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# Functional properties of square banana (*Musa balbisiana*) starch

Lázaro de la Torre-Gutiérrez, Luis A. Chel-Guerrero, David Betancur-Ancona *

*Facultad de Ingeniería Química, Universidad Autónoma de Yucatán, Av. Juárez No. 421, Cd. Industrial, C.P. 1288, Apdo. Postal 26, Suc. Las Fuentes, Mérida, Yucatán, Mexico*

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**Abstract**

Starch was isolated from unripe square banana (*Musa balbisiana*) fruit and its functional properties were determined. Square banana starch peak gelatinisation temperature was 79.8 °C and the transition enthalpy was 17.3 J/g. At 90 °C, the solubility was 16.8%, the swelling power was 17.1 g water/g starch and the water absorption capacity was 14.3 g water/g starch. The paste properties were: temperature, 81 °C; maximum viscosity, 326 BU; breakdown, 22 BU; setback, 40 BU and consistency, 18 BU. The clarity, expressed as transmittance, was 17.5%, and gel deformation was 32.4% with a 0.03 kgf maximum load. This starch had high syneresis and low stability in refrigeration and freezing cycles. Given its properties, square banana starch has potential applications in food systems requiring high temperature processing, such as jellies, sausages, bakery and canned products. It is inappropriate, however, for use in refrigerated or frozen foods.


*Keywords:* Banana; *Musa balbisiana*; Starch; Functional properties

## 1. Introduction

Banana production in tropical countries is an important economic activity. The banana belongs to the family *Musaceae* and there are probably over 30 well-known species within the genus *Musa* and more than 700 varieties (Lehman, Jacobasch, & Schmiedl, 2002). Originally from Southeast Asia, it is also widely cultivated in Africa, India and Latin America. Banana grows well in a temperature range of 25–30 °C but can tolerate temperatures as low as 15 °C and as high as 35 °C (Crane & Balerdi, 1998). The widely cultivated fruit banana *Musa sapientum* and the starch banana *Musa paradisiaca*, also called plantain, descend from two wild ancestors, *Musa acuminata* Colla and *Musa balbisiana* Colla. Unripe banana fruits have a higher starch concentration than ripe fruit, and this starch degrades to a relatively small monosaccharide (Stover & Simmonds, 1987).

Starch is an important naturally occurring polymer with diverse applications in food and polymer science. Annual worldwide starch production is 66.5 million tons (FAOSTAT, 2002) and the modern food industry's growing demand for starches has created interest in identifying new sources of this polysaccharide (Betancur-Ancona, Gallegos-Tintoré, & Chel-Guerrero, 2004). Starch accounts for a significant fraction of a large range of crops. Cereals (e.g. corn, wheat, rice, oat, barley) contain from 60% to 80% of this carbohydrate, legumes (e.g. chickpea, bean, pea) from 25% to 50%, tubers (e.g. potato, cassava, cocoyam, arrowroot) from 60% to 90% and some green or immature fruit (e.g. banana, mango) contain as much as 70% in dry base (Bello-Pérez, Agama-Acevedo, Sánchez-Hernández, & Paredes-López, 1999; Thomas & Atwell, 1999).

Corn is commonly used for starch isolation in the United States but in Mexico it is primarily used in food applications (e.g. tortillas). Isolating starch from corn in Mexico is impractical because national production is insufficient to meet human consumption needs. Clearly, alternative starch

* Corresponding author. Tel.: +52 999 9460989; fax: +52 999 9460994.
*E-mail address:* bancona@uady.mx (D. Betancur-Ancona).

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sources are needed (Flores-Gorosquera et al., 2004) from outside the standard range of cereal grains (e.g. corn, wheat, rice) and tubers (e.g. potato, cassava) (Betancur-Ancona, Chel-Guerrero, Camelo-Matos, & Dávila-Ortiz, 2001). Fruits such as banana and mango are promising new starch sources since they already form part of the worldwide food system. Current starch research has focused on the search for non-conventional starch sources with diverse physicochemical, structural and functional characteristics that provide them with a broad range of potential industrial uses.

Physicochemical (e.g. gelatinisation and retrogradation) and functional (e.g. solubility, swelling, water absorption, syneresis and rheological behaviour of pastes and gels) properties must be identified before determining the potential uses of starches in food systems and other industrial applications (Wang & White, 1994). A fundamental characteristic of native starches from different vegetables sources is that their granule size distribution and molecular structures influence their physicochemical and functional properties. These properties (e.g. thickening power) then influence a starch's usefulness in food and industrial applications.

