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Structural, physicochemical and rheological characterization of *Tacca involucrata* starch

Louis M. Nwokocha[a], Chandra Senan[b], Peter A. Williams[b,*]

[a] Department of Chemistry, University of Ibadan, Ibadan, Nigeria
[b] Center for Water Soluble Polymers, Glyndwr University, Wrexham, UK

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ABSTRACT

Starch was isolated from white and yellow *Tacca involucrata* tubers and the characteristics studied. The granule morphology was the same for both starches but they differed in granule size distribution: white tacca (6.13–18.12 μm), yellow tacca (4.19–11.98 μm). Yellow tacca exhibited an A-type X-ray diffraction pattern but white tacca had a C-type diffraction pattern. White tacca had a slightly higher weight average M_w (2.12×10^7 g/mol) than yellow tacca (1.85×10^7 g/mol). Yellow tacca had lower gelatinization temperature, higher swelling power, higher amylose leaching and higher freeze–thaw stability compared with white tacca. However, the flow characteristics and small deformation mechanical spectra of the starch gels did not differ greatly. The high paste clarity of tacca starches at higher starch concentrations indicates a potential for application in food products like pies and puddings where clarity is desirable.

1. Introduction

Tacca involucrata, Sch. and Thonn., is a rhizome and is usually found in the savannah grassland. It belongs to the family *Taccaceae*. It is a perennial herb with a round swollen tuber underneath the ground from which shoots out a leaf stalk up to 1 m long. The plant had a long history of being a major source of carbohydrate in the savannah belt of Nigeria until the advent of cassava when its importance waned. It is now harvested wild. The tuber is first boiled to remove the toxic element and then converted to flour and employed in a variety of food preparations (Freedman, 1998). *T. involucrata* is an under-utilized crop with a high potential as a source of industrial starch. The common variety has an orange-yellow tuber, but the isolated starch is white similar to potato starch. Zaku, Aguzue, Thomas, and Barminas (2009) isolated 30.23% of starch from *T. involucrata* tubers and reported the proximate composition. The starch had low lipid content (0.09%) as is common to tuber starches. Attama and Adikwu (1999) reported that the starch granules were predominantly oval with a single, double or triple cleft hilum. They also reported amylose content of 36% and gelatinization temperature of 52–65 °C for the starch. Manek et al. (2005) in their study on tacca starch reported mean granule size of 2.64 μm, an A-type X-ay diffraction pattern with 35% crystallinity and a gelatinization temperature of 68.56 °C. Kunle, Ibrahim, Emeje, Shaba, and Kunle (2003) have compared the swelling power and solubility of tacca starch with maize and potato starches and reported higher values for tacca starch. Ofoefule, Osuji, and Okorie (2004) studied the effect of physical and chemical modification on the efficiency of *T. involucrata* starch as a pharmaceutical disintegrant and reported that the pregelatinized starch had a higher efficiency. Available literature on tacca starch is scanty when compared with starches from other rhizome tubers like cocoyam (Lauzon et al., 1995; Lawal, 2004; Perez, Schultz, & De Delahaye, 2005) and Canna (Chuenkamol, Puttanlek, Rungsardthong, & Uttapap, 2007; Hung & Morita, 2005; Piyachomkwan et al., 2002; Thitipraphunkul, Uttapap, Piyachomkwan, & Takeda, 2003). There has not been any report on the properties of starch from different varieties of tacca. In this study we reported the properties of starch isolated from white and yellow tacca tubers.

2. Materials and methods

T. involucrata tubers used in this study were collected from two different locations around Eruwa, Ibadan, with the assistance of the Forest Research Institute of Nigeria, Ibadan. One set was collected from normal grassland (tuber pulp was orange-yellow, labelled yellow tacca), the second set was collected from a swamp (tuber pulp was white, labelled white tacca).

* Corresponding author. Tel.: +44 1978293 083.
E-mail address: p.a.williams@glyndwr.ac.uk (P.A. Williams).

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2.1. Starch isolation

The tubers were washed, peeled and cut into 2 cm chips and homogenized in a Phillips blender with minimal amount of water. The slurry was mixed with five times its volume of water and sieved with a muslin cloth. The starch milk was allowed to settle and the supernatant decanted. This was washed several times with fresh water. The resultant white starch was air dried and stored in a sealed plastic bag. Starch samples oven dried at 105 °C to constant weight indicated moisture content of 12.8% for white tacca and 10.1% for yellow tacca.

2.2. Microscopy

Granule micrographs were obtained with a JSM 35 Genie Scanning Electron Microscope (Jeol Ltd, Tokyo, Japan) and the granule size analysis carried out with a BT-1600 Image particle size analyzer (Bettersize Instruments Ltd) coupled to a light microscope (objective magnification ×40) (Meiji Techno, Japan). The computer-controlled video was processed and the granule characteristics determined.

