used for starch production, as references. Moisture, ash, protein, and phosphorus contents of the starches varied from 4.34 to 9.48%, 0.26 to 0.31%, 0.05 to 0.42% and 0.018 to 0.995%, respectively with NSP starches showing significantly (p < 0.05) higher protein and lower ash content. The starches differed in amylose content, granule shapes, mean granule sizes, particle size distribution, enzyme digestibility; swelling power and solubility pattern. Higher retrogradation tendency was observed in NSP1 and CP starch pastes compared to those of CSP and NSP2. Thermal properties varied in the various starches. NSP1 and 2 showed higher gelatinization temperatures (73.17, 71.64°C), lower peak viscosities (2269, 2295 cP) and lower stability ratios (0.49, 0.54), respectively compared to the Chinese starches. Mean granule size and phosphorus content of the starches had substantial effect on their pasting properties. However, variability observed in the properties of the various starches further projected their useful and comparative potentials in food and non-food applications.

Key words: Sweet potato, starch, pasting properties, thermal properties, retrogradation, digestibility.

INTRODUCTION

Sweet potato ranks as the seventh most important food crop in the world after wheat, rice, maize, potato, barley, and cassava with a global annual production of over 133 million tons. It is an important root crop that provides food to a large segment of the world population, especially in the tropics and subtropics where the bulk of these crops are cultivated and consumed. Asia is the largest sweet potato-producing region with 125 million tons of annual production. China accounts for about 90% of worldwide sweet potato production with an annual production of 117 million tons (CIP, 2011). West African sweet potato production is about 2.516 million tons per annum with Nigeria being one of the largest producers (FAO, 2006).

Generally, root and tuber crops are rich sources of starch containing 70 to 80% of water, 16 to 24% trace quantities (< 4%) of protein and lipids besides other minerals and vitamins (Hoover, 2001). Starch plays a vital role in developing food products either as a raw material or as a food additive such as thickener, stabilizer or texture enhancer (Aina et al., 2010). In China, sweet potato roots and its products have been widely used in starch noodles, bakery foods, snack foods, confectionery products, starch syrup production, alcohol production and in the brewing industries (Chen et al., 2003) whereas 80% of the few sweet potato cultivars produced in Nigeria are used for household consumption either in boiled, fried or roasted form due to low level of processing and...
industrial utilization (Odebode et al., 2008; FAO, 2002).

The functionality of starches in any application is governed by its physicochemical properties (Chen et al., 2003). Industrial interest in new value added starch products has resulted in many investigations being carried out on the characterization of starches isolated from sweet potato roots of different genotypes and botanical sources. These starches are known to differ in their physicochemical properties and these differences have been attributed to variation in amylose/amylopectin ratio in starch granules, granule size distribution, mean granule size, mineral content and the presence of naturally occurring non carbohydrate impurities in the starches (Zhu et al., 2011; Oduro et al., 2000; Garcia and Walter, 1998; Aina et al., 2010). On the other hand, only very limited information is available on the physicochemical properties of Nigerian sweet potato starches (Osunbahunsi et al., 2003) which hinders its further processing and utilization in various industries.

In addition, the high agronomic yield potential of sweet potato as a food security crop in Nigeria has stimulated researches geared towards converting the potential into increased output by increased sweet potato production and better sweet potato cropping systems (Babatunde et al., 2007; Odebode et al., 2008). Since Nigeria is one of the largest producers of sweet potato in Africa, a study on the physicochemical properties of their starches would be useful and as well improve the utilization of these starches in various applications.

Therefore, this study is aimed at investigating the physicochemical properties of starches isolated from two popular Nigerian sweet potato cultivars using Chinese sweet potato, cassava and potato widely used for starch production on an industrial scale as references.

MATERIALS AND METHODS

Two popular Nigerian sweet potato cultivars (NSP1 and 2), Chinese sweet potato (CSP), Chinese potato (CP) and Chinese cassava (CC) were used in this study. NSP1 and 2 were purchased from a retail outlet in Lagos, Nigeria, while Chinese tubers and roots were obtained from Beijing, China. The sweet potato peels varied in color from purple (CSP) to dark brown (NSP1) while NSP2 had golden brown peels. The internal color of the roots varied from white (NSP1 and CSP) to yellow (NSP2). The potato variety (CP) is known to be a starchy cultivar with golden brown skin. However, this variation in the flesh color had no significant effect on the color of their starches.

Starch extraction

The tubers were washed, cut into small pieces, placed in 0.1% (w/v) sodium bisulphite solution (1 kg of tuber in 1 L of solution) for 10 min and then blended in a domestic juice extractor for 3 to 4 min with distilled water. The resulting slurry was passed through fine muslin cloth to separate the cell debris and the suspension as described by Peshin (2001). The filtrate was collected, washed with portable tap water and filtered three times using 150 mm sieve. The filtrate was allowed to settle overnight at room temperature, the supernatant was decanted and the precipitated starch was removed from the container into oven trays lined with aluminium foil, then oven dried at 45°C for 24 h. The dried starch was finely ground using a high-speed universal hand mill (FW100, Tianjin, China) and then packaged in tightly covered polypropylene containers and stored in a refrigerator at 4°C prior to use.