In an effort to generate data useful in developing possible applications for banana starch, the study objective was to determine the functional properties of starch isolated from square banana (*M. balbisiana*) in comparison to corn starch.

## 2. Materials and methods

### 2.1. Fruit and chemicals

Unripe square banana (*M. balbisiana* Colla) fruits were obtained from the March 2003 harvest in the state of Tabasco, Mexico. All chemicals were reagent grade and purchased from J.T. Baker (Phillipsburg, NJ).

### 2.2. Starch isolation

Unripe fruits were peeled, cut into 2 $cm^3$ cubes and dried in a convection oven at 60 °C for 24 h. The dried cubes were milled in a Cyclotec (Tecator, Sweden) mill and sifted through 80-mesh screen to produce a flour. The starch was isolated using a modified version of Bello-Pérez et al. (1999) method. Briefly, 1 kg of banana flour was suspended in a sodium bisulfite solution (1500 ppm $SO_2$) at 1:5 (w/v) and the suspension left to soak under constant agitation for 1 h. The suspension was screened through 80-mesh to separate the fiber-containing solid fraction from the starch-containing liquid fraction. The liquid fraction was left to precipitate for 4 h and the supernatant removed with a siphon. The remaining liquid was washed three times by re-suspension in distilled water and the starch recovered after the final wash by centrifuging at 1100*g* for 12 min in a Mistral 3000i centrifuge. After isolation the starch was dried at 60 °C in a convection oven for 2 h. It was then weighed, milled in a Cyclotec (Tecator, Sweden) mill, sifted through a 100-mesh screen and stored at room temperature in sealed containers until processed for the physicochemical characterisation.

### 2.3. Functional Properties

#### 2.3.1. Differential scanning calorimetry (DSC)

Starch gelatinisation was determined with a DSC-7 (Perkin–Elmer Corp., Norwalk, CT), using the technique described by Ruales and Nair (1994). The DSC equipment was calibrated with indium and the data analysed using the Pyris software program. Two milligrams (d.b.) of starch were weighed into an aluminum pan and moisture level adjusted to 70% by adding de-ionised water. The pan was then hermetically sealed and left to equilibrate for 1 h at room temperature. Samples were scanned at temperatures between 30 °C and 120 °C at a rate of 10 °C/min. Gelatinisation temperature was determined by automatically computing initial temperature ($T_i$), maximum peak temperature ($T_p$), final temperature ($T_f$), and gelatinisation enthalpy ($\Delta H$) from the resulting thermogram.

#### 2.3.2. 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 (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 put in the tube, which was placed in a water bath for 30 min at a constant temperature (60, 70, 80 or 90 °C). The suspension was then centrifuged at 2120 g for 15 min, the supernatant decanted and the swollen granules weighed. A 10 ml sample was taken from the supernatant, placed in a crucible and dried in an air convection oven (Imperial V) at 120 °C for 4 h to constant weight. Percentage solubility and swelling power were calculated using the 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 expressed as weight of the gel formed per sample, divided by treated sample weight.

#### 2.3.3. Retrogradation

The differential scanning calorimetry (DSC) method was used (Gudmundsson & Eliasson, 1992). Samples were prepared in the same way as for gelatinisation determination. Aluminum 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, 14 and 21 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 aluminum pan was used as a control.

#### 2.3.4. Pasting properties

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

#### 2.3.5. Starch gel clarity

Starch gel clarity was measured using the method of Bello-Pérez et al. (1999). 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 of transmittance (%$T$) was determined from these suspensions at 650 nm using a spectrophotometer (Beckman DU-650, CA, USA).

#### 2.3.6. 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 was heated to 95 °C at a rate of 1.5 °C/min in the Brabender viscoamylograph, held at this temperature for 10 min and 40 mL lots of paste transferred to 50 mL Erlenmeyer flasks. 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 device and compressed at a speed of 1 mm/sec using a 5 mm probe and a 5 kg cell.

#### 2.3.7. 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 was 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 another 15 min. Portions of 50 mL were placed in centrifuge tubes, cooling down to room temperature and stored at 4 °C and −10 °C. These were centrifuged at 8000$g$ for 10 min in a J2-HS centrifuge (Beckman Instruments, Inc. CA, USA) and measurements taken of water separation from the starch gels at 1, 2, 3, 4 and 5 days.