2.3. X-ray diffraction

The starch samples were pulverized to powder particle size of less than 63 μm mesh sieve and equilibrated in a desiccant in a desiccator overnight. The samples were placed in the cavity of a disc sample holder of the diffractometer. Diffraction diagrams were recorded using Inel X-ray equipment (Inel CSP120, 45410 Artenay, France) operating at 40 kV and a generator current of 30 mA. Cu Kα1 radiation (λ = 0.15405 nm) was selected using a quartz monochromator and scanned between 3° 2θ and 30° 2θ. A curved position detector was used to monitor the intensities using 2 h exposure periods. PeakFit software (Systat software Inc., Chicago, USA) was used to quantitatively estimate the degree of crystallinity using the Erfc Pk type in peak fitting and analysis of the amorphous area ($r^2 > 0.99$). The percentage crystalline area was obtained by difference.

2.4. Determination of the blue value and amylose content

To 0.1 g starch (dry basis, db) in a test tube was added 1 ml of ethanol (95%) to disperse the starch followed by 9 ml of 1 M NaOH solution. The mixture was heated in a water bath to gelatinize and solubilise the starch. This was transferred quantitatively into a 100 ml standard volumetric flask and made up to the mark with distilled water. 5 ml (i.e. 5 mg) of the solution was taken into a 100 ml volumetric flask and 1 ml of 1 M acetic acid added followed by 2 ml stock iodine solution (0.2 g I_2/2 g KI made up to 100 ml) and made up to the mark with distilled water. This was left for 20 min for the colour to fully develop (Juliano, 1971). The solution was put in a 1 cm cuvette and scanned in a Lambda 25 UV/Visible Spectrophotometer (Perkin Elmer, Massachusetts 02451 USA) (wavelength 350–950 nm, scan speed 480) using iodine solution of the same concentration, but without starch, in the reference cell. A calibration curve was prepared with pure potato amylose (Type III: from potato, Sigma) in the concentration range 10–50 mg from which the amylose content of the starches was obtained by extrapolation from the absorbance–amylose concentration curve using the absorbance at 620 nm.

The blue value was calculated according to Gilbert and Spragg (1964) using

$$\frac{\text{Maximum absorbance} \times 4}{\text{Starch concentration (mg/dL)}}$$

2.5. Molecular weight characterization

The molecular weight distribution was determined using gel permeation chromatography (GPC). The starch sample used was purified by dissolving in 90% dimethyl sulphoxide (DMSO) solution (Stevenson, Doorenbos, Jane, & Inglett, 2006) overnight, followed by precipitation with hot isopropanol. The samples were prepared by dispersing the starch (~0.2%, w/w) in 0.1 M KSCN solution for 12 h by a magnetic stirrer at room temperature and then heating in water bath at 90 °C for 10 min. 10 ml of the solution was placed in a microwave bomb and heated in a microwave oven at full power for 40 s, brought out and kept in an ice bath to cool. The solution was filtered through a 0.45 μm Whatman nylon filter and injected into the rheodyne connected to a guard column and two Suprema columns (3000 Å and 30,000 Å) (PSS, D-55120 Mainz, Germany) packed with 10 μm beads of polyhydroxymethacrylate copolymer network in series to a multiangle laser light scattering and a refractive index detector (MALLS/RI) (Optilab DSP, Wyatt Technology Corporation, Santa Barbara Ca93103). The columns were placed in an oven maintained at 59 °C. The eluant was 0.1 M $NaNO_3$ solution containing 0.005% of sodium azide pumped (Waters: 515 HPLC Pump, Milford, MA 01757, USA) through a degasser (CSI 6150, Cambridge Scientific Instruments, England) at a flow rate of 0.5 ml/min. The chromatogram was analyzed with Astra software and the molecular weight distribution calculated using the Berry second order model. A refractive index increment, dn/dc, of 0.146 ml/g (White, 1999) was used.

2.6. Gelatinization properties

The gelatinization properties of starch were determined with a differential scanning calorimeter (Micro DSC III, Setaram Instruments, 69300 Caluire, France). 10% starch dispersions were placed in the sample cell and an equal mass of water was placed in the reference cell. The samples were heated from 25 °C to 100 °C at a scanning rate of 0.5 °C/min. The effect of different concentrations (0.02, 0.1, 0.2 and 0.4 M) of sodium chloride on gelatinization was investigated using the same weight of the sodium chloride solution in the reference cell.

2.7. Swelling power and amylose leaching

Starch (0.1% w/w, db) was dispersed in distilled water by means of a magnetic stirrer. Dispersion aliquots (10 g) containing 1 mg/ml starch were transferred into pre-weighed tubes, sealed and immersed in a thermostatic water bath for 30 min at temperatures of 60, 65, 70, 75, 80, 85 and 95 °C. The samples were agitated throughout the heating period to maintain a starch suspension. The samples were centrifuged at 1500 rpm for 10 min. The supernatant was carefully drawn up. The weight of the paste was determined and used to calculate the swelling power as weight of paste divided by the original weight of dry starch. 2.5 ml of the supernatant was transferred into a 50 ml volumetric flask, followed by the addition of 0.5 ml of acetic acid (1 M) and 1 ml of stock iodine solution (0.2 g I_2/2 g KI made up to 100 ml) and the volume made up to the mark. The solution was shaken and the absorbance at 620 nm measured after 20 min (Juliano, 1971). The amylose concentration was extrapolated from a standard absorbance–amylose curve. The amylose content was expressed as mg amylose/100 mg starch.

