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Physicochemical and functional properties of makal (*Xanthosoma yucatanensis*) starch

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Abstract

Physicochemical and functional properties of makal (*Xanthosoma yucatanensis*) starch were determined. Granules were oval in shape and 12.4 μm average diameter. Starch purity was high (96.7%) with low protein (0.1%), fat (0.2%), fibre (0.4%) and ash (0.1%) contents. Amylose content was 22.4%. The gelatinization temperature was 78.5 °C and transition enthalpy was 15 J/g. At 90 °C, solubility was 32.9%, swelling power was 28.6 g water/g starch and water absorption capacity was 19.2 g water/g starch. Pasting characteristics were: temperature 75 °C, maximum viscosity 280 BU, breakdown −8 BU, setback 180 BU and consistency 172 BU. Clarity, expressed as transmittance, was 35.8%. Gel deformation was 20.8% with a 0.03 kgf maximum load. Makal starch's high gelification temperature and firmness make it appropriate for use in high temperature food systems, but its low stability in refrigeration and freezing cycles make it inadequate for use in foods subject to those conditions.

Keywords: Starch; Makal; *Xanthosoma yucatanensis*; Functional properties

1. Introduction

As a raw material, starch has applications ranging from imparting texture and consistency to foods to the manufacture of paper, adhesives and biodegradable packaging. Starch is the most commonly used functional ingredient (e.g. thickener, stabilizer, gelling agent) in the food industry. The annual worldwide production of starch is 66.5 millions tons (FAOSTAT, 2002). Growing demand for starches in the industry has created interest in new sources of this polysaccharide, such leaves, legume seeds and fruits (Betancur-Ancona, Gallegos-Tintoré, & Chel-Guerrero, 2004).

The most important properties to consider when determining starch uses in food systems and other industrial applications are physicochemical (e.g. gelatinization and retrogradation) and functional (e.g. solubility, swelling, water absorption, syneresis and rheological behaviour of pastes and gels) (Wang & White, 1994). A fundamental characteristic of native starches from different vegetal sources is that their granule and molecular structures influence their physicochemical and functional properties.

The most significant sources of starch are cereal grains, such as corn, wheat and rice, and tubers, such as potato and cassava (Betancur-Ancona, Chel-Guerrero, Camelo-Matos, & Dávila-Ortiz, 2001). Current starch research is focussed on searching for non-conventional starch sources with diverse physicochemical, structural and functional characteristics that give them a broad range of potential industrial uses. Tubers such as sweet potato and arrowroot are promising new starch sources as they are a vital part of the world-wide food system.

The thickening power of starches makes them useful in food and industrial applications. The clarity and good gel strength of cassava (*Manihot esculenta*) starch make it useful in a wide variety of food products (Moorthy, 2002). A potentially useful tuber found in the southeast of Mexico is *Xanthosoma yucatanensis*, a tuber locally

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known as "makal". It grows near bodies of water or in wet environments, has radial leaves with long petioles and its root is edible. Though little information is currently available on makal, it may have a substantial starch content (Martinez, 1978).

The present study was aimed to investigate the physicochemical and functional properties of starch isolated from the tuber "makal" (*X. yucatanensis*).

2. Materials and methods

2.1. Tubers and chemical

Fresh makal (*X. yucatanensis*) roots were obtained from the February, 2003, harvest in the state of Yucatan, Mexico. All chemicals were reagent grade and purchased from J.T. Baker (Phillipsburg, NJ).

2.2. Starch isolation

Starch isolation from *X. yucatanensis* was done with the wet-milling method. Briefly, roots were manually peeled, cut into cubes (approx. 3 cm) and suspended in a sodium bisulfite solution (1500 ppm of SO_2) at a 1:3 (w/v) ratio for 30 min. The cubes were then milled in a Fatosa C-3527 cutter for 2 min to reduce particle size and the resulting mass was added to a sodium bisulfite solution (1500 ppm of SO_2) at a 1:1 (v/v) ratio. This suspension was then run twice through a colloidal mill (Koromex G-91T085-18) to further reduce particle size and extract the starch. This starch suspension was filtered through plastic cloth (80-mesh) strainers to eliminate the fibre, and the filtrate was allowed to settle at 4 °C for 4 h to recover the starch. Once recovered, the starch fraction was washed three times by resuspension in distilled water, dried at 55 °C for 12 h in an air convection oven, weighed and milled in a Cyclotec (Tecator, Sweden) mill until it passed through a 20-mesh screen. Physicochemical characterizations were done of this starch fraction.