All physicochemical and functional property determinations were done in triplicate and commercial corn (*Zea mays*) starch (Maizena™) was used for comparison.

### 2.4. Statistical evaluation

The central tendency and deviation of the results were determined with statistical analysis. A Student $t$ statistic with a 5% significance level was applied to compare the differences between means of the square banana and corn starch functional properties using the Statgraphics plus 5.1computer software.

## 3. Results and discussion

### 3.1. Differential scanning calorimetry (DSC)

The square banana starch had high gelatinisation temperatures, with an initial granule gelatinisation temperature ($T_i$) of 71.6 °C, a peak temperature ($T_p$) of 78.9 °C and a final temperature ($T_f$) of 89.9 °C, all significantly different ($P < 0.05$) from the corn starch gelatinisation temperatures (Table 1). 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) (Pérez, Breene, & Bahnassey, 1998), "macho" variety banana (69.6, 74.5 and 81.6 °C) and "criollo" variety banana starches (71.4, 75.0 and 80.4 °C) (Bello-Pérez, Sáyago, Villagomez, & Montiel, 2000). Square banana starch required higher temperatures to ensure complete gelatinisation and pasting than is common for other starches. This makes it potentially useful in products in which delayed pasting is desired, such as retorted canned foods.

The square banana starch required more energy to gelatinise (17.3 J/g gelatinisation enthalpy ($\Delta H$)) than "criollo" banana starch (14.8 J/g) (Bello-Pérez et al., 1999), mango starch (13.2 J/g) (Kaur, Narpinder, Kawaljit, & Harmeet, 2004), corn starch (10.3 J/g) (Betancur-Ancona et al., 2001) or potato starch (4.6 J/g) (Pérez et al., 1998). Square banana starch $\Delta H$ was lower, however, than that of "macho" banana starch (18.3 J/g) (Torruco-Uco, 2004). This confirms the observations of Yuan, Thompson, and Boyer (1993) that lower gelatinisation enthalpy values are linked to higher amylose levels in the starches of different corn genotypes, which they support with the high amylose

Table 1
Differential scanning calorimetry (DSC) of square banana (*Musa balbisiana*) starch, compared to other starches

| Starch | $T_i$ (°C) | $T_p$ (°C) | $T_f$ (°C) | $\Delta H$ (J/g) |
|---|---|---|---|---|
| Square banana | 71.6[a] | 79.8[a] | 89.9[a] | 17.3[a] |
| Corn | 62.3[b] | 66.3[b] | 72.9[b] | 10.3[b] |
| "Criollo" banana[c] | 71.4 | 75.0 | 80.4 | 14.8 |
| "Macho" banana[c] | 69.6 | 74.5 | 81.6 | 13.0 |
| "Chausa" mango[d] | 76.4 | 80.2 | 85.7 | 13.2 |
| Potato[e] | 60.0 | 69.0 | 80.0 | 4.6 |

[a,b] Different letter superscripts in the same column indicate statistical difference ($P < 0.05$).
[c] Bello-Pérez et al. (2000).
[d] Kaur et al. (2004).
[e] Pérez et al. (1998).

(49.3%) and low gelatinisation enthalpy (10.2 J/g) values of onion starch (Szczodrak & Pomeranz, 1992).

### 3.2. Water absorption capacity (WAC), swelling power (SP), and solubility

Water absorption capacity (WAC), swelling power (SP) and solubility were directly correlated to increases in temperature. The square banana starch WAC (Fig. 1) and SP patterns (Fig. 2) show that its granules did not swell appreciably at temperatures below 70 °C. At temperatures above 70 °C, they swelled rapidly due to the breaking of intermolecular hydrogen bonds in amorphous areas that allows irreversible and progressive water absorption, as reported by Bello-Pérez et al. (1999) for "macho" banana starch.

Between 70 and 90 °C, square banana starch SP (17.1 g water/g starch at 90 °C) was lower than that of "macho" banana starch but slightly higher than that of cassava starch (16.6 g water/g starch) and corn starch (16.8 g water/g starch) (Betancur-Ancona et al., 2001). The square banana starch SP values resulted from its high amylopectin content (77.8%), as manifested in its highly ramified structure. It may also have been caused by its granule size heterogeneity, as shown in its wide granule diameter range (8–68 μm) (De la Torre-Gutiérrez, 2004). This pattern is similar to that reported by Sasaki and Matsuki (1998) in which swelling power is positively correlated to starch granule diameter and distribution but negatively correlated to gelatinisation temperature, amylopectin chain length and amylose content.