Proximate composition

The moisture content of the starches was determined by drying to constant weight in an air oven at 105°C for 24 h. Ash and lipid content was determined according to the method of AOAC method 923.03 (2000) and AOAC method 960.39 (2000), respectively. Protein content was analyzed as total nitrogen content by Kjeldahl procedure; a factor of 6.25 was used for conversion of nitrogen to crude protein (AOAC method 955.04, 2000). A standard spectrophotometric method (ISO 3946, 1982) was employed to determine the phosphorus content. The starch content was determined enzymatically using the Amyloglucosidase / α-amylase assay kit (Megazyme, Ireland) based on the total starch standard assay procedure (AOAC method 996.11, 2000).

Amylose and amylopectin content

Amylose content of the starch samples was determined colorimetrically according to the method of Hoover and Ratnayake (2001) based on amylose–iodine complex formation. Amylopectin content was calculated by difference (100 - amylose %).

Starch granular characterization

The starch granules were observed using a Scanning Electron Microscope (SEM). The starch granules were sprinkled on a double-sided tape mounted on a SEM stub. The samples were coated with gold and placed in the SEM (Hitachi S3400N) chamber. Photomicrographs were taken using a scanning electron microscope apparatus at an accelerating voltage of 15 kV.

Starch particle size distribution

Particle size distribution of the starch samples was measured using Baite particle size analyzer (BT-9300H; Dandong better size instrument Ltd., Dandong, China). The mean granule size of each starch sample characterized by volume mean diameter was measured.

Enzyme digestibility of starches

The enzyme digestibility of starches was carried out based on pancreatin hydrolysis as previously described (Zhu et al., 2011). 500 mg raw starch was dispersed in 15 ml sodium phosphate buffer (0.15 M, pH 6.5) with gelatin (30 mg) (10010328, Sinopharm Chemical reagent co. Ltd.) and pancreatin (30 mg) (P7545-25G, Sigma/Aldrich, St Louis, MO) in a precisely weighed tube. Tubes were capped and incubated in a water bath at 37°C with constant shaking for 6 h, 5 ml H2SO4 (1.0%, w/v) was added to stop the reaction, and the suspension was centrifuged at 20,000 x g for 10 min. The supernatant was discarded, and the precipitate was re-suspended in 80% aqueous ethanol solution (15 ml) and centrifuged at 20,000 x g for 5 min. The supernatant was discarded and the tubes with the precipitate were dried in a forced-air oven at
80°C overnight to a constant weight. The starch enzyme digestibility was calculated from the weight loss after digestion and expressed as percentage (%).

Swelling power and solubility

Swelling power and solubility of the starches at different temperatures were determined according to the method described by Crosbie (1991) with slight modifications. This was carried out by heating starch water slurry (0.35 g of dry starch in 12.5 ml of distilled water) of each sample in a water bath at different temperatures (50, 60, 70 and 80°C) for 30 min, with constant mixing. The resulting slurries were cooled to room temperature and centrifuged at 2000 × g for 15 min.

On the other hand, the effect of pH on swelling and solubility of the starch samples were analyzed using the method of Adebowale et al. (2002) with modifications. Starch water slurry of the same concentration stated above was prepared and the pH from 2 to 12 was adjusted to the desired values using 0.1 M HCl or 0.1 M NaOH. The slurries were allowed to stand at 30±2°C for 30 min and then centrifuged at 2000 × g for 15 min.

The supernatant was decanted into an evaporating dish, dried at 100°C for 4 h. The dried supernatant and sediment were weighed. The solubility (S, %) and swelling power (SP, g/g, dry basis) was calculated as follows:

\[
S(\%) = \frac{\text{mass of dried supernatant}}{\text{mass of dry starch}} \times 100
\]

\[
SP(g/g) = \frac{\text{sediment weight}}{\text{mass of dry starch}} \times (100 - S)
\]

Retrogradation properties

Starch retrogradation measured by syneresis was carried out according to the method described by Kuar et al. (2002) with slight modifications. Starch water slurry of the same concentration stated above was prepared and the pH from 2 to 12 was adjusted to the desired values using 0.1 M HCl or 0.1 M NaOH. The slurries were allowed to stand at 30±2°C for 30 min and then centrifuged at 2000 × g for 15 min. The supernatant was decanted into an evaporating dish, dried at 100°C for 4 h. The dried supernatant and sediment were weighed. The solubility (S, %) and swelling power (SP, g/g, dry basis) was calculated as follows:

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\]

Thermal properties

Thermal properties were analyzed using differential scanning calorimeter (DSC Q200 TA instruments, New Castle, DE) according to the method of Kuar et al. (2002) with slight modifications. Starch (2 to 5 mg) was accurately weighed into an aluminum pan and water was added (1.3 w/w dry bases:water). The pans were hermetically sealed and equilibrated at room temperature for 2 h prior to the analysis. DSC was calibrated using indium and an empty pan was used as the reference. Samples were heated at 10°C/min over a temperature range of 30 to 120°C. These gelatinization parameters: Peak temperature (T_p); Onset gelatinization temperature (T_o); conclusion temperature (T_c) and enthalpy of gelatinization (ΔH_gel) were recorded. Gelatinization temperature range (R) was calculated as (T_c-T_o).