2.3. Granule size and microscopic appearance

Starch granule size and shape were determined according to McMaster (1964), using a Leica optical microscope with ocular graduations for observation and direct measurement. Samples of 0.5% starch suspension were placed on slides. Granules were viewed in the total area occupied by the sample on the slide, and measurements taken of the long axis and short axis diameters of 300 granules (600 measurements, two on each granule). Reported were long and short axes diameters and averages of these measurements.

2.4. Chemical composition

Nitrogen, ash and moisture contents were determined according to AOAC (1997) procedures (methods 954.01, 920.39, 923.03, and 925.09, respectively). Nitrogen content (N_2) was determined with a Kjeltec Digestion System (Tecator, Sweden), using cupric sulfate and potassium sulfate as catalysts. Protein content was calculated as nitrogen × 6.25. Lipids content was determined by the Morrison and Coventry (1985) method, using 75% aqueous *n*-propanol at 100 °C. Ash content was calculated as sample weight after burning at 550 °C for 2 h. Moisture content was measured as sample weight-loss after oven-drying at 110 °C for 2 h. Carbohydrates were estimated as nitrogen-free Extract (N.F.E.). Apparent amylose content was estimated after iodine complexation, using the method of Morrison and Laignelet (1983). Amylopectin content was calculated by the difference of total starch minus amylose content. Total starch was determined using the enzymatic/colorimetric method of Tovar, Björck, and Asp (1990), as follows: pre-treatment with 2 M KOH, incubation with Termamyl for 15 min at boiling temperature, and digestion with amyloglucosidase at 60 °C for 30 min. Released glucose was quantified by a glucose oxidase/peroxidase colorimetric assay.

2.5. Functional properties

2.5.1. Differential scanning calorimetry (DSC)

Starch gelatinization was determined with a DSC-7 (Perkin–Elmer Corp., Norwalk, CT), using the technique described by Ruales and Nair (1993). The DSC device was calibrated with indium and the data analyzed using the Pyris software programme. Two milligrammes (d.b.) of starch were weighed into an aluminium pan and the moisture level adjusted to 70% by adding de-ionized water. The pan was then hermetically sealed and left to equilibrate for 1 h at room temperature. Samples were scanned at temperatures between 30 and 120 °C at a rate of 10 °C/min. Gelatinization temperature was determined by automatically computing initial temperature (T_i), maximum peak temperature (T_p), final temperature (T_f), and gelatinization enthalpy (ΔH) from the resulting thermogram.

2.5.2. Solubility, swelling power (SP) and water absorption capacity (WAC)

Solubility, water absorption and swelling power patterns at 60, 70, 80 and 90 °C were determined using a modified version of Sathe and Salunkhe's (1981) method. Briefly, 40 ml of a 1% starch suspension (w/v) was prepared in a previously tared, 50 ml centrifuge tube. A magnetic agitator was placed in the tube, and it was kept at a constant temperature (60, 70, 80 or 90 °C) in a water bath for 30 min. The suspension was then centrifuged at 2120*g* for 15 min, the supernatant decanted and the swollen granules weighed. From the supernatant, 10 ml were dried in an air convection oven (Imperial V) at 120 °C for 4 h in a crucible to constant weight. Percentage solubility and swelling power were calculated using the following formulas:

$$\% \text{ Solubility} = \text{dry weight at } 120\,^{\circ}\text{C} \times 400/\text{sample weight}$$

$$\text{Swelling Power} = \text{weight of swollen granules} \times 100/\text{sample weight} \times (100 - \% \text{ solubility})$$

Water absorption capacity was measured using the same conditions as above, but was expressed as weight of the gel formed per sample, divided by treated sample weight.

