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Banana starch structure and digestibility

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ABSTRACT

It is well known that raw banana starch is a good source of resistant starch. Less is known, however, regarding the digestion property of gelatinized banana starch. In this study, banana starch cooked for 20 min in excess water had a significant fraction of slowly digestible starch (19%), as well as resistant fraction (27%). Amylopectin is thought to be responsible for its slow digestion property, since banana starch studied here has a relatively low amylose content of 11.2%. Chain-length distribution analysis revealed that banana amylopectin has a significantly different structure from corn or potato amylopectin in that it has a higher proportion of very long chains. Retrogradation studies support the view that banana starch retrogrades at a substantially faster rate than corn or potato starch leading to less digestible cooked starch. Additionally, banana starch has unique pasting properties making it behave like a chemically lightly cross-linked starch. Banana starch is unique, both nutritionally and functionally, to warrant further investigation on potential commercial uses.

1. Introduction

Digestibility of raw native starches has been attributed to the interplay of many factors, such as starch source, granule size, amylose to amylopectin ratio, extent of molecular association between starch components, the type and degree of crystallinity, amylose chain length, amylopectin fine structures, and presence of amylose–lipid complexes (Cummings & Englyst, 1995; Han & Hamaker, 2001). Morphology and ultra structure, such as the specific area, channels and porosity of granules should also be considered (Colonna, Leloup, & Buleon, 1992; Gallant, Bouchet, Buleon, & Perez, 1992; Huber & BeMiller, 1997).

Nutritionally, starch digestion is divided into rapidly digestible (RDS), slowly digestible (SDS), and resistant starch (RS) fractions. Human studies have shown that the RDS fraction compares well with glycemic index that is purported to increase the likelihood impact diabetes/pre-diabetes, cardiovascular disease indices, and obesity (Ludwig, 2000). SDS provides slow glucose release over the course of the small intestines that may affect activity level and mental alertness. RS is classified as fiber sometimes and is fermented to produce high levels of butyrate that is beneficial for colonic health.

Native raw banana starch appeared to be highly resistant to hydrolysis by enzymes (Zhang, Whistler, BeMiller, & Hamaker, 2005). Englyst and Cummings (1986) found that up to 78% of ingested α-glucans from raw banana starch escaped digestion in the small intestine of ileostomates. Starch fractions in raw banana flour (total starch content 75%) were reported to be RDS 3%, SDS 15%, and RS 57% (Englyst, Kingman, & Cummings, 1992). Microscopic observations revealed that raw banana flour contained irregularly shaped starch granules with smooth surfaces. A smooth and dense surface of native banana starch granules could partially account for their resistance. It is likely, as indicated by scanning and transmission electron microscope studies (Gallant et al., 1992), that the starch granule has an external thick layer (several μm) of larger blocklets that impede enzyme action and reduce the rate of hydrolysis. Perhaps the density of such blocklets is higher at the periphery of banana starch granules. In addition, some residual cell walls present in banana flour may have entrapped starch granules, thereby protecting them from enzymic attack (Faisant et al., 1995; Tester & Karkalas, 2002). It is likely that both intrinsic resistance and encapsulation of starch granules are responsible for the low digestibility of raw banana starch and flour.

Starches, as ingredients, have much larger markets in cooked processed products opposed to as in the uncooked form. After cooking, the easily digestible/hydrolyzable starch fraction of banana starch was only 47% of the total, comparable to that of a known low-digestible cooked yam starch (40%) (Cerning-Beroard & Le Dividich, 1976). Digestion performance of cooked banana starch would be of importance to the food industry, since the

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consumption of cooked starch in human food is much more common than that of raw starch, so the influence of cooking on rate and degree of banana starch digestion needs to be further investigated. Recently banana starch was added to spaghetti and the starch digestibility was assessed in the cooked samples. This study showed that the addition of banana starch improved the level of healthy RS and could have great potential for commercial acceptability as a functional food (Hernández-Nava et al., 2009). Ovando-Martinez, Sayago-Ayerdi, Agama-Acevedo, Goni, and Bello-Perez (2009) prepared pasta from unripe banana flour to increase indigestible carbohydrates. Digestion properties of cooked banana starch gave an indication that it may have a comparative long digestion characteristic. If banana starch is slowly digestible, such starch could be used in formulation of starch-based processed foods for low glycemic indices and extended energy release characteristics. The value of banana starch, if any, will be superior properties for specific niche applications since no starch competes economically with native and modified corn starches at this time.