Square banana starch solubility began to increase at 70 °C (Fig. 3). This was associated with its high gelatinisation temperature and is the result of the swollen starch granules allowing amylose exudation. "Macho" banana starch exhibits similar behaviour (Bello-Pérez, Contreras, Romero, Solorza-Feria, & Jiménez-Aparicio, 2002) but corn starch differs since its solubility rises beginning at 60 °C. Square banana starch solubility also increased with temperature, reaching 16.8% at 90 °C. At this temperature, "macho" banana starch has higher solubility (17.48%) (Bello-Pérez et al., 2002) but corn starch has lower solubility (15.8%) (Betancur-Ancona et al., 2001). The solubility of square banana starch would provide better aqueous starch dispersion in food applications, as well as higher water absorption and retention.

### 3.3. Retrogradation

Refrigerated storage (4 °C) of the square banana starch pastes resulted in formation of associated structures with melting temperatures between 59.6 and 60.8 °C (Table 2). Retrogradation clearly began during the first day of storage ($\Delta H = 5.2$ J/g) and increased gradually until day 21 (9.5 J/g). Square banana starch enthalpy values were higher than those of corn starch (2.1–3 J/g) (Bello-Pérez, 1995).

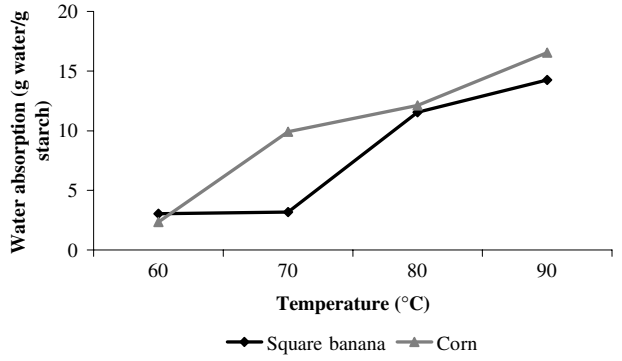


Fig. 1. Water absorption of square banana (*Musa balbisiana*) and corn (*Zea mays*) starches.

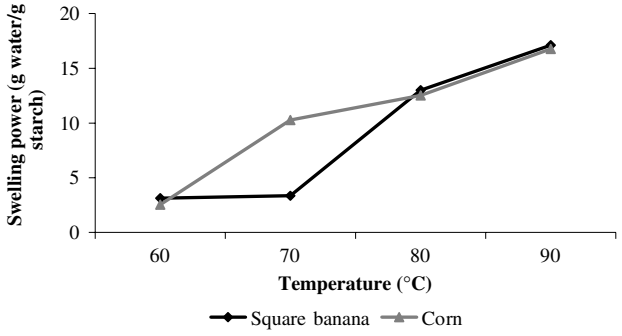


Fig. 2. Swelling power of square banana (*Musa balbisiana*) and corn (*Zea mays*) starches.

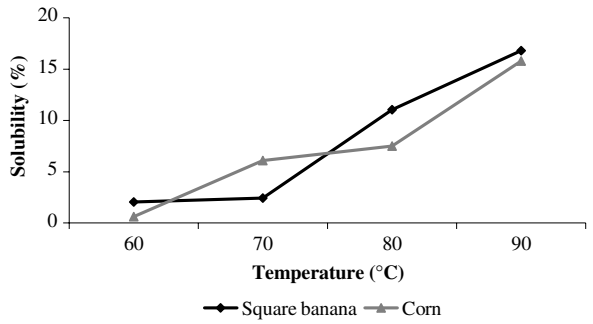


Fig. 3. Solubility (%) of square banana (*Musa balbisiana*) and corn (*Zea mays*) starches.