2.5.3. Retrogradation

Gudmundsson and Eliasson's (1996) trough differential scanning calorimetry (DSC) method was used. Samples were prepared in the same way as for gelatinization determination. Aluminium pans with starch paste samples were heated in an oven at 105 °C for 15 min and then stored at 4 °C for 1, 2, 3, 7 and 14 days. When removed from storage, the pans were left at room temperature for 2 h before analysis and then scanned at temperatures between 30 and 120 °C at a rate of 10 °C/min. An empty aluminium pan was used as a control.

2.5.4. Pasting properties

Pasting properties were evaluated by the method of Wiesenborn, Orr, Casper, and Tacke (1994), using a viscoamylograph (Brabender PT-100, Germany). Briefly, 400 ml of 8% (d.b.) starch suspension were heated to 95 °C at a rate of 1.5 °C/min, held at this temperature for 15 min, then cooled to 50 °C at the same rate and held at this second temperature for a further 15 min. The resulting amylograms were used to calculate maximum viscosity, consistency, breakdown and setback in Brabender Units (BU).

2.5.5. Starch gel clarity

Starch gel clarity was measured by the method of Bello-Pérez, Agama-Acevedo, Sánchez-Hernández, and Paredes-López (1999), determining transmittance of a 1% starch paste at 650 nm, using a spectrophotometer (Beckman DU-650, CA, USA). Starch suspensions (1%) in tubes with threaded caps were placed in a water bath at 100 °C for 30 min, agitated by vortexing every 5 min, and left to cool to room temperature. Percentage transmittance (%*T*) was determined in these suspensions.

2.5.6. Gel firmness

Gel firmness was evaluated according to a modified version of Hoover and Senanayake's (1995) method, using an Instron Universal Machine. Briefly, 400 ml of 8% (d.b.) starch suspension were heated to 95 °C at a rate of 1.5 °C/min in the Brabender viscoamylograph, held at this temperature for 10 min and the paste transferred in 40 ml portions into 50 ml beakers. These were allowed to cool to room temperature, covered with parafilm and stored at 4 °C for 24 h. The gels were then removed from the flasks, cut at a height of 3 cm and gel penetration measured with an Instron model 4411. Each gel was placed perpendicularly in the equipment and compressed at a speed of 1 mm/s using a 5-mm probe and a 5-kg cell.

2.5.7. Refrigeration and freezing stability

Stability under refrigeration and freezing conditions was evaluated using a modified version of Eliasson and Ryang's (1992) method. Pastes were prepared in a Brabender viscoamylograph. Briefly, 400 ml of 6% (d.b.) starch suspension were heated to 95 °C at a rate of 1.5 °C/min, held at this temperature for 15 min, then cooled to 50 °C at the same rate and held at this second temperature for a further 15 min. Portions of 50 ml were placed in centrifuge tubes, cooled to room temperature and stored at 4 °C and −10 °C, and then centrifuged at 8000*g* for 10 min in a J2-HS centrifuge (Beckman Instruments, Inc. CA, USA). The water separating from the starch gels during 1, 2, 3, 4 and 5 days was measured.

All the physicochemical and functional properties were measured in triplicate and cassava (*M. esculenta*) starch was included for comparison.

2.6. Statistical evaluation

All physicochemical determinations were done in triplicate. A statistical study was done to determine the data's central tendency and deviation. An analysis of variance with a significance level of 5% was done and Duncan's test applied to determine differences between means using the Statgraphics plus 5.1 computer software.