2.8. Determination of paste clarity

Paste clarity was determined by the method of Singhal and Kulkarni (1990) by measuring the percentage light transmitted by different concentrations of starch (1.0–3.0% w/v, db) at 660 nm on

a UV/Visible Spectrophotometer. Distilled water was used in the reference cell.

2.9. Freeze–thaw stability

The freeze–thaw stability was determined according to the method of Singhal and Kulkarni (1990) on 5% (w/v, db) starch paste prepared by heating the starch dispersion in a water bath maintained at 95 °C for 30 min. The starch paste was stored at 4 °C (18 h) and thawed at 25 °C (3 h), and centrifuged at 2500 rpm for 10 min and the weight of exudates determined over a 6-day period. Freeze–thaw stability was calculated as percentage weight of exudates per weight of paste.

2.10. Rheological properties

The rheological properties were investigated on 4.0% and 6.0% starch pastes. The starch dispersions were heated in sealed tubes immersed in a water bath maintained at a temperature of 99 °C for 30 min. The samples were agitated during the first 3 min of immersion during which pasting occurred and left to cook. The pastes were removed and left at 25 °C and the rheological properties examined after 1 h. The flow properties were measured on a controlled stress Rheometer (AR 2000, TA Instruments Ltd, Newcastle, UK) with cone and plate geometry (40 mm, 2° cone and 53 μm gap). Measurements were carried out at 25 °C at shear rates of 10^{-3}–1000s^{-1}. The viscoelastic properties of the starch pastes were determined by carrying out a frequency sweep in the range of 10^{-2}–120 rad/s within the viscoelastic region (strain, 1.0%). The linear viscoelastic region was obtained by performing a stress sweep within the range of 0.01–50 Pa at an angular frequency of 2.683 rad/s. The storage modulus (G') and loss modulus (G'') of the starch pastes were analyzed by the TA Data Analysis software.

3. Results and discussion

3.1. Granule characteristics

The light micrographs of white tacca and yellow tacca starch granules are shown in Fig. 1. Both starches contained oval and polyhedral granules. Compound granules were visible in white tacca starch. The granules of white tacca are bigger than yellow tacca starch granules (Fig. 1 and Table 1). The granule size of white tacca ranged from 6.13 to 18.12 μm with average size of 12.32 μm while yellow tacca starch granules ranged from 4.19 to 11.98 μm with granule average of 6.89 μm. About 97% of yellow tacca starch granules (by number) were less than 10 μm whereas only 20% of white tacca was in this size range. White tacca also showed a wider range of granule size distribution. Yellow tacca had smaller L/D ratio and greater roundness than white tacca. In another work, Manek et al. (2005), while examining the functional properties of tacca starch reported a mean granule size of 2.64 μm. Tacca starch granules were smaller than those reported for potato starch (5–100 μm; Thomas & Atwell, 1999). The average granule sizes reported for some other rhizome starches were: cocoyam (red, 14.2 μm and white, 12.5 μm; Lauzon et al., 1995), canna (10–80 μm; Piyachomkwan et al., 2002). Granule size has been reported to influence starch properties such as gelatinization (Goering & DeHass, 1972), enzyme and acid hydrolysis (Tester, Qi, & Karkalas, 2006; Vasanthan & Bhatty, 1996).

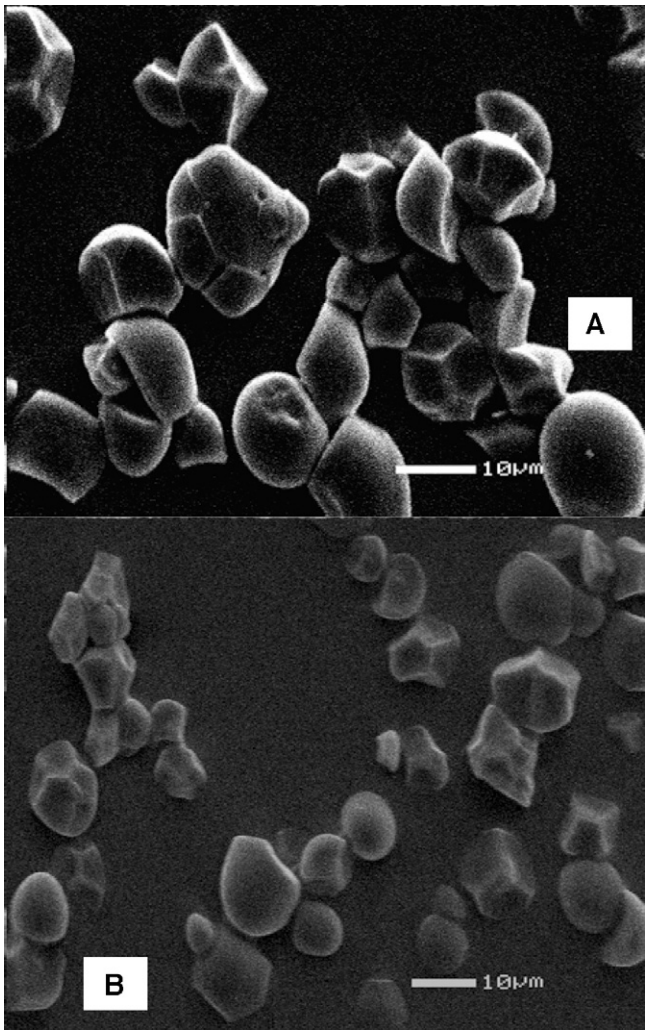

Fig. 1. Scanning electron micrographs of white tacca (A) and yellow tacca (B) starch granules.