Pasting properties

Pasting properties of the starches were studied with a rapid visco analyser (RVA-4 Newport Scientific Pty Ltd., Warriewood, NSW, Australia). 8% (w/w, dry basis) starch suspensions were equilibrated at 50°C for 1 min and were sheared at a paddle speed of 160 rpm heated from 50 to 95°C, at the rate of 12.2°C/min and held at 95°C for 2.5 min, cooled from 95 to 50°C at a rate of 11.8°C/min and held at 50°C for 2 min. The peak, breakdown, hot paste cold paste, setback viscosities, setback, stability ratios, pasting temperature and peak time were recorded.

Statistical analysis

All experiments were conducted in duplicates. The data were analyzed using analysis of variance. Pearson’s correlation coefficients (r) were calculated for the various physicochemical properties and means were compared by turkey test at p < 0.05 using SAS 8.1 software (SAS, 2000).

RESULTS AND DISCUSSION

The chemical composition of the isolated starch samples

The chemical compositions of the Nigerian sweet potato starches as compared to Chinese sweet potato, cassava and potato starches are shown in Table 1. The purity of the starches was reasonably high. Moisture content (4.34 to 9.48%) fall within the moisture level (10 to 20%) recommended for commercial starches (Soni et al., 1993) and are below the maximum value (13%) prescribed for safe storage in most starch producing countries (ISI, 1970). Climatic factors in addition to the process and the extent of drying influence the moisture content of starches. NSK starches had significantly (p < 0.05) higher protein content compared to CSP, CC and CP starches all of which are lower than 0.5%. However, varying degree of protein in the starches shows the extent of the complete removal of protein, present in the starches during processing.

The ash content of CSP starch was significantly higher than NSP, CC and CP starches. It ranged from 0.23 to 0.31% and fall within the limit (0.5%) recommended for grade A industrial starches (Radley, 1976). High ash content could be attributed to the presence of phosphate groups in starches (Hoover, 2001). No significant difference was observed in the lipid content of NSP1, NSP2, CSP and CC starches but all of them are much higher in lipid content than CP starch. The presence of lipid in starch could be influenced by various pre-treatments of the roots and tubers.

Amylose and amylopectin content slightly varied in all the starches with values 18.52 to 23.64% and 76.36 to 81.48%, respectively. Among the sweet potato cultivars, NSP1 showed the highest amylose content which is not significantly different from that of CP starch but higher than those of NSP2, CSP and CC starches. The amylose content in this study is in good agreement with values previously reported on cassava sweet potato and cassava starches (Moorthy et al., 2002; Anggraini et al., 2009; Visser et al., 1997). Differences in amylase
contents of sweet potato starches have been reported (Oduro et al., 2000; Garcia and Walter, 1998) and ascribed to differences in genotype, environmental factors and starch processing methods which in turn influences starch physicochemical properties. In addition, the iodine binding properties of starches seem to differ in different plant species. High amylose starches would be suitable for coating fried products, pasta, sweets and bread production (Vignaux et al., 1998) and ascribed to differences in genotype, particle size distribution analysis of the starches, the results showed that the mean granule size and granule size range (11.82 µm, 1.05 to 36.08 µm) of CC starch was not clearly different from that of the NSP2 starch (11.70 µm, 1.05 to 36.08 µm) but was different from that of CSP (12.71 µm, 0.95 to 44.69 µm) and NSP1 (11.98, µm, 0.95 to 40.15 µm) which showed a wider range and higher mean granule size values. All these mean granule sizes and ranges are much less than that of CP starch which had the widest and highest granule size range and mean granule size of 1.62 to 68.58 µm and 20.51 µm, respectively. In comparison with previous report on starches from some Chinese sweet potato cultivars (Chen et al., 2003), the mean granule sizes and the granule size distribution of the sweet potato starches were slightly higher and wider, respectively.

Lindeboom et al. (2004) reported that membranes and physical characteristics of the plastids may be responsible for conferring a particular shape or morphology to starch granules during granule development. Therefore, the variability observed in the morphology of these starch granules could be attributed to the origin, biochemistry of the chloroplast as well as the physiology of the plants which are the major factors responsible for the morphology of starch granules. Granule size and particle size distribution of starches markedly influences the functional properties of starches like; swelling power, solubility and digestibility (Moorthy et al., 2002).

### Enzyme digestibility of starches

The enzyme digestibility of Nigerian sweet potato starches as compared to Chinese sweet potato, cassava and potato starches measured by pancreatin hydrolysis exhibited significant variations as shown in Figure 2. Enzyme digestibility of starches plays a key role in evaluating their nutritive value and utilization in diverse applications. The susceptibility of starches to enzymatic hydrolysis has been ascribed to the interaction of various factors including starch source, granule morphology, crystallinity patterns (A,B,C), amylose-lipid complex, binding site, hydrolysis conditions (concentration, pH and temperature) and type of enzyme (Oates, 1997; Rocha et al., 2010). NSP1 and 2 starches showed a lower susceptibility to pancreatin hydrolysis than CSP starch while CC starch was the most susceptible. The highest resistance of raw starch