3. Results and discussion

3.1. Granule size and microscopic appearance

Photographic images of the makal (*X. yucatanensis*) starch granules (Fig. 1) showed them to be spherical–oval, similar in shape to potato starch granules but different from cassava (Swinkels, 1985). Makal starch granules had an average size of 12.4 μm, which is similar to that reported for tuber starches like those of cassava (12.9 μm) (Charles, Chang, Ko, Shiroth, & Huang, 2005)

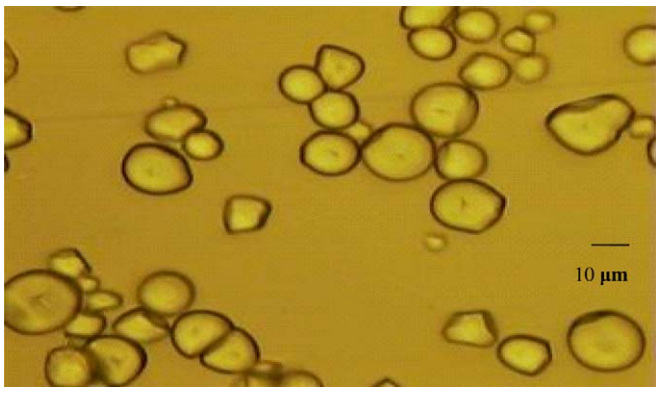

Fig. 1. Microphotograph of starch granules of makal (*Xanthosoma yucatanensis*).

and *Pachyrhizus ahipa* varieties (9.3–14.6 μm) (Forysth et al., 2002), but lower than that oval granules (type A) of potato (approximately 33 μm of major axis) (Swinkels, 1985). The makal starch granule diameter distribution indicated that 70% of the granules measured 16 μm (long axis) and 75% measured 12 μm (short axis).

3.2. Chemical composition

3.2.1. Proximate composition

The makal starch had low protein, fibre, fat and ash values, indicating that the makal starch produced in the present study was extremely pure. These values are similar to those of cassava starch (Moorthy, 2002), even though there is a statistical difference between them ($p < 0.5$) (Table 1). Because of its low (0.1%) protein content, makal starch can be used in the manufacture of high-glucose syrups as this protein level is lower than FDA protein content limits for corn starch (0.4%) used for this purpose. Total starch content in the makal starch was 97%, which is higher than that reported for different *P. ahipa* varieties (56–59%) and similar to those of potato (97%) and cassava starches (97%) (Bertolini, Creamer, Eppink, & Boland, 2005).

3.2.2. Amylose and amylopectin

Amylose content in the makal starch was 22.4% and amylopectin content was 77.6% (Table 1), which differ from those for corn starch (28.3% and 71.7%) (Betancur-Ancona et al., 2001), red sweet potato (34.2% and 65.9%) (Osundahunsi, Fagbemi, Kesselman, & Simón, 2003) and malanga (*Xanthosoma saggitifolium*) (24.0% and 76%) (Moorthy, 2002). Amylose and amylopectin contents, as well as protein and lipid contents (Charles et al., 2005), are determinant in certain structural and functional characteristics and thus dictate what can be added to a specific food to improve product characteristics and appearance.

3.3. Functional properties

3.3.1. Differential scanning calorimetry (DSC)

The makal starch had high gelatinization temperatures, with an initial granule gelatinization temperature (T_i) of 72.6 °C, a peak temperature (T_p) of 78.5 °C, and a final temperature (T_f) of 84.2 °C, all significantly different from cassava starch gelatinization temperatures (Table 2). These temperatures are higher than those reported for corn (62.3, 66.3 and 72.9 °C) (Betancur-Ancona et al., 2001), potato (60, 69 and 80 °C), cassava (62.4, 69.3 and 84.1 °C) (Pérez, Breene, & Bahnassey, 1998) and white sweet potato (66.7, 70.7 and 74.8 °C) (Osundahunsi et al., 2003) starches. More energy was required to gelatinize makal starch, as shown by its 15.0 J/g gelatinization enthalpy (ΔH), than that reported by Betancur-Ancona et al. (2001) for cassava (9.6 J/g) and corn (10.3 J/g), or by Pérez et al. (1998) for potato (4.6 J/g) and cassava (4.8 J/g) starches. However, it was similar to the ΔH reported for white sweet potato (10.5 J/g) (Osundahunsi et al., 2003). This confirms Szczodrak and Pomeranz's (1992) observations that lower gelatinization enthalpy values are linked to higher amylose levels, which they support with the high amylose values (49.3%) and low gelatinization enthalpy (10.2 J/g) of onion starch.