The structure–function relationships of starches have been shown to be of great importance to food industry. The knowledge of the molecular structures can differentiate and define starch products and control important properties, such as digestibility, solution stability, viscosity, gel strength, water adsorption, and shelf-life, etc. In this study digestibility of cooked banana starch and flour were examined among with some common food starches. Moreover, banana amylopectin fine structure, retrogradation mechanism, and the pasting properties were studied to investigate at the molecular level to gain an understanding of structure–function relationships.

2. Materials and methods

2.1. Samples and controls

Normal corn, waxy corn, potato, and cross-linked waxy corn starches (Rezista®) were commercially prepared products (Tate and Lyle, Decatur, IL). Banana flour was a gift from University of Costa Rica. Banana starch was isolated under Whistler's (1998) method.

2.2. In vitro digestion properties of banana starch, both raw and cooked

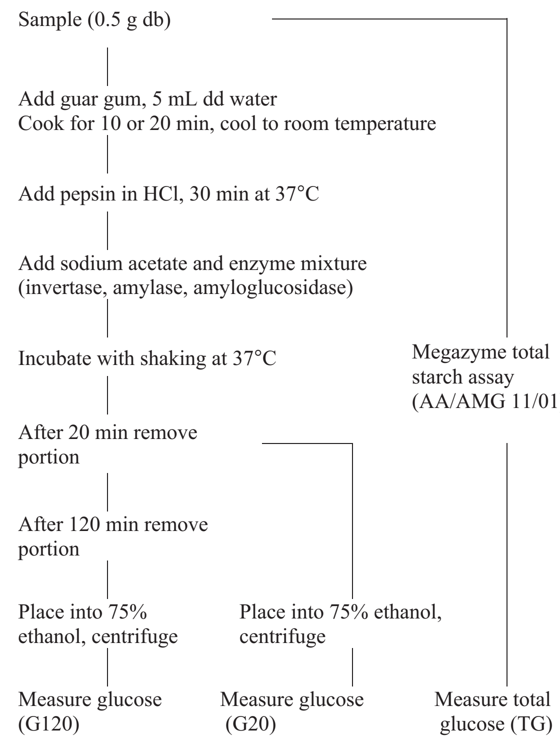
Starch samples (0.5 g db) and water (5 mL) were added to 50 mL polypropylene centrifuge tubes. The tubes were capped and the contents were vortexed for 5 min. Each starch sample was left uncooked, cooked in a boiling-water bath for 10 min, and 20 min, respectively. The tubes were allowed to cool to room temperature. Three separate tubes were prepared and duplicate aliquots were taken from each of the three.

The method of Englyst et al. (1992) and Englyst, Veenstra, and Hudson (1996) was used to determine *in vitro* values for rapidly digestible, slowly digestible, and resistant starch fractions. Free glucose was also measured separately in banana flour. Summary of the analytical protocol for measurement for total glucose (TG), the glucoses released at 20 min, and 120 min are shown in Scheme 1 Starch fractions (%) were calculated as follows:

$$\%\text{RDS} = \frac{(\text{G20} - \text{free glucose}) \times 0.9}{\text{total starch}}$$

$$\%\text{SDS} = \frac{(\text{G120} - \text{G20}) \times 0.9}{\text{total strach}}$$

$$\%\text{RS} = \frac{\text{TS} - (\text{free glucose} \times 0.9) - (\text{RDS} + \text{SDS})}{\text{total starch}}$$



Scheme 1. Summary of the analytical protocol for measurement for total glucose (TG), the glucoses released at 20 min (G20), and 120 min (G120) of incubation.

2.3. Chemical analysis

Banana starch and flour with several other common food starches were analyzed for nitrogen (N) content by nitrogen combustion (Perkin-Elmer Series II Nitrogen Analyzer Model 2410 Boston, MA). A factor of 6.25 was used to convert nitrogen to protein. Moisture contents were determined by AACC method 4-19 (AACC, 2000). Ash contents were determined by AACC Method 08-01 (AACC, 2000). Samples were incinerated overnight in a muffle furnace at 500 °C. Amylose contents of starches were determined by the modified Concanavalin (Con) A method using the Megazyme Amylose/Amylopectin Kit (Wicklow, Ireland). All chemical analyses were performed at least in duplicate.