### Morphological properties

The variability in the granular shapes of the entire starch samples are shown in Figure 1. The shapes of CC, CSP, NSP1 and 2 starch granules were heterogeneous, having different shapes varying from polygonal, round, oval, cupoliform, to bell shapes while that of CP starch was less heterogeneous showing round and oval shapes. From the particle size distribution analysis of the starches, the results showed that the mean granule size and granule size range (11.82 µm, 1.05 to 36.08 µm) of CC starch was not clearly different from that of the NSP2 starch (11.70 µm, 1.05 to 36.08 µm), but was different from that of CSP (12.71 µm, 0.95 to 44.69 µm) and NSP1 (11.98, µm, 0.95 to 40.15 µm) which showed a wider range and higher mean granule size values. All these mean granule sizes and ranges are much less than that of CP starch which had the widest and highest granule size range and mean granule size of 1.62 to 68.58 µm and 20.51 µm, respectively. In comparison with previous report on starches from some Chinese sweet potato cultivars (Chen et al., 2003), the mean granule sizes and the granule size distribution of the sweet potato starches were slightly higher and wider, respectively.

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### Table 1. Chemical composition of starches isolated from Nigerian sweet potato compared with Chinese sweet potato, cassava and potato starches (w/w, %).

<table>
<thead>
<tr>
<th>Source</th>
<th>Moisture</th>
<th>Protein (db)</th>
<th>Ash (db)</th>
<th>Lipid (db)</th>
<th>Starch (db)</th>
<th>Amylose</th>
<th>Amylopectin</th>
<th>P (db)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NSP1</td>
<td>7.96 ± 0.28</td>
<td>0.34 ± 0.02</td>
<td>0.26 ± 0.00</td>
<td>0.20 ± 0.01</td>
<td>96.18 ± 0.33</td>
<td>22.95 ± 0.80</td>
<td>77.05 ± 0.80</td>
<td>0.0213 ± 0.00</td>
</tr>
<tr>
<td>NSP2</td>
<td>7.77 ± 0.34</td>
<td>0.42 ± 0.02</td>
<td>0.23 ± 0.01</td>
<td>0.26 ± 0.01</td>
<td>95.13 ± 0.26</td>
<td>18.52 ± 0.32</td>
<td>81.48 ± 0.32</td>
<td>0.0205 ± 0.00</td>
</tr>
<tr>
<td>CSP</td>
<td>9.48 ± 0.24</td>
<td>0.26 ± 0.01</td>
<td>0.31 ± 0.01</td>
<td>0.17 ± 0.06</td>
<td>93.14 ± 0.48</td>
<td>19.89 ± 0.32</td>
<td>80.11 ± 0.32</td>
<td>0.0245 ± 0.00</td>
</tr>
<tr>
<td>CC</td>
<td>4.34 ± 0.26</td>
<td>0.21 ± 0.00</td>
<td>0.27 ± 0.01</td>
<td>0.24 ± 0.04</td>
<td>93.02 ± 0.19</td>
<td>20.68 ± 0.16</td>
<td>79.32 ± 0.16</td>
<td>0.0181 ± 0.00</td>
</tr>
<tr>
<td>CP</td>
<td>7.92 ± 0.21</td>
<td>0.05 ± 0.00</td>
<td>0.29 ± 0.04</td>
<td>0.14 ± 0.02</td>
<td>94.76 ± 0.39</td>
<td>23.64 ± 0.16</td>
<td>76.36 ± 0.16</td>
<td>0.0995 ± 0.00</td>
</tr>
</tbody>
</table>

1Means in a column with the same letters are not significantly different at p < 0.05. 2Dry basis. 3Phosphorus content.
to pancreatin was shown by CP starch. Higher resistance and higher susceptibility of potato and cassava starches to enzyme digestibility, respectively compared to that of sweet potato have been previously reported and attributed to their X-ray diffraction patterns, which are known to be A-type in Cassava and sweet potato, whereas potato starch exhibits a B-type pattern (Rocha et al., 2010). However, Leach and Schoch (1961) reported that the susceptibility of starches to enzymatic attack was not related to external surface area, X-ray diffraction patterns, swelling power or solubility.

**Swelling and solubility properties**

Figure 3A and B showed the swelling power and solubility properties of the Nigerian sweet potato, Chinese sweet potato, cassava and potato starches as a function of temperature. Solubility and swelling power provides the evidence of interactions between the water molecules and
the starch chains in the crystalline and amorphous regions (Ratnayake et al., 2002). Swelling power increased with increased temperature (50 to 80°C) in the starch samples. It ranges from 2.03 to 20.32, 1.86 to 22.99, 1.98 to 23.73, 2.39 to 13.95, and 2.18 to 18.08 g/g for NSP1, NSP2, CSP, CC, and CP, respectively. NSP2 and CSP showed significantly higher swelling power compared with NSP1. The sweet potato starches showed a greater intra-granular organization as indicated by their high relaxation temperature (70°C), on the other hand, CC and CP starches exhibited weak intra-granular organization as indicated by their low relaxation temperature (60°C) and its rapid swelling at lower temperatures. Starch granules with strong bonds in their crystalline area swell less in cold water. In addition to bonding degrees at molecular level, other factors like; composition and branching of the outer parts in the amylopectin molecule also influences the swelling power of starches. High swelling starches are useful in the manufacture of confectionaries and other industrial applications.