Makal starch normally requires higher temperatures to ensure complete gelatinization and pasting than do other starches. This makes it potentially useful in products in which delayed pasting is desired, such as in retorted canned foods.

3.3.2. Swelling power (SP), water absorption capacity (WAC) and solubility

Water absorption capacity (WAC), swelling power (SP) and solubility were directly correlated to increases in temperature. The makal starch water absorption (Fig. 2) and swelling power patterns (Fig. 3) show that its granules do not swell appreciably at temperatures bellow 70 °C. As

Table 1
Chemical composition of makal starch compared with other starches (%d.b.)

Components	Starches				
	Makal	Cassava	Corn[c]	Sweet potato red[d]	Malanga[e]
Moisture	8.9[a]	12.7[b]	10.9	4.8	12
Crude protein	0.1[b]	0.1[a]	0.1	5.6	NR
Lipids	1.0[a]	1.1[a]	0.4	2.3	0.4
Crude fibre	0.4[a]	1.7[b]	0.6	0.0	0.2
Ash	0.1[a]	0.3[b]	0.2	0.3	0.2
N.F.E.	98.4[a]	96.8[b]	98.9	87.0	99.2
Total starch	96.7[a]	94.6[a]	99.0	NR	NR
Amylose	22.4[b]	17.3[a]	28.3	34.2	24
Amylopectin	77.6[a]	82.7[b]	71.7	65.9	76

[a–b] Different letter superscripts in the same row indicate statistical difference ($P < 0.05$).
NR, not reported.
[c] Betancur-Ancona et al. (2001).
[d] Osundahunsi et al. (2003).
[e] Moorthy (2002).

Table 2
Differential scanning calorimetry of makal starch compared with other starches

Almidón	T_i (°C)	T_p (°C)	T_f (°C)	ΔH (J/g)
Makal	72.6[b]	78.5[b]	84.2[b]	15.0[b]
Cassava	57.6[a]	65.2[a]	75.4[a]	9.6[a]
Corn[c]	62.3	66.3	72.9	10.3
Potato[d]	60.0	69.0	80.0	4.6
Cassava[d]	62.4	69.3	84.1	4.8
Cocoyam[d]	74.0	78.0	87.0	3.9
Malanga[e]	66.0	69.9	81.8	12.9
Sweet potato white[f]	66.7	70.7	74.8	10.5
Sweet potato red[f]	67.2	71.5	75.7	11.0

[a–b] Different letter superscripts in the same column indicate statistical difference ($P < 0.05$).
[c] Betancur-Ancona et al. (2001).
[d] Pérez et al. (1998).
[e] Moorthy (2002).
[f] Osundahunsi et al. (2003).

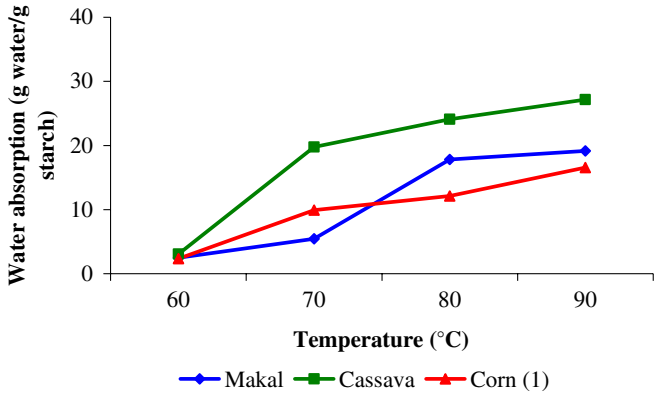

Fig. 2. Water absorption of makal, cassava and corn starches.