Table 2
Retrogradation kinetic of square banana (*Musa balbisiana*) starch

| Days | Square banana | |
|---|---|---|
| | $T_p$ (°C) | $\Delta H$ (J/g) |
| 1 | 59.6[a] | 5.2[a] |
| 2 | 59.7[a] | 8.2[b] |
| 3 | 60.2[a,b] | 8.5[b] |
| 7 | 60.8[b] | 8.5[b] |
| 14 | 60.3[a,b] | 8.7[b] |
| 21 | 60.0[a,b] | 9.5[c] |

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

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

### 3.4. Pasting properties

Pasting properties are influenced by granule size, the amylose/amylopectin ratio, starch molecular characteristics and the conditions of the thermal processes used to induce gelatinisation (Zhou, Robards, Glennie-Holmes, & Helliwell, 1998). The square banana starch paste profiles differed from those of corn starch. Corn starch exhibited a classic amylogram curve but the square banana starch did not develop a well-defined maximum viscosity peak and its value was higher (Fig. 4, Table 3). The breakdown value was the same for the square banana and corn starch pastes (22 BU) but the square banana starch had lower consistency (18 BU) and setback (40 BU) values than did corn starch (282 and 304 BU, respectively) (Betancur-Ancona et al., 2001). These low values suggest that square banana starch would have high paste stability in mechanical processes, as is the case with red and white sweet potato starches (Osundahunsi, Fagbemi, Kesselman, & Simón, 2003).

The consistency of square banana starch in heating and cooling process, measured with continuous shearing force, makes it potentially useful in products requiring sterilisation, such as sauces and baby food. Its pasting properties indicate that it remains stable in cooking processes, but its viscosity increased when cooled, indicating that it is not stable in cooling processes. These are vital aspects to consider when incorporating this starch into a food production process.

#### 3.4.1. Starch gel clarity and firmness

The square banana starch transmittance (%*T*) (i.e. clarity) value (17.5%) showed it to be less translucent than commercial corn starch (22.4%) (Betancur-Ancona et al., 2001) but more translucent than "macho" banana starch (14.3%) (Table 4). Hoover, Sailaja, and Sosulski (1996) reported that degree of transmittance is directly affected by degree of water absorption capacity. This coincides with the present results in that the square banana starch had a lower water absorption capacity, as well as lower paste clarity, than corn starch.

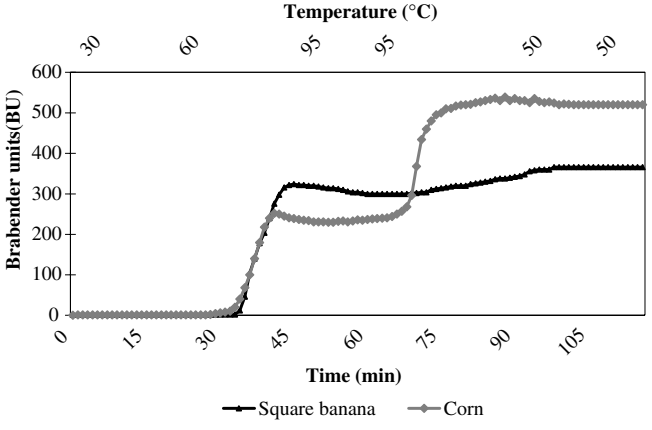


Fig. 4. Viscoamylogram of square banana (*Musa balbisiana*) and corn (*Zea mays*) starches.

Table 3
Paste properties of square banana (*Musa balbisiana*) and corn (*Zea mays*) starches

| Parameters | Starch | |
|---|---|---|
| | Square banana | Corn |
| Initial gelatinization temperature (°C) | 81 | 80 |
| Peak viscosity (BU) | 326 | 252 |
| Viscosity at 95 °C (BU) | 320 | 244 |
| Peak viscosity temperature (°C) | 95 | 92 |
| Viscosity at 95 °C for 15 min (BU) | 304 | 230 |
| Viscosity at 50 °C (BU) | 344 | 534 |
| Viscosity at 50 °C for 15 min (BU) | 366 | 520 |
| Breakdown (BU)[a] | 22 | 22 |
| Consistency (BU)[b] | 18 | 282 |
| Setback (BU)[c] | 40 | 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).

The square banana starch paste presented moderate transmittance values. Considering that paste clarity is a quality characteristic because it gives shine and opacity to product colour, square banana starch could be used in food systems that do not require transparency, such as fillers for cakes, seasonings, and salads.