Table 1
Some characteristics of white and yellow tacca starches.

Characteristics	White	Yellow
Granular		
Granule size distribution (μm)	6.13–18.2 (av. 12.32)	4.19–11.98 (av. 6.89)
Length/diameter	1.32	1.13
Roundness	0.63	0.83
Blue value and amylose content		
λ_{max} (nm)	592–595	597–599
Blue value	0.4693 ± 0.000^{a}	0.5243 ± 0.001^{b}
Amylose content (%)	22.1 ± 0.03^{a}	24.4 ± 0.06^{b}
Molecular		
Molecular weight (g/mol)	2.1154×10^{7} (0.4%)	1.854×10^{7} (0.4%)
Radius of gyration (nm)	88.6 (0.3%)	78.4 (0.3%)
Polydispersity	1.586 (0.5%)	1.707(0.5%)

Errors are standard deviations of three determinations. Values in a row with different superscripts are significantly different ($p < 0.05$).

3.2. X-ray diffraction

Fig. 2 shows the X-ray diffractograms of the starches. Yellow tacca gave characteristic peaks at 15.2, 17.4, 18.5, 23.0 and 23.3° 2θ while white tacca gave characteristic peaks at 5.6 (very small), 15.2, 17.4, 18.0, 23.0, 23.3 and 24.4° 2θ. Diffraction peaks at 15, 17, 18 and 23° 2θ are characteristic of an A-type diffraction pattern while B-type has characteristic peaks at 5.6, 15, 17, 23 and 24° 2θ. C-type is a mixture of A- and B-types diffraction pattern. From the diffractograms, yellow tacca has typical A-type diffraction pattern while white tacca has a C-type diffraction pattern. This is the first time a C-type X-ay diffraction pattern is reported for tacca starch. An A-type diffraction is common in cereal starches and

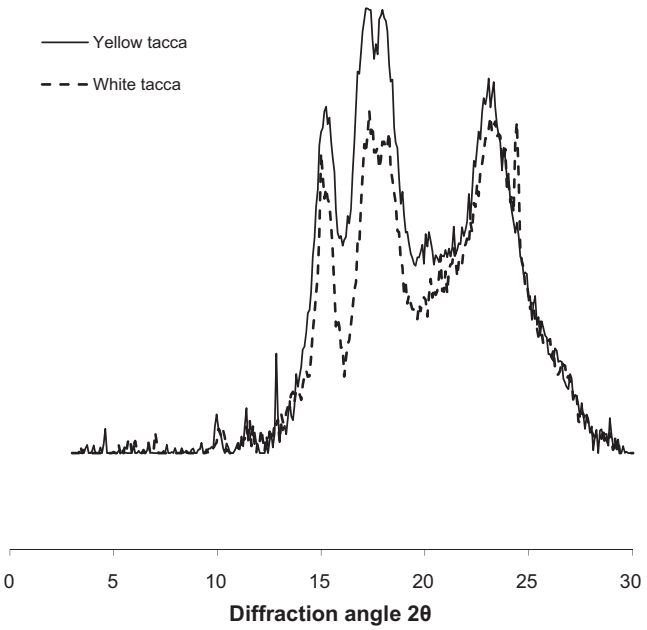

Fig. 2. X-ray diffractograms of tacca starches.

tubers like cassava; B-type in potato and C-type in pea starches and sago starch (Ahmad, Williams, Doublier, Durand, & Buleon, 1999). The amorphous area calculated for the starches was: yellow tacca (56.84%) and white tacca (57.9%) indicating crystallinities of 43.16% and 42.1%, respectively. Manek et al. (2005) reported an A-type X-ray diffraction pattern and a crystallinity of 35% for tacca starch. An A-type X-ray diffraction pattern was reported for cocoyam starch (Lauzon et al., 1995; Lawal, 2004) and a B-type for canna starch (Watcharatewinkul, Puttanlek, Rungsardthong, & Uttapap, 2009).

3.3. Blue value and amylose content

Starch–iodine reaction is very important for the determination of amylose and amylopectin content of starch (Tomasik & Schilling, 1998). While amylose gives a blue colour with iodine, amylopectin gives a purple to reddish brown colour. Table 1 shows the λ_{max}, blue values and amylose contents for tacca starches. The λ_{max} for yellow tacca (597–599 nm) and white tacca (592–595 nm) are in the range 588 to 620 nm for amylose in starches (Yu et al., 1996). Both the blue value (BV) and amylose content (AC) were higher for yellow tacca (BV, 0.5143; AC, 24.4%) than for white tacca (BV, 0.4693; AC, 22.1%) and these were significantly different ($p < 0.05$) for the two starches. The values of AC for white and yellow tacca starches are less than the values reported for tacca starch in the literature (Attama & Adikwu, 1999; Zaku et al., 2009), in the range of values reported for some other rhizome starches (Lauzon et al., 1995; Thitipraphunkul et al., 2003) but higher than 20% reported for potato starch (Thomas & Atwell, 1999). Starch physicochemical properties are affected by the amylose/amylopectin ratio, the characteristics of each component such as molecular weight, degree of branching and the manner in which these components are arranged within the starch granule (Leach, 1965).