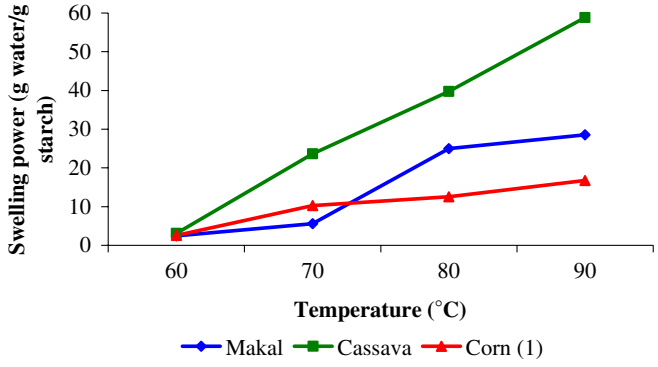

Fig. 3. Swelling power of makal, cassava and corn starches.

the temperature increase above 70 °C, they swell rapidly. Between 80 and 90 °C, the swelling of makal starch is between those of cassava starch and corn starch, reaching 28.6 g water/g starch at 90 °C, as compared to 58.8 g water/g starch for cassava starch and 16.76 g water/g starch for corn starch (Betancur-Ancona et al., 2001). The observed makal starch swelling power values result from its high amylopectin content (77.6%), as shown in its highly ramified structure, indicated for the hydrodynamic radius ($R_H = 61.7$ nm) (Torruco-Uco, 2004). This pattern is similar to that reported by Sasaki and Matsuki (1998) in which swelling power is positively related to starch granule diameter and distribution, but negatively related to gelatinization temperature, amylopectin chain length and amylose content.

Gujska, Reinhard, and Khan (1994) report a notable increase in solubility for pinto bean, navy bean and field pea starches, beginning at 70 °C, because the swollen starch granules allow amylose exudation. This is similar to the behaviour of makal starch (Fig. 4), which is associated with its high gelatinization temperature, but differs from the rise in corn starch solubility beginning at 60 °C. Makal starch solubility also rises with temperature, reaching 32.8% at 90 °C, which is lower than that for cassava (53.8%) but higher than that for corn (15.8%) at the same temperature (Betancur-Ancona et al., 2001).

3.3.3. Retrogradation

Refrigerated storage of the makal starch pastes formed associated structures with melting temperatures in the range 55.5–59.9 °C (Table 3). Retrogradation clearly began during the first day of storage at 4 °C ($\Delta H = 6.3$ J/g) and increased slowly until day 14 (16.7 J/g).

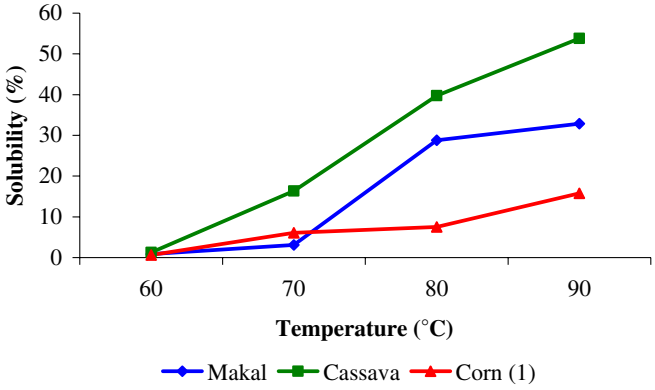

Fig. 4. Solubility (%) of makal, cassava and corn starches.

Table 3
Kinetics of retrogradation of makal starch, compared with other starches

Days	Makal	
	T_p (°C)	ΔH (J/g)
1	59.9	6.3
2	58.2	13.2
3	56.5	14.9
7	55.5	14.5
14	57.9	16.2

[a–d] Different superscripts in the same column indicate statistical difference ($P < 0.05$).

In a study of corn and amaranth starches and amylopectins, Bello-Pérez (1995) found that the slow association of amylopectin side chains is important in the overall retrogradation process.