2.4. Pasting properties

The pasting properties of banana starch/flour and several common food starches were measured according to AACC Approved Method 61-02 with a Rapid Visco-Analyzer (RVA-4 Series, Newport Scientific Pvt Ltd, Warriewood, NSW, Australia). RVA analyses were set for 23 min. Starch was weighed into a RVA aluminum canister, and distilled water was added to a total weight 30 g. Sample was first held for 1.5 min at 50 °C, heated to 95 °C at 6 °C/min, held for 5.0 min at 95 °C, cooled to 50 °C at 6 °C/min, and finally held for 2 min at 50 °C. The temperature corresponding to the initial increase in viscosity was designated the pasting temperature.

2.5. Amylopectin preparation

Banana starch (25 mg) was dissolved in 10 mL 90% dimethyl sulfoxide (DMSO) with stirring in a hot water bath. Ethanol (100%, 15 mL) was added to the solution to precipitate the starch and the mixture was centrifuged at 5500 g for 15 min (Beckman Coulter, CA). The precipitates were washed with 15 mL 100% ethanol and centrifuged three times. The precipitate was then dissolved with

7.5 mL purified water in a boiling water bath for 20 min with stirring, and cooled to room temperature. The solutions were loaded onto a column (2.6 × 90 cm) containing Sepharose CL-2B (exclusion range 1×10^5–2×10^7, Pharmacia Biotech, Inc., Piscataway, NJ, USA) and fractionated by descending chromatography at a flow rate of 0.4 mL/min using purified water containing 0.02% sodium azide as eluant. Fractions (3 mL) were collected, aliquots of fractions (0.5 mL) were diluted in purified water to 2.5 mL, and then 0.2 mL of 2% iodide solution (2 g I_2 and 20 g KI in 1000 mL water) was added. The absorbance at 630 nm was read. The lowest iodine absorbance value was used to differentiate the end of the eluted amylopectin peak from the beginning of the amylose peak. The amylopectin fractions were collected from two runs and freeze-dried. Corn and potato amylopectins were obtained from Sigma (A-7780) and Fluka Biochemica (9037-22-3), respectively.

2.6. Branch-chain-length distribution of amylopectin

Branch-chain-length distribution of amylopectin was determined following the procedure described by Jane and Chen (1992) and Wong and Jane (1997, 2002). Starch was debranched using isoamylase (Megazyme, Wicklow, Ireland), and the branch chain-length distribution was determined using a high-performance anion-exchange chromatograph (HPAEC) equipped with an enzyme (amyloglucosidase)-column reactor that converts all maltooligosaccharides into glucose so that all fractions have identical response factors, making the analysis quantitative, and a pulsed amperometric detector (PAD) (Dionex, Sunnyvale, CA). A CarboPac PA 200 anion-exchange analytical column (250 × 3 mm^2) was used for sample separation. Chains were categorized as (short to long) A, B1, B2, and B3 and longer chains according to the protocol of Hanashiro, Abe, and Hizukuri (1996).

2.7. X-ray diffraction of original and retrograded banana starch

Starch (50 g) and distilled water (450 mL) were placed in a 500 mL beaker, covered with aluminum foil, and cooked at 95 °C in a boiling water bath with stirring shear of 100 rpm for 20 min. Starch pastes were cooled to room temperature on bench, and then stored at 4 °C for 0–24 h. After the retrogradation storage, starch samples were freeze-dried promptly.

X-ray diffraction patterns were obtained with an X-ray diffractometer (Siemens, Germany) equipped with a copper anode X-ray tube. The diffractometer was operated at 20 mA and 40 kV, and the spectra were scanned over a diffraction angle (2θ) range of 10–40° at a step size of 0.1° and a count time of 0.5 s. Percent crystallinity was calculated as the percentage of peak area to the total diffraction area. Freeze-dried cooked corn starch was ground for 20 min in ball mill (Retsch, Brinkmann 60 Hz 40 w, GmbH & Co. KG 5657 HAAN, Germany), and served as an amorphous control.