3.4. Molecular weight and radius of gyration of tacca starches

The GPC elution profiles for tacca starches are presented in Fig. 3. The chromatograms showed presence of two main components as indicated by the presence of two peaks. Starch is made up of two fractions: amylopectin – a higher molecular weight, highly branched molecular fraction and amylose – a lower molecular weight, linear molecular fraction. The poor separation of the two peaks indicates overlap of the two starch fractions hence it was not possible to estimate the components separately. Hence the weight average molecular weight was determined. From Table 1, the M_w of white tacca (2.1154×10^7 g/mol was slightly higher than yellow tacca, (1.854×10^7 g/mol). However, R_w was lower and M_w/M_n higher for yellow tacca than for white tacca. In an optimization study of conditions for determination of M_w, Othman, Al-Assaf, and Hassan (2010) obtained M_w of 2.91×10^7 g/mol and radius of gyration of 123.8 nm for sago starch. Yokoyama, Renner-Nantz, and Shoemaker (1998) have calculated the M_w of different starches including cassava (5.7×10^7 g/mol), waxy corn (2.28×10^8 g/mol) and waxy rice (8.9×10^7 g/mol) using the Berry method and remarked that the M_w depended on the method of calculation.

3.5. Gelatinization properties

The gelatinization properties of yellow and white tacca starches were studied in water and different concentrations of sodium chloride. The results are shown in Table 2. In water, yellow tacca starch exhibited a lower gelatinization temperature: onset ($T_o = 74.1\,^\circ$C), peak ($T_p = 76.2\,^\circ$C) and range ($T_o - T_c = \Delta T = 6.0\,^\circ$C) than white tacca ($T_o = 77.3\,^\circ$C; $T_p = 80.1\,^\circ$C; $\Delta T = 7.0\,^\circ$C). The two starches did not differ widely in their endothermic enthalpies. The higher gelatinization temperature of white tacca indicates it had stronger intra-granular bonds than yellow tacca. Our result shows a correlation between granule size distribution and gelatinization range

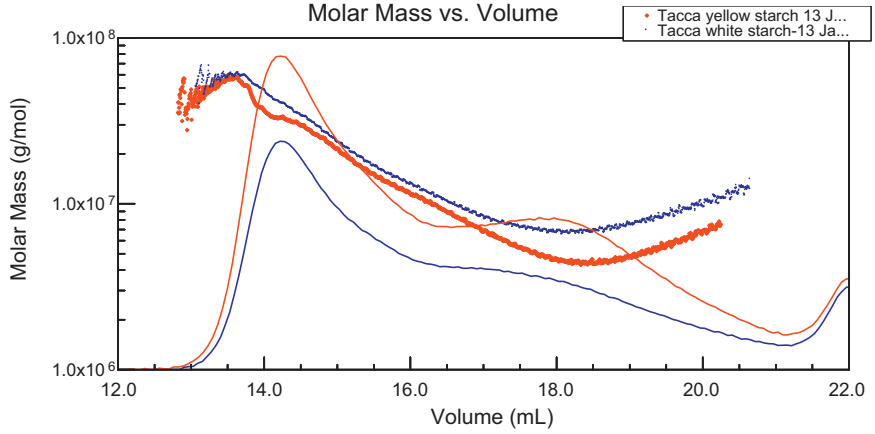

Fig. 3. GPC elution profiles of tacca starches.

Table 2
Gelatinization properties of white and yellow tacca starches in different concentrations of NaCl solution.

	T_o (°C)	T_p (°C)	T_c (°C)	ΔT (°C)	ΔH (J/g)
A. White tacca					
Water	77.3	80.1	84.3	7.0	13.3
0.02 M	79.5	82.1	85.9	6.4	15.5
0.1 M	80.9	83.4	87.1	6.2	14.9
0.2 M	82.2	84.7	88.5	6.3	14.3
0.4 M	83.9	86.4	90.1	6.2	13.7
B. Yellow tacca					
Water	74.1	76.2	80.1	6.0	13.6
0.02 M	76.4	78.4	81.9	5.5	14.1
0.1 M	77.8	79.8	83.1	5.3	14.4
0.2 M	79.2	81.2	84.6	5.4	14.1
0.4 M	80.7	82.6	85.7	5.0	14.2

T_o, T_p, T_c are the onset, peak and completion temperatures, respectively. ΔT and ΔH are the gelatinization temperature range and endothermic enthalpy of gelatinization, respectively.