3.3.4. Pasting properties

Pasting properties are influenced by a number of factors, including: granule size, amylose/amylopectin ratio, starch molecular characteristics, and the conditions of the thermal processes used to induce gelatinization (Zhou, Robards, Glennie-Holmes, & Helliwell, 1998). The pasting and paste profiles of makal starch are similar to those of corn starch (Fig. 5). The breakdown value for a makal starch paste is almost zero (−8 BU), which is not the case for cassava (306 BU) or corn (22 BU) starches (Table 4). This starch also had consistency (180 BU) and setback (172 BU) values that are lower than those for corn starch (282 and 304 BU) (Betancur-Ancona et al., 2001), suggesting high paste stability in mechanical processes, as is the case with red and white sweet potato starches (Osundahunsi et al., 2003).

The consistency of the makal starch in heating and cooling processes, measured with continuous shearing force, makes it potentially useful in products requiring sterilization, such as sauces and baby food. The pasting properties indicate that its thickening property is stable in cooking processes. However, its viscosity increased when the paste was cooled, meaning it is not stable in the cooling process, which is important to consider when incorporating this starch into a product.

Table 4
Paste properties of makal, cassava and corn starches

Parameters	Starch		
	Makal	Cassava	Corn[d]
Gelatinization initial temperature (°C)	75	69	80
Peak viscosity (BU)	280	469	252
Viscosity at 95 °C (BU)	288	281	244
Peak viscosity temperature (°C)	84	95	92
Viscosity at 95 °C for 15 min (BU)	288	163	230
Viscosity at 50 °C (BU)	460	231	534
Viscosity at 50 °C for 15 min (BU)	520	238	520
Breakdown (BU)[a]	−8	306	22
Consistency (BU)[b]	180	75	282
Setback (BU)[c]	172	−231	304

BU, Brabender Units.
[a] Breakdown: peak viscosity (BU) – viscosity at 95 °C for 15 min (BU).
[b] Consistency: viscosity at 50 °C (BU) – peak viscosity (BU).
[c] Setback: viscosity at 50 °C (BU) – viscosity at 95 °C for 15 min (BU).
[d] Betancur-Ancona et al. (2001).

3.3.5. Starch gel clarity and firmness

Makal starch transmittance (%T) values (36.8%) showed it to be more translucent than commercial corn starch (22.4%) (Betancur-Ancona et al., 2001) and but significantly less than cassava starch (51.8%) (Table 5). Hoover, Sailaja, and Sosulski (1996), comment that starch paste

Table 5
Clarity (%T), and gel firmness of makal and cassava starches

Starch	% Transmitance at 650 nm	Deformation (%)	Load max (kgf)
Makal	36.8[a]	20.8[a]	0.03[b]
Cassava	51.8[b]	36.2[b]	0.01[a]

[a–b] Different superscripts in the same column indicate statistical difference ($p < 0.05$).

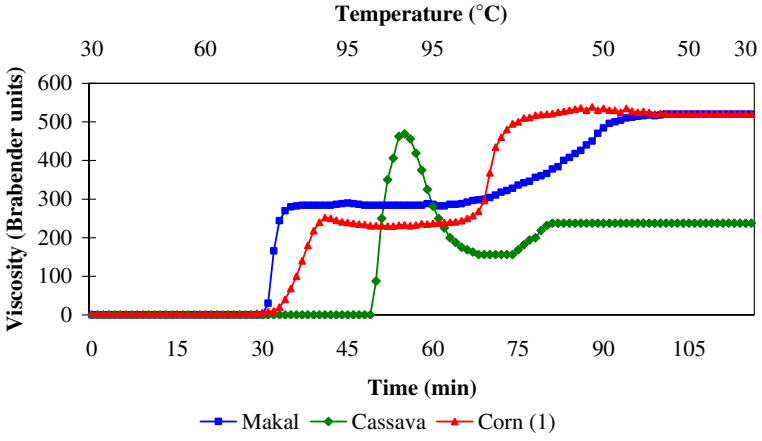

Fig. 5. Viscoamylogram of makal, cassava and corn starches.