2.8. Thermal properties of native and retrograded starches

Differential scanning calorimetry (DSC) was used to determine thermal transitions associated with starch gelatinization and melting of retrograded crystallites. Starch (3 mg) was weighed into a DSC aluminum pan. Distilled water (6 μL) was added, and pans were hermetically sealed. Sample pans were equilibrated for 1 h prior to testing. Starch dispersions were gelatinized in triplicate using a TA Instruments 2920 Modulated DSC (New Castle, DE) from 25 to 120 °C at a heating rate of 10 °C/min. An empty pan was used as a reference, and the system was calibrated with indium. Pans were rapidly cooled to room temperature and then subjected to the following temperature cycle: 4 °C for 24 h followed by 23 °C for 24 h. This temperature cycle was repeated to increase crystal formation. Samples were then rescanned. Initial, peak, and enthalpies of transitions were recorded for both native and retrograded starches.

Table 1
Englyst digestion values of starch fractions of banana starch and with comparison of values for some common food starches (same starch basis, 100 g, excluding free glucose, g/100 g).

Starches	Rapidly digestible	Slowly digestible	Resistant starch
Banana starch – raw	6.8 (0.6)	8.7 (0.9)	84.5
Cooked 10′	52.8 (3.7)	17.0 (1.2)	30.2
Cooked 20′	53.9 (3.4)	19.1 (5.4)	27.0
Banana flour – raw	6.4 (2.1)	10.2 (1.0)	83.4
Cooked 10′	72.8 (4.2)	16.7 (6.0)	10.5
Cooked 20′	76.4 (1.4)	11.3 (2.4)	12.4
Potato starch – raw	8.1 (1.4)	8.4 (1.3)	83.6
Cooked 10′	66.8 (6.2)	6.0 (0.5)	27.1
Cooked 20′	74.1 (6.2)	9.3 (5.5)	16.5
Waxy corn starch – raw	33.1 (2.5)	42.8 (4.6)	24.1
Cooked 10′	60.2 (2.6)	21.7 (5.7)	18.1
Cooked 20′	75.4 (6.5)	14.7 (4.4)	9.9
Normal corn starch – raw	20.5 (1.8)	48.4 (6.6)	31.1
Cooked 10′	62.6 (3.0)	16.0 (5.3)	21.4
Cooked 20′	69.9 (6.0)	14.0 (3.6)	16.1
Cross-linked waxy corn – raw	19.8 (3.2)	6.7 (2.5)	73.5
Cooked 10′	44.5 (2.8)	6.0 (0.6)	49.4
Cooked 20′	45.6 (3.7)	5.4 (1.8)	48.9

3. Results and discussion

3.1. In vitro digestion properties of both raw and cooked starch

Data was calculated as percent of total starch (Table 1). Although the Englyst assay protocol stipulates using same sample weights, we felt that the data would be more useful if converted to a same starch basis. Therefore, the results directly show rapidly digestible, slowly digestible, and resistant starch that can be compared between isolated starch, banana flour, and some common food starches. Most notable in the results are differences in 20 min cook starch samples. Banana starch had lower rapidly digestible (54%), and higher slowly digestible (19%) and resistant (27%) fractions compared to potato (74%, 9%, and 17%, respectively) or corn (70%, 14%, and 16%, respectively) starches. Cooked normal corn starch had approximately 16% higher and potato 20% higher RDS compared to banana starch. Moreover, it is sometimes useful to combine SDS and RS fractions giving 46% for banana, 26% for potato, and 30% for normal corn as percent of total starch. Thus, cooked banana starch shows promise as a starch additive with relatively balanced energy release, and a good proportion of SDS and RS.

3.2. Paste viscosity properties

RVA pasting viscosities are shown in Fig. 1A and B. Banana starch showed higher pasting viscosities than the corn or wheat starches tested. At low concentrations (4–7%), banana starch granules apparently resist mechanical disruption. At higher concentrations the viscosity drops slightly during the 95 °C hold (Fig. 2). Banana starches at higher concentrations underwent pronounced setback (retrogradation) during cooling. The pasting temperatures are 75 °C, 81 °C and 71 °C in banana, normal corn and waxy corn starches. The relatively low or no obvious breakdown is seen in banana starch, a phenomena similar to a slightly cross-linked starch. During the holding period at 95 °C, it is furthermore evident that the banana starch is stable when stirred. The viscosity after cooling is significantly higher than all of the control starches.

It suggests that banana starch can be a functional native starch thickener that withstands heat and shear to a degree usually see or associated with chemically modified starches. Because chemically

Table 2
Chemical analysis of banana starch and flour with other food starches.