Solubility of starches ranged from 0.74 to 18.57, 0.77 to 25.35, 0.38 to 17.37, 1.05 to 6.6 and 0.71 to 5.95% in the NSP1, NSP2, CSP, CC, and CP, respectively with NSP 2 having the highest (25.35%) value at 80°C. The solubility of the starches increased with increase in temperature from 50 to 80°C. This result is in agreement with the findings of Collado and Corke, (1997) in their study on 44 Philippines sweet potato varieties. The low values of solubility observed for the starches at low temperatures suggested the existence of moderately strong uniform inter associative forces within the granules prior to its disruption at high temperatures. The swelling power and solubility profiles of the sweet potato starches indicated that NSP1 starch granules had a greater intra-granular organization in which most of the bonding forces required energy supplied in the temperature range 70 to 80°C to cause relaxation (Nwokocha et al., 2009). These intermolecular bonds relax with increase in thermal

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**Figure 2.** Enzyme digestibility of Nigerian sweet potato starches as compared with Chinese sweet potato, cassava and potato starches. Bars labelled with different letters are significantly different at $p < 0.05$ level for each sample. NSP1, Nigerian sweet potato 1; NSP2, Nigerian sweet potato 2; CSP, Chinese sweet potato; CC, Chinese cassava; CP, Chinese potato.
agitation causing the starch granules to imbibe water and swell. Other factors that influence the solubility of starches include: origin, granule size and other components of the starch (Hoover, 2001).

The swelling power and solubility of the starches as affected by pH is presented in Figure 3C and D. Significant variations were observed in the swelling and solubility pattern of some of the starches at either alkaline or acidic pH values. The Nigerian and Chinese sweet potato starches showed high swelling power and solubility at pH 12. CC starch had the highest swelling power at both acidic and alkaline regions compared with other starches. The swelling power of all the sweet potato starches decreased at pH value of 4. Higher swelling power observed in alkaline condition (pH 12) is similar with the findings of Shieldneck and Smith (1971) and this was ascribed to starch-protein interaction at alkaline pH, when both starch and protein have negative charges, whereas in acidic conditions, protein bears a positive charge.

The alkaline and acidic conditions had significant influence on the solubility of all the starches. All the starches considered exhibited similar solubility in the pH

Figure 3 (A, B, C, D). Effect of temperature and pH on solubility and swelling power of Nigerian sweet potato as compared with Chinese sweet potato, cassava and potato starches. NSP1; NSP2; CSP; CC; CP. Bars labelled with different letters are significantly different at p < 0.05 level for each sample. NSP1, Nigerian sweet potato 1; NSP2, Nigerian sweet potato 2; CSP, Chinese sweet potato; CC, Chinese cassava; CP, Chinese potato.
range 2 to 12 with the highest solubility at pH 12. The increased solubility at alkaline pH could have resulted from the increased hydrophilic character of the starches at these pH values (Adebowale et al., 2002).

Retrogradation properties

Syneresis, an index for the degree of starch retrogradation at low temperatures which is an undesired property in both food and non food applications is shown in Figure 4. The results showed that the retrogradation values varied in all the starch samples and it increased with increase in storage days. Starch pastes of NSP1 starch exhibited higher retrogradation tendency due to the large volume of water expelled during the retrograding process compared with those of NSP2 and CSP. CP showed the highest retrogradation value during the seventh day of storage at 4°C. In general, high amylose content results in high retrogradation tendency (Singh et al., 2003). Therefore, the higher retrogradation tendency observed in the starch pastes from the CP and NSP1 may be due to their higher amylose content (Table 1). In addition, the structural arrangement of starch chains within the amorphous and crystalline regions of ungelatinized granules indirectly influences the extent of granule breakdown during gelatinization and the interaction that occurs between starch chains during gel storage which in turns influences retrogradation properties of starches (Kuar et al., 2002).

Thermal properties

The thermal properties (onset transition temperatures \(T_0\); peak temperatures \(T_p\); conclusion transition temperatures \(T_c\); gelatinization ranges-R and enthalpies of gelatinization-\(\Delta H_{gel}\)) of the various starches are presented in Table 2. All the thermal properties, except \(T_c\), varied significantly in the Nigerian and Chinese sweet potato starches. The temperature at which heated starch granules undergo transition from the crystalline state to a
gel is referred to as "gelatinization temperature". This is an important parameter in starch characterization. T_o and T_p of the starch samples ranged from 62.31 to 73.17°C and 67.30 to 76.04°C, respectively. NSP 1 and 2 starches showed a higher T_o and lower T_p compared to CSP while all these values (T_o and T_p) observed in CSP, NSP1 and NSP2 starches are significantly higher than those of CC and CP starches. The enthalpy of gelatinization (ΔH_{gel}) was observed to be the lowest for NSP2 (8.12 J/g), whereas it was highest for CP (13.38 J/g). ΔH_{gel} is an indicator of loss of molecular order and it also gives an overall measure of crystallinity within starch granules during gelatinization (Cooke and Gidley, 1992). A lower ΔH_{gel} indicates a lower degree of intergranular organization within starch granules. According to Vasanthan et al. (1999), starches with higher gelatinization transition temperatures (T_o and T_p) and enthalpy would require higher heat of solubilisation.