Square banana starch deformation (32.48%) and maximum load (0.03 kgf) values (Table 4), both of which are associated with gel firmness, were different from those of "macho" banana starch (38.5%, 0.02 kgf). Wang and White (1994) stated that increases in gel firmness are generally associated with increases in amylose and amylopectin molecule re-crystallisation, which agrees with the higher retrogradation and firmer gels of square banana starch observed here. Amylose is the main component involved in production of the dense network structure that gives gels their firmness during the cooling process (Zhou et al., 1998). Given the gel firmness and elasticity of square banana starch, it could be incorporated into food systems such as jellies, marmalades, breads and sausages.

Table 4
Clarity (%*T*) and gel firmness of square and "macho" banana starches

| Starch | % Transmittance at 650 nm | Deformation (%) | Load max (kgf) |
|---|---|---|---|
| Square banana | 17.5[a] | 32.4[a] | 0.03[a] |
| "Macho" banana[c] | 14.3[b] | 38.5[b] | 0.02[b] |

[a,b] Different letter superscripts in the same column indicate statistical difference ($P < 0.05$).
[c] Torruco-Uco (2004).

### 3.5. Refrigeration and freezing stability

Square banana starch had higher syneresis and therefore lower stability in refrigeration, than did corn starch (Fig. 5). This confirms the square banana starch retrogradation pattern results. High syneresis is not seen as beneficial in the food industry, since starches with this property readily absorb and eliminate water, like a sponge. In contrast, less water separated from the square banana starch gels than from corn starch gels in freezing cycles (Fig. 6), although the amount of water separated from the gels during freezing increased over time. This is probably due to a redistribution and dilution of the starch paste produced by ice crystal growth-breakup Soni, Sharma, Srivasta, and Gharia, 1990, in which retained water was expelled from the inter- and intra-molecular associations, resulting in separate phases: a polymer-rich gel and a polymer-poor liquid. Baker and Rayas-Duarte (1998) have reported this behaviour in corn starches and stated that corn and amaranth starches have low freezing–thawing gel stability. Bello-Pérez et al. (1999) also reported low freezing–thawing gel stability, but for plantain and banana starches. The low freezing–thawing gel stability of square banana starch indicates it is not appropriate for use in food systems involving refrigeration or freezing processes.

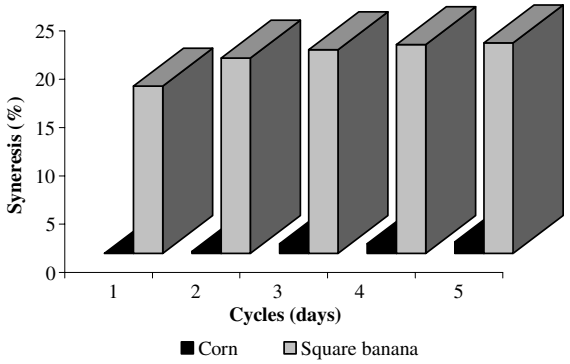


Fig. 5. Refrigeration (4 °C) stabilities of square banana (*Musa balbisiana*) and corn (*Zea mays*) starches.

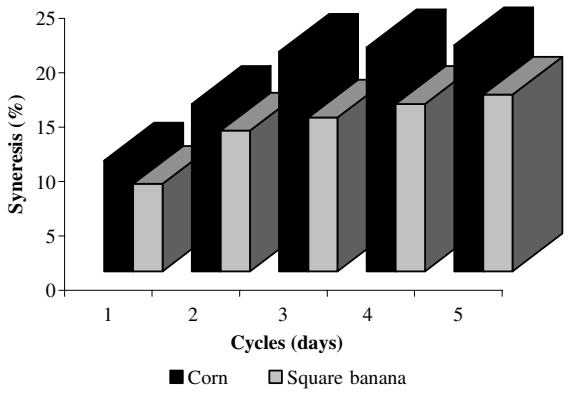


Fig. 6. Freezing (−10 °C) stabilities of square banana (*Musa balbisiana*) and corn (*Zea mays*) starches.

## 4. Conclusions

The functional properties of starch from unripe square banana (*M. balbisiana*) fruit, a non-conventional source, suggest it may have numerous possible uses as an ingredient in food systems and other industrial applications. This starch's high gelatinisation temperature (79.8 °C) together with its water absorption (14.3 g water/g starch), swelling power (17.1 g water/g starch) and solubility (16.8%) 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, stabiliser or gelling agent in refrigerated or frozen foods.

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