(ΔT) with white tacca which had a wider granule size range having a higher ΔT value. ΔT has also been reported to depend on the difference in the degree of heterogeneity of the crystallites within the starch granules (Gunaratne and Hoover, 2000). Manek et al. (2005) in their study reported a gelatinization temperature of 68.56 °C for tacca starch which is lower than the values obtained in this report. Gelatinization temperature of 71.9 °C was reported for canna starch (Watcharatewinkul et al., 2009) while 66.11 °C and 76.04 °C were reported for cassava and cocoyam starches, respectively (Nwokocha, Aviara, Senan, & Williams, 2009). Several workers have studied the effect of sodium chloride concentration on starch gelatinization (Ahmad & Williams, 1999; Chiotelli, Pilosio, & Le Meste, 2001; Wootton & Bamunuarachchi, 1980), especially as it is an additive to improve the flavour of foods. They have reported complex effects dependent on solute concentration, solute–water and solute–starch interactions. From our results, T_p shifted to progressively higher temperatures as the concentration of sodium chloride increased for both starches, with $T_{p,white} > T_{p,yellow}$. The increase in T_p with increasing sodium chloride concentration is attributed to the gradual decrease in available water resulting from the hydration of Na^+ and Cl^- (Ahmad & Williams, 1999). ΔT decreased with increase in sodium chloride concentration. ΔH increased as concentration of sodium chloride increased to 0.02 M and decreased with further increase in concentration however the variation was minimal in the concentration range studied and yellow tacca did not give a well defined trend. The decrease in ΔH is attributed to the increasing exothermic enthalpy of hydration at increasing sodium chloride concentration which offset the endothermic melting enthalpy.

3.6. Swelling power and amylose leaching

The swelling power and amylose leaching patterns of tacca starches are presented in Fig. 4. The starches did not indicate any noticeable swelling up to 70 °C (Fig. 4A). Yellow tacca starch lost its granule crystallites first as indicated by an enormous change in swelling power at 75 °C and white tacca at 80 °C. The starches attained the maximum swelling power at 90 °C. Beyond this point, the swollen granules burst followed by granule fragmentation and solubilization evident in lower values of swelling power. From the swelling patterns, it could be said granular structure was more ordered in white tacca than in yellow tacca; this agrees with the data on the gelatinization properties. The amylose leaching profiles (Fig. 4B) followed a similar trend with swelling power. Yellow tacca with smaller starch granules exhibited higher swelling power and amylose leaching than white tacca. This is possibly due to its higher specific surface area (Chiotelli & Le Meste, 2002). From Fig. 4C, in the

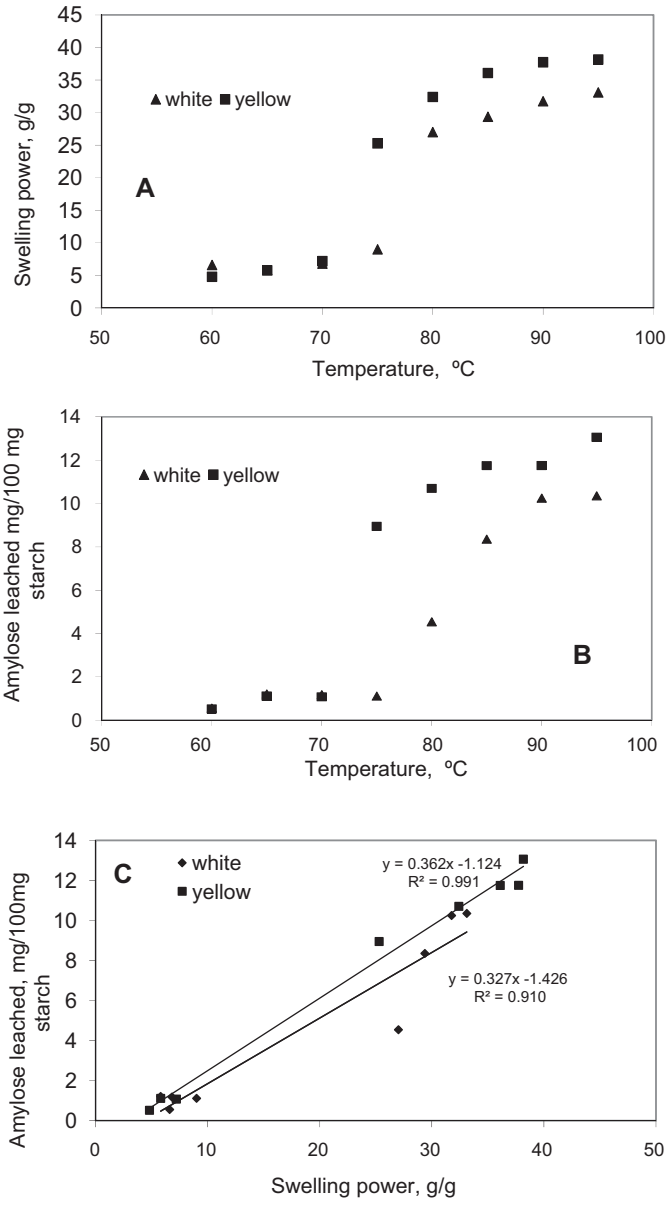

Fig. 4. Swelling power (A) and amylose leached (B) vs. temperature; amylose leached vs. swelling power (C), of tacca starches.

regions of low swelling power (SP < 10 g/g), the amount of amylose leached was less than 2 mg/100 mg starch. The amount of amylose leached increased linearly with swelling power and was more in yellow tacca (slope = 0.36) than in white tacca (slope = 0.33). This is because the process of swelling loosens the granules permitting water uptake and diffusion of the amylose from the granule interior into the surrounding medium. The influence of granule size on swelling and solubility has been extensively studied. In one such report, Zheng and Sosulski (1997) observed that at similar amylose content, smaller granules tend to have lower pasting temperature and more amylose leakage than larger granules.