Significantly (p < 0.05) higher T_c value was observed in the NSP1 and 2 compared with CC and CP starches while CSP showed the highest T_c in all the starch samples. The difference in the gelatinization parameters among the various starches analyzed can be traced to the environmental differences, variation in the starch intermolecular bond, mineral composition, proportion of large and small granules and molecular architecture of the crystalline region of starches (Kaul et al., 2007).

Gelatinization range (R) calculated as T_c to T_o varied significantly (p < 0.05) within the Nigerian sweet potato and the Chinese starches. CSP starch showed the widest gelatinization range while low values were observed in the Nigerian sweet potato starches. Higher gelatinization range has been attributed to a higher degree of crystallinity which imparts higher structural stability resulting in higher resistance to the penetration of water molecules into the crystalline areas (Barichello et al., 1990). According to Ratnayake et al. (2001), the results showed that the numbers of double helices (in the amorphous and crystalline domains) that disentangled and melted during gelatinization are different in NSP starches but relatively similar in CSP, CC and CP starches. It also showed that the degree of heterogeneity of the starch crystallites within NSP starch granules is greater than that in the CSP starch granule.

### Pasting properties

The pasting properties of suspensions of the Nigerian sweet potato starches as compared with Chinese sweet potato, cassava and potato starches are shown in Table 3. Different pasting temperatures were observed among the Nigerian and Chinese sweet potato starches while no significant difference was observed for CC and CP starches. The pasting temperatures observed in CSP and NSP starches were significantly higher than CP and CC starches (p < 0.05). These are consistent with the transition temperatures measured using DSC and are also in accordance with those previously reported for Caribbean sweet potato starches (Aina et al., 2010).

The peak time (PT) of the NSP starches ranged from 3.93 to 4.0 min which are much faster than those 4.4, 4.87 and 6.77 min of CSP, CC and CP starch, respectively. The peak viscosity (PV), hot paste viscosity (HPV), cold paste viscosity (CPV) and setback viscosity (SBV) of the Nigerian sweet potato and the Chinese sweet potato, cassava and potato starches varied significantly (p < 0.05), and are in the order: CP > CSP > NSP1 > NSP2. Higher peak viscosity, hot paste viscosity, cold paste viscosity, stability and setback ratios were observed in Chinese sweet potato starch compared with Nigerian sweet potato starches. Peak viscosity shows the maximum swelling of starch granule prior to disruption; therefore, starches with high peak viscosities have weaker cohesive forces within its crystalline structure than those with lower peak viscosities. Aina et al. (2010) reported some low peak viscosity Caribbean sweet potato starches as ideal types for use in the manufacture of weaning foods. Currently, to fully utilize cereals for weaning foods, the grain has to be malted to reduce the capacity to withstand severe processing condition as indicated by its higher stability ratio than the Nigerian sweet potato starches while CP starch showed the highest

<table>
<thead>
<tr>
<th>Source</th>
<th>T_o (°C)</th>
<th>T_p (°C)</th>
<th>T_c (°C)</th>
<th>ΔH_{gel} (J/g)</th>
<th>R (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NSP1</td>
<td>73.17±0.09^a</td>
<td>75.97±0.16^a</td>
<td>81.87±1.80^ab</td>
<td>9.90±1.41^ab</td>
<td>8.70±2.15^a</td>
</tr>
<tr>
<td>NSP2</td>
<td>71.88±0.10^b</td>
<td>74.90±0.00^b</td>
<td>80.86±1.26^ab</td>
<td>8.12±0.19^b</td>
<td>8.98±1.33^b</td>
</tr>
<tr>
<td>CSP</td>
<td>66.82±0.22^c</td>
<td>76.04±0.19^a</td>
<td>83.85±1.15^a</td>
<td>11.45±1.44^ab</td>
<td>17.03±3.16^a</td>
</tr>
<tr>
<td>CC</td>
<td>62.47±0.44^d</td>
<td>67.30±0.12^c</td>
<td>77.94±0.88^bc</td>
<td>9.93±0.02^ab</td>
<td>15.47±0.44^a</td>
</tr>
<tr>
<td>CP</td>
<td>62.31±0.18^d</td>
<td>67.90±0.28^d</td>
<td>76.08±0.13^c</td>
<td>13.38±0.03^a</td>
<td>13.77±0.05^a</td>
</tr>
</tbody>
</table>

^1Means in a column with the same letters not significantly different at p < 0.05. T_o = Onset transition temperature; T_p = peak transition temperature; T_c = conclusion transition temperature; R = gelatinization range (T_c - T_o); ΔH_{gel} = enthalpy of gelatinization.
Table 3. Pasting properties of Nigerian sweet potato starches as compared with Chinese sweet potato, cassava and potato starches.