Starch sources	Moisture (%)	Total starch (% db)	Amylose (% db)	Protein (% db)	Ash (% db)
Banana	11.9	94.5	11.2	0.39	0.10
Banana flour	9.3	81.1	9.2	4.76	3.04
Normal corn	12.0	95.8	21.7	0.56	0.09
Waxy corn	10.9	96.5	–	0.40	0.10

crosslinked starches are used in many applications where stable-viscosity is needed, it would be an advantage in the reduction of the use of chemically modified products, if native starch could perform the same as chemically modified. As a native, natural, and potentially organic starch, banana starch shows a superior property of behaving somewhat like a lightly cross-linked starch (Table 2).

3.3. Amylopectin fine structures

In the present study, banana starch amylopectin structure was compared with corn and potato amylopectins. Purified amylopectin was enzymically debranched and linear chains were analyzed. Amylopectin chain-length distribution profiles for banana, corn, and potato are shown in Fig. 2 as short to long chains and data are summarized in Tables 3A and 3B. The lowest detectable DP was 6 and the highest was about 90, which agreed with an interesting fact that DP 6 is the shortest branch chain length found in all amylopectins (Hanashiro et al., 1996; Jane et al., 1999; Koizumi, Fukuda, & Hizukuri, 1991). Conventionally, chains with DP 6–12

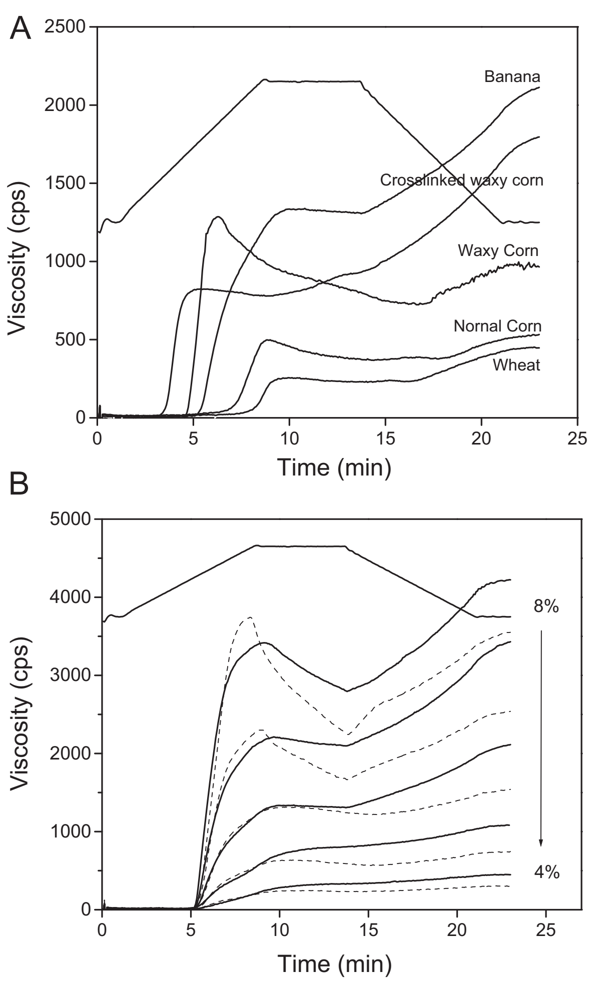


Fig. 1. RVA profiles of banana starch and several typical food starches at 6% (db) (A), banana starch and flour (dash) from concentrations of 4–8% (db) (B).