3.7. Paste clarity and freeze–thaw stability

Starch is employed as a thickener in many foods. Improved paste clarity is a useful property in the manufacture of some foods like jellies, sausages and fruit pies, which require transparency (Jyothi, Rajasekharan, Moorthy, & Sreekumar, 2005).

The clarity of such starch-thickened food is important if the food product is to retain its appeal to the consumers. Starches with high paste clarity are preferred for this reason. Fig. 5A shows the light transmittance of the tacca starches as a function of starch concentration. Yellow tacca had slightly higher clarity than white tacca. The starches had minimum clarity at starch concentration of 1.5% with light transmittance increasing as starch concentration increased. Similar observations have been reported for certain starches (Nwokocha et al., 2009; Pomeranz, 1991). The high paste clarity at higher starch concentration indicates that tacca starches would be suitable for the manufacture of food products where clarity is desirable.

Retrogradation is important when starch is used as a food ingredient in processing and preservation, because the quality of the food texture and physical properties deteriorate as retrogradation progressed. Fig. 5B shows the effect of cold storage on the retrogradation properties of tacca starches. Yellow tacca survived two freeze–thaw cycles before any noticeable syneresis was observed whereas white tacca did not survive the first freeze–thaw cycle. After 6 freeze–thaw cycles, the percentage syneresis was 36.72 for white tacca and 29.09 for yellow tacca. This indicates retrogradation was more in white tacca than yellow tacca starch. Retrogradation is the consequence initially of the association of amylose molecules which lead to formation of a gel network. The degree of association increases with time resulting in syneresis.

3.8. Rheological properties

The viscosity–shear rate profiles for 4% and 6% (w/v) pastes of tacca starch are showing in. 6A. The flow curves were fitted to different viscosity–shear rate models. The Carreau model (Eq. (1)) gave the lowest standard error and was used to determine the flow characteristics of the pastes.

$$\frac{\eta - \eta_\infty}{\eta_\circ - \eta_\infty} = \frac{1}{(1 + (\kappa^* \gamma_\bullet)^2)^{N/2}} \quad (1)$$

where η, η_o, η_∞ are shear, zero shear and infinite shear viscosities (Pa s), respectively. κ^* is consistency (s). N is rate index (dimensionless).

The profiles showed a viscosity plateau (η_o) at lower shear rates and a shear thinning region at higher shear rates. The viscosity of the starch pastes was concentration dependent with η_o at 6% higher than η_o at 4% (yellow tacca: η_o = 883.1 Pa s at 6% and 83.65 Pa s at 4%; white tacca: η_o = 860.6 Pa s at 6% and 108.6 Pa s at 4%). Similar trend has been reported for other polysaccharides (Doublier & Wood, 1995). The Carreau rate index was higher at 6% than at 4% for the two starches. Both starches exhibited similar flow behaviour as indicated by close superimposition of the flow curves. The variation of G' and G'' with angular frequency is shown in Fig. 6B. G' was higher than G'' for both starch concentrations indicating gel-like characteristics. The starch gels at 4% showed greater dependence