<table>
<thead>
<tr>
<th>Source</th>
<th>PV (cP)</th>
<th>HPV (cP)</th>
<th>BDV (cP)</th>
<th>CPV (cP)</th>
<th>SBV (cP)</th>
<th>PT (Min)</th>
<th>Stability ratio</th>
<th>Setback ratio</th>
<th>P temp (°C)</th>
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</thead>
<tbody>
<tr>
<td>NSP1</td>
<td>2669 ± 0.71a</td>
<td>1312 ± 22.63a</td>
<td>1357 ± 23.33a</td>
<td>1904 ± 14.85c</td>
<td>592 ± 7.78c</td>
<td>3.93 ± 0.00d</td>
<td>0.49 ± 0.00d</td>
<td>1.45 ± 0.04bc</td>
<td>78.55 ± 0.00a</td>
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<tr>
<td>NSP2</td>
<td>2295 ± 12.02d</td>
<td>1242 ± 2.12d</td>
<td>1053 ± 9.90c</td>
<td>1700 ± 6.36d</td>
<td>458 ± 2.24d</td>
<td>4.00 ± 0.00d</td>
<td>0.54 ± 0.00c</td>
<td>1.37 ± 0.00bc</td>
<td>76.83 ± 0.04c</td>
</tr>
<tr>
<td>CSP</td>
<td>3381 ± 21.92b</td>
<td>2281 ± 8.49d</td>
<td>1100 ± 13.44b</td>
<td>2998 ± 18.38b</td>
<td>717 ± 9.90b</td>
<td>4.44 ± 0.05c</td>
<td>0.67 ± 0.00b</td>
<td>1.31 ± 0.00c</td>
<td>77.70 ± 0.07b</td>
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<tr>
<td>CC</td>
<td>2033 ± 12.73a</td>
<td>997 ± 12.73a</td>
<td>1036 ± 0.00c</td>
<td>1468 ± 7.78a</td>
<td>470 ± 4.95c</td>
<td>4.87 ± 0.00bc</td>
<td>0.49 ± 0.00d</td>
<td>1.47 ± 0.03a</td>
<td>71.18 ± 0.04d</td>
</tr>
<tr>
<td>CP</td>
<td>4133 ± 6.36b</td>
<td>4053 ± 9.90a</td>
<td>80 ± 16.26d</td>
<td>6073 ± 105.36a</td>
<td>2020 ± 95.46a</td>
<td>6.77 ± 0.14b</td>
<td>0.98 ± 0.00c</td>
<td>1.50 ± 0.02a</td>
<td>71.18 ± 0.04d</td>
</tr>
</tbody>
</table>

1Means with the same letters in the same column are not significantly different at p<0.05. PV, Peak viscosity; HPV, hot paste viscosity; BDV, breakdown viscosity; CPV, cold paste viscosity; SBV, setback viscosity; PT, peak time; Stability ratio= HPV/PV; Setback ratio= CPV/HPV; P, temp, Pasting temperature.

in all the starches considered. NSP1 showed the highest setback ratio (1.45) compared to the CSP and NSP2 indicating a higher retrogradation tendency (Figure 4) of the starch pastes resulting from the association of the leached amylose molecules, high amylose results in high retrogradation rate, consequently in high setback ratio (Collado and Corke, 1997). The significantly higher peak viscosity observed in CP starch could be attributed to its high phosphorus content (Table 1; Kuar et al., 2005) and the presence of fairly high percentage of large granule sizes in comparison with other starches. Breakdown viscosity (BDV), which is a measure of the resistance to heat and shear was significantly (p < 0.05) higher in NSP1 compared with that of CSP, NSP2 and CC while it was far higher than that of CP starch. However, Amylose, branched chain length of amylopectin, granule size and phosphorus content have been reported to be major factors affecting pasting properties of starches (Kuar et al., 2005).

Correlation analysis among the various physicochemical properties

Pearson’s correlation coefficients for the relationship between the various physicochemical properties of the various starches used in this study are shown in Table 4. Phosphorus content was positively correlated to mean granule size (MGS) (r = 0.998, p ≤ 0.01), HPV (r = 0.994, p ≤ 0.01), CPV (r = 0.969, p ≤ 0.01), SBV (r = 0.995, p ≤ 0.01), stability ratio (SR) (r = 0.995, p ≤ 0.01) and PT (r = 0.960, p ≤ 0.01) but negatively correlated to BDV (r = -0.959, p ≤ 0.01). Previous studies reported a positive correlation of phosphorus content with Peak, breakdown and setback viscosities (Zaidul et al., 2007; Noda et al., 2004). This is partially consistent with our study and in some aspects disagreed, as a negative correlation was observed between phosphorus content and BDV. Swelling power resulting from temperature changes positively correlated with swelling resulting from pH (r = 0.896, p ≤ 0.05), PT (r = 0.890, p ≤ 0.05), and negatively correlated with pasting temperature (P temp) (r = -0.884, p ≤ 0.05). Swelling power (SP) as affected by pH negatively correlated with T_p (r = -0.974, p ≤ 0.01), and P temp (r = -0.964, p ≤ 0.01). MGS had significant positive correlation with HPV (r = 0.955, p ≤ 0.01), CPV (r = 0.974, p ≤ 0.01), SBV (r = 0.998, p ≤ 0.01), SR (r = 0.962, p ≤ 0.01), PT (r = 0.946, p ≤ 0.05) but had a significant negative correlation with BDV (r = -0.958, p ≤ 0.01). T_p positively correlated with T_c (r = 0.908, p ≤ 0.05) and P temp (r = 0.993, p ≤ 0.01). T_c positively correlated with P temp (r = 0.895, p ≤ 0.05).