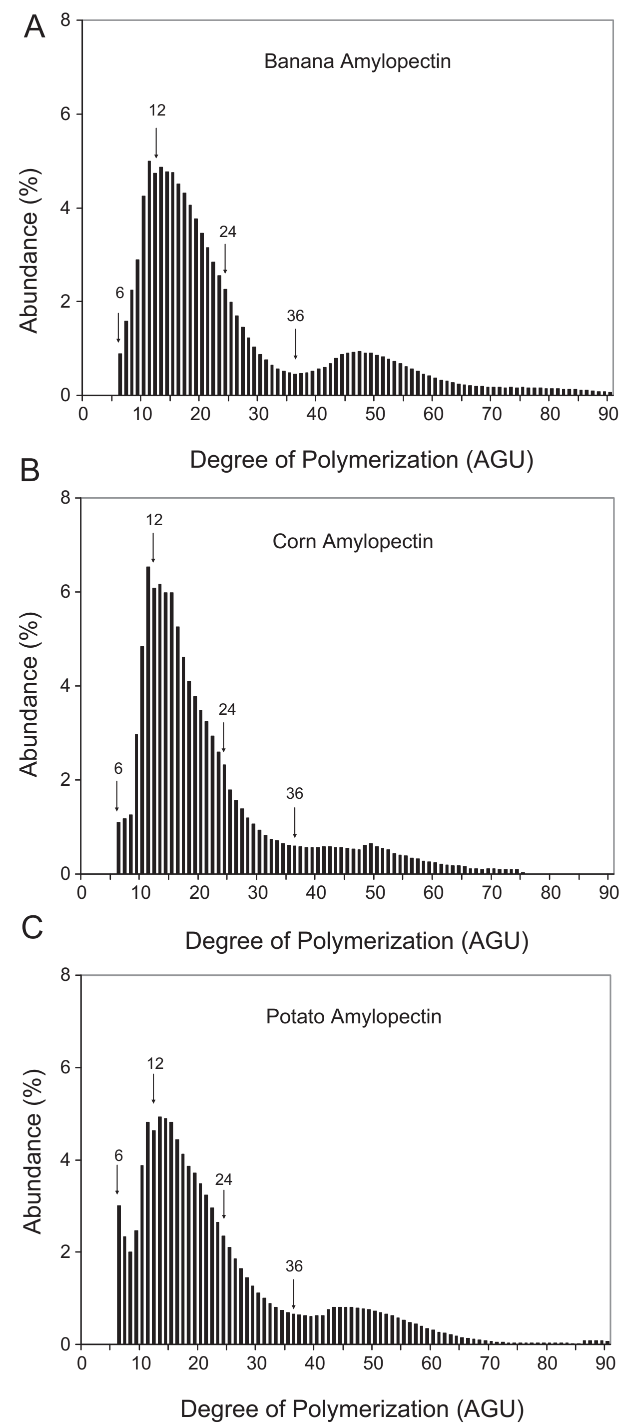


Fig. 2. Chain length distribution of isoamylase-debranched banana amylopectin (A), corn amylopectin (B), potato amylopectin (C) from determined by HPAEC–PAD.

Table 3A
Chain length distribution (wt %) of debranched amylopectins from banana, corn, and potato.

Amylopectin	Branch chain length distribution (wt %)			
	DP 6–12	DP 13–24	DP 25–36	DP > 36
Banana	21.6	45.3	11.7	21.4
Corn	23.9	50.5	12.1	13.5
Potato	22.6	44.7	14.1	18.6

were assigned as A-chains. The rest of the chains were assigned as B1 (DP 13–24), B2 (DP 25–36) and chains with DP >36 were assigned as B3 and very long chains. Banana starch amylopectin clearly showed differences when compared to corn or potato amylopectin. The distribution of the short chains (DP 6–12) is very characteristic for amylopectins and was characterized as a "fingerprint" of the starches. Banana amylopectin displays a lower proportion of short chains DP 6–12 (21.6%) and higher proportion of long chains DP > 36 (21.4%). Moreover, banana amylopectin displays an increase in DP 6–8 (Fig. 2A), but it is more pronounced than in the case of normal corn (Fig. 2B). Potato amylopectin shows a higher population of short chains DP 6–7 (Fig. 2C and Fig. 3B), which has been found in some tubers, roots and legume starches (Jane et al., 1999).

Amylopectin fine structure can greatly influence its behavior in food systems. Chain length distribution (branching) plays an important role in determining functional properties. Higher number of short branch chains contributes to lower crystallinity, gelatinization temperature, viscosity, and degree of retrogradation, and solution solubility. On the other hand, starch molecules with longer branch chain length and a lower degree of branching contribute to higher gelatinization temperature, degree of retrogradation, gel firmness and lower degree of digestibility. From previous work in our laboratory, we had hypothesized that amylopectin with higher proportion of long linear chains in its branched structure would likely lead to less digestible starch (Han & Hamaker, 2001). Banana debranched profiles showed a higher proportion of long chains of amylopectin (degree of polymerization DP > 36) and in addition, longer linear chains were present. We believe that the higher proportion of long chains of banana amylopectin allows for greater retrogradation (reassociation) on cooling after cooking that makes these complexes less susceptible to enzymic degradation.