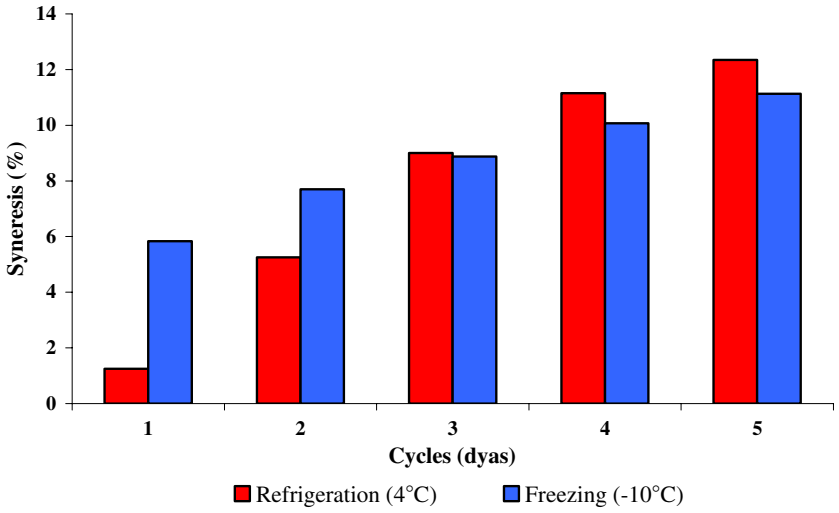

Fig. 6. Refrigeration (4 °C) and freezing (−10 °C) stabilities of makal starch.

degree of transmittance is directly affected by degree of swelling. This coincides with the present results in that the makal starch had greater swelling power and consequent higher clarity in its paste, than had corn starch. The makal starch paste's higher transmittance is probably because its amylose contents have greater clarity (Swinkels, 1985).

Clarity is a key parameter in starch paste quality because it gives shine and opacity to product colour. The makal starch's excellent clarity makes it potentially useful in products such as fruit pie fillings and candies.

The deformation (20.8%) and maximum load (0.03 kgf) values of makal starch (Table 5), both associated with gel firmness, were statistically different ($P < 0.05$) and slightly higher than those for cassava (36.2%, 0.01 kgf). Wang and White (1994) conclude that increases in gel firmness are generally associated with increases in amylose and amylopectin molecule re-crystallization, which agrees with the higher retrogradation and firmer gels of makal starch observed in the present study. Zhou et al. (1998) report that, during cooling, amylose is the main component in producing the dense network structure that gives gels their firmness.

3.3.6. Refrigeration and freezing stability

Makal starch had high syneresis, and therefore low stability, in refrigeration and freezing cycles (Fig. 6). The amount of water separated from the gels during freezing increased with storage time. Baker and Rayas-Duarte (1998) have reported this behaviour for corn starches, mentioning low freezing–thawing gel stability for corn and amaranth starches. Likewise, Bello-Pérez et al. (1999) found low gel stability in these same processes for plantain and banana starches. Makal starch's low gel stability under these conditions suggests it is not adequate for use in food systems involving refrigeration or freezing processes.

4. Conclusions

The physicochemical and functional properties of starch from the tuber makal (*X. yucatanensis*), a non-conventional source, suggest that it may have broad possibilities as an ingredient in food systems and other industrial applications. Makal starch granule size was 12.4 μm, meaning that it may be highly digestible. Its low protein content (0.1%) would make it useful in the manufacture of high-glucose syrups. This starch's high gelatinization temperature (78.5 °C), together with its water absorption (19.2 g water/g starch), swelling power (28.6 g water/g starch) and solubility (32.9%) values make it potentially useful in products subject to high temperatures, such as canned goods, baby food, sauces, bread products, jellies, candies and sausages. However, its high firmness and syneresis (i.e. low stability) under refrigeration and freezing conditions make it inadequate for use as a thickener, stabilizer and gelling agent in refrigerated or frozen foods.

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