The positive correlations between the transition temperatures (T_c and T_p) and pasting temperature (P temp) are in accordance with the findings of Wang et al. (2010). PV significantly correlated positively with HPV (r = 0.965, p ≤ 0.01), CPV (r = 0.945, p ≤ 0.01), SBV (r = 0.886, p ≤ 0.05), HPV showed significant positive correlation with CPV (r = 0.996, p ≤ 0.01), SBV (r = 0.966, p ≤ 0.01), SR (r = 0.993, p ≤ 0.01) and negatively correlated significantly with BDV (r = -0.888, p ≤ 0.05). BDV showed highly significant negative correlations with CPV (r = -0.912, p ≤ 0.05), SBV (r = -0.938, p ≤ 0.05), PT (r = -0.964, p ≤ 0.01) and SR (r = -0.928, p ≤ 0.05). Kaur et al. (2007) also reported a highly negative correlation between BDV and PT. CPV showed positive correlation with PT (r = 0.895, p ≤ 0.01), SBV (r = -0.985, p ≤ 0.01) and negatively correlated with SR (r = -0.991, p ≤ 0.01). SBV correlated positively with PT (r = 0.930, p ≤ 0.05) and SR (r = 0.930, p ≤ 0.05). However, agreements and discrepancies observed in the correlation patterns between the physicochemical properties from this study and previous studies may be attributed to the differences in the type and the biological sources.
Nigerian sweet potato starches were studied. Variations (p < 0.05) were observed in the properties of the Nigerian and Chinese starches which could be due to different factors, such as environmental conditions, genotypic differences, etc. The starches differed in amylase, ash, phosphorus contents, granule sizes, shapes and particle size distribution. Significantly (p < 0.05) lower enzyme digestibility was observed in Nigerian sweet potato starch compared to Chinese sweet potato starch but much higher than that of CP. Both Nigerian and Chinese sweet potato starches showed lower solubility at lower temperatures while at higher temperatures (80°C), they showed higher solubility values as compared with cassava and potato starches. The gelatinization studies showed higher gelatinization temperatures of 73.17 and 71.64°C in NSP1 and 2 starches, respectively. The pasting properties of starches showed that the peak, hot paste, cold paste and setback viscosities of the NSP starches were lower than that of CSP and CP. Pearson’s correlation analysis showed that the mean granule size and

of the starches used while the physicochemical properties showing insignificant or no correlations may have resulted from lack of variations rather than lack of intrinsic relationship (Zhu et al., 2011).

**Conclusion**

The physicochemical properties of two popular Nigerian sweet potato starches were studied with reference to Chinese sweet potato, potato and cassava starches. Variations (p < 0.05) were observed in the properties of the Nigerian and Chinese starches which could be due to different factors, such as environmental conditions, genotypic differences, etc. The starches differed in amylase, ash, phosphorus contents, granule sizes, shapes and particle size distribution. Significantly (p < 0.05) lower enzyme digestibility was observed in Nigerian sweet potato starch compared to Chinese sweet potato starch but much higher than that of CP. Both Nigerian and Chinese sweet potato starches showed lower solubility at lower temperatures while at higher temperatures (80°C), they showed higher solubility values as compared with cassava and potato starches. The gelatinization studies showed higher gelatinization temperatures of 73.17 and 71.64°C in NSP1 and 2 starches, respectively. The pasting properties of starches showed that the peak, hot paste, cold paste and setback viscosities of the NSP starches were lower than that of CSP and CP. Pearson’s correlation analysis showed that the mean granule size and

<table>
<thead>
<tr>
<th>Parameter</th>
<th>AC</th>
<th>PC</th>
<th>SP&lt;sub&gt;temp&lt;/sub&gt;</th>
<th>SP&lt;sub&gt;PH&lt;/sub&gt;</th>
<th>Syn</th>
<th>MGS</th>
<th>T&lt;sub&gt;s&lt;/sub&gt;</th>
<th>T&lt;sub&gt;p&lt;/sub&gt;</th>
<th>T&lt;sub&gt;c&lt;/sub&gt;</th>
<th>ΔH&lt;sub&gt;gel&lt;/sub&gt;</th>
<th>R</th>
<th>PV</th>
<th>HPV</th>
<th>BDV</th>
<th>CPV</th>
<th>SBV</th>
<th>SR</th>
<th>SBR</th>
<th>PT</th>
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<td>0.969**</td>
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</table>

*p<0.05; **p<0.01. AC, Amylose content; PC, phosphorus content; SP<sub>temp</sub>, swelling power as affected by temperature; SP<sub>PH</sub>, swelling power as affected by pH; Syn, syneresis; MGS, mean granule size; T<sub>s</sub>, onset transition temperature; T<sub>p</sub>, peak transition temperature; T<sub>c</sub>, conclusion transition temperature; ΔH<sub>gel</sub>, enthalpy of gelatinization; PV, peak viscosity; HPV, hot paste viscosity; BDV, breakdown viscosity; CPV, cold paste viscosity; SBV, setback viscosity; SR, stability ratio; SBR, setback ratio; PT, peak time; P<sub>temp</sub>, pasting temperature.
phosphorus content of the starches had substantial effect on the pasting properties of the starches. In all, the variability observed in the physicochemical properties of the Nigerian and Chinese sweet potato, cassava and potato starches further projected their useful and comparative potentials in various industrial applications.

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REFERENCES


Carbery, North Carolina, USA.