3.4. Thermal properties

X-ray diffractometry and differential scanning calorimetry were employed to study the gelatinization behaviors of the native and retrograded starches. The native crystal polymorph of banana starch was found to be a B-type in this study. Retrogradation resulted in formation of crystalline regions in cooked starch pastes. Degree of crystallinity, after cooling the cooked pastes to room temperature along with the retrogradation storage and freeze-dry was calculated in Table 4. A high rate of retrogradation of cooked banana starch was found through X-ray diffraction analysis (Fig. 4). DSC results showed potato starch had the lowest onset and gelatinization temperatures, while banana starch had the highest values (Table 5A). Moreover, banana starch exhibited

Table 3B
Chain length distribution (mol %) of debranched amylopectins from banana, corn, and potato.

Amylopectin	Branch chain length distribution (mol %)			
	DP 6–12	DP 13–24	DP 25–36	DP > 36
Banana	39.3	46.2	7.2	7.3
Corn	39.6	49.0	6.8	4.6
Potato	42.0	43.4	8.2	6.3

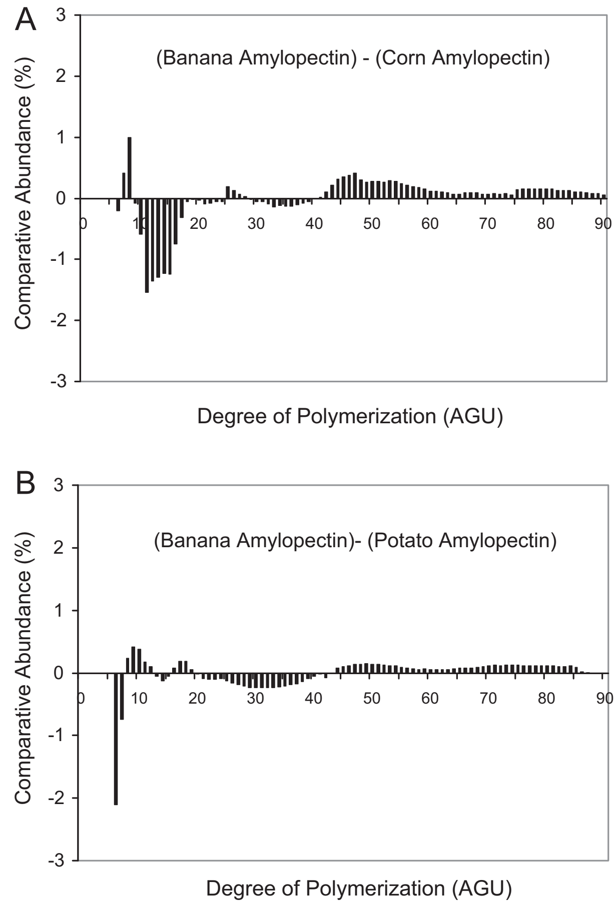


Fig. 3. Comparative chain length distribution chromatogram of isoamylase-debranched banana – corn amylopectin (A), banana – potato amylopectin (B) from determined by HPAEC–PAD.

Table 4
Crystallinity (%) of cooked banana starch after cooling to room temperature along with retrogradation storage and freeze-dry.

Retrograded time (h)	Crystallinity (%)
0	20.5
1	23.2
6	23.2
24	26.0
Raw	33.2

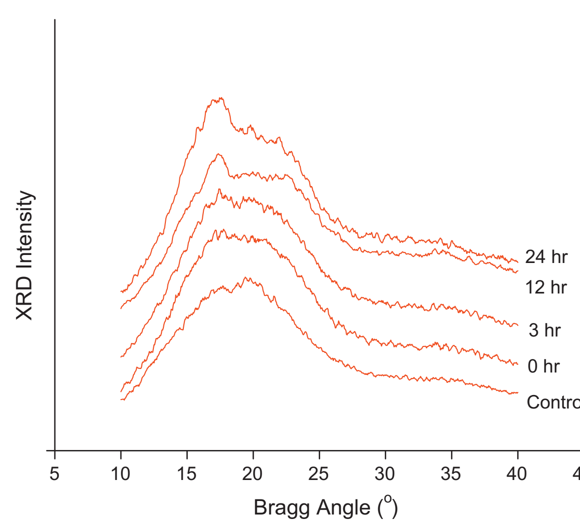


Fig. 4. XRD pattern of retrograded banana (cooked for 20 min, retrograded at 4 °C for 0 h, 3 h, 12 h, 24 h, and then freeze-dried.