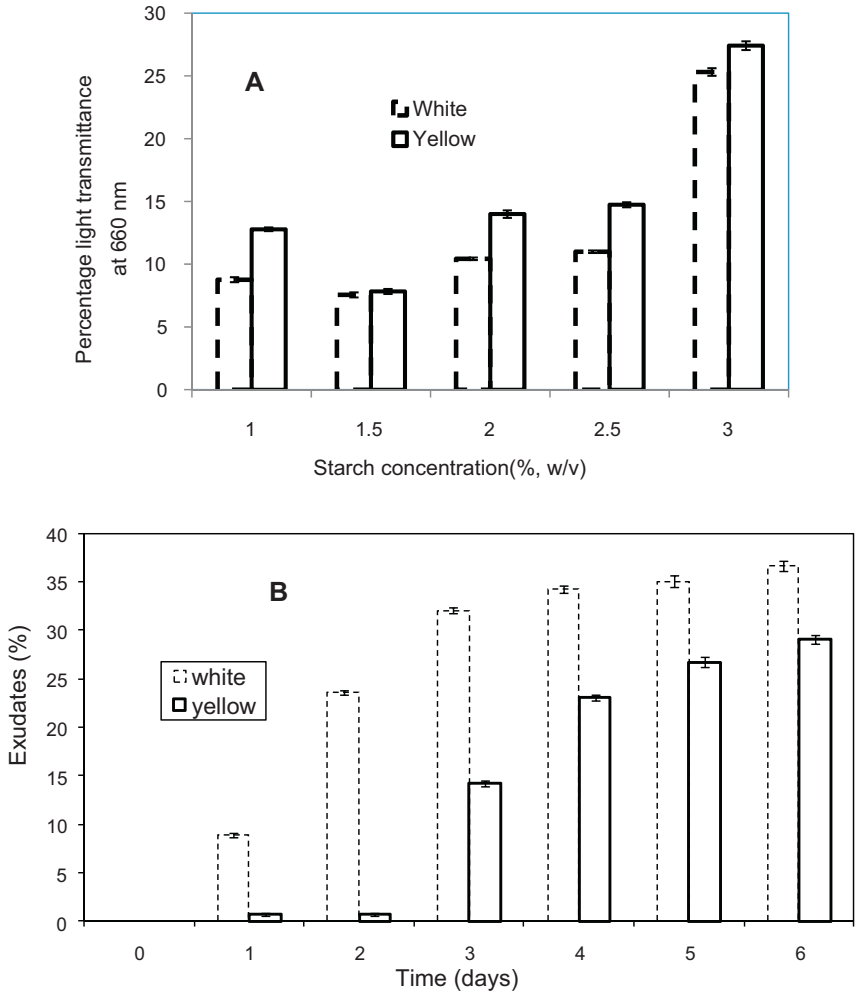

Fig. 5. Paste clarity (A); freeze–thaw stability (B), of tacca starches.

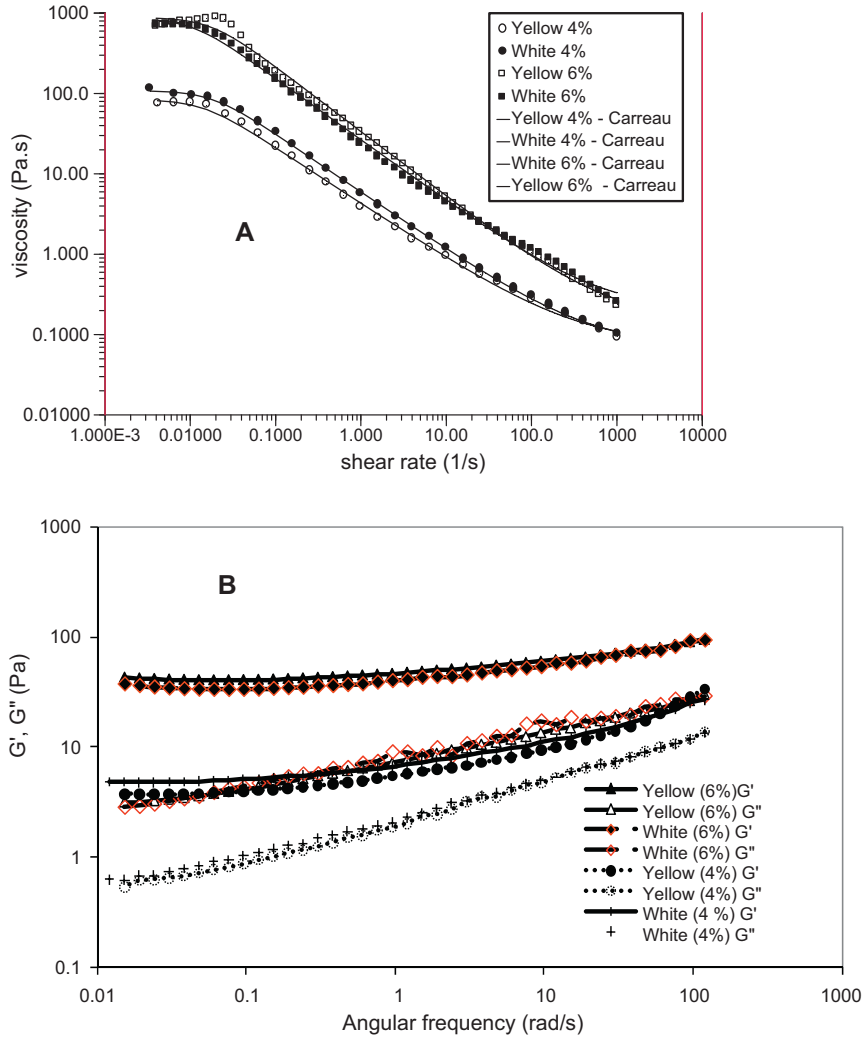

Fig. 6. Viscosity-shear rate profiles (A); G', G'' vs. angular frequency (B), of 4% and 6% tacca starch pastes at 25 °C.

of G' and G'' on the oscillation frequency than the starch gels at 6% as the gap between G' and G'' was narrower with increasing angular frequency for 4% starch gels. The mechanical spectra showed close superimposition of the G' and G'' at 4% and 6% indicating similar viscoelastic properties.

4. Conclusion

Starch was isolated from two varieties of *T. involucrata* and the characteristics studied. Both white tacca and yellow tacca differed in granule size distribution, X-ray diffraction pattern, gelatinization temperature, swelling power and amylose leaching, and freeze–thaw stability. The flow characteristics and mechanical properties of the starch pastes did not differ greatly. The properties of tacca starch indicated it could be suitable in processed foods like pies and puddings.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.carbpol.2011.05.024.

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