Table 5A
Differential scanning calorimetry results for gelatinization of starches.

Starch	Onset temp. T_o (°C)[b]	Peak temp. T_g (°C)	$T_g - T_o$	Enthalpy (ΔH) (J/g, db starch)[a]
Banana	70.8 (0.3)	74.5 (0.2)	3.7 (0.1)	17.5 (0.3)
Corn	65.9 (0.2)	71.3 (0.4)	5.4 (0.3)	13.3 (0.4)
Potato	62.7 (0.3)	66.8 (0.2)	4.1 (0.2)	16.4 (0.3)

[a] Enthalpy calculated on a dry weight basis of starch.
[b] Mean of triplicate measurements with starch deviation.

Table 5B
Differential scanning calorimetry results for the retrograded (temperature-cycles) starch gels.

Starch	Onset temp. T_o (°C)[b]	Peak temp. T_g (°C)	$T_g - T_o$	Enthalpy (ΔH) (J/g, db starch)[a]
Banana	46.5 (0.9)	58.3 (0.9)	11.9 (0.5)	8.8 (0.4)
Corn	45.5 (0.5)	55.2 (1.2)	9.7 (0.7)	6.2 (0.6)
Potato	48.4 (0.5)	60.4 (0.7)	12.1 (0.4)	7.1 (0.6)

[a] Enthalpy calculated on a dry weight basis of starch.
[b] Mean of triplicate measurements with starch deviation.

the highest enthalpy values (17.5 J/g), which agreed with the results of Espinosa-Solisa, Jane, and Bello-Pereza (2009). DSC thermal data confirmed that the crystals formed during storage of gelatinized banana starch had the largest thermal stability because they dissociated at higher temperature accompanied by a larger enthalpy change (Table 5B). Retrogradation properties suggested the greater retrogradation (reassociation) on cooling after cooking that makes these complexes in banana starch and banana starch-containing foods less susceptible to enzymic degradation. Bello-Perez, Ottenhof, Agama-Acevedo, and Farhat (2005) studied the retrogradation phenomenon of banana starch extrudates and found that banana starch retrogradation reached a maximum value at approximately 11 h of storage. Banana starch showed a fast retrogradation kinetic that could be related to the amylopectin chain length.

3.5. *Structural characteristics and their relation to digestion properties*

Chemical composition of banana starch and flour, and other comparative starches, is shown in Table 2. Protein content of the banana starch is typical for a purified food starch. Most notable was the finding that banana starch in this study has a relatively low amylose content of 11.2%. Because amylose is normally associated with lower digestion properties of cooked starches, it was quite significant that cooked banana starch or flour had more slowly digestible and resistant starch than the higher amylose-containing starches (corn and potato). This indicated to us that banana amylopectin is responsible for its slow digestion property.

The thermal and fine structural data support the view that banana starch amylopectin has a structure such that higher reassociation of the molecules occurs on cooling that, in turn, leads to a lower rate of starch digestion (lower value for rapidly digestible starch, and higher values for slowly digestible and resistant starches). The results presented in this study show a potential for cooked banana starch and flour fulfill the role of a slowly digestible starch or a starch with controlled energy release. Fine structural data on banana amylopectin structure show differences that support its lower *in vitro* digestion properties. The analytical results indicate that banana starch has some unique properties that may be beneficial to health and textural applications.

4. Conclusions

It is well known that raw banana starch is a good source of resistant starch. However less was known regarding digestion property of cooked banana starch – either as an isolated starch or in its native flour form. *In vitro* studies have shown that cooked banana starch has a lower RDS of 54%, compared to cooked potato (74% RDS) and corn (70% RDS) starches. Cooked banana starch had a significant fraction of slowly digestible starch. Combined SDS and RS for cooked banana starch was 46%, a high value compared with potato or corn starch. Our studies also confirmed that banana starch has unique pasting properties making it behave like a chemically lightly crosslinked starch.

Studies of the structure of the other major starch molecular fraction – amylopectin revealed that banana amylopectin has a significantly different structure from corn in that it has a higher proportion of very long chains. These long chains make up their dimensional highly branched, high molecular weight amylopectin molecules. These very long chains may inter penetrate each other with or without the participation of amyloses to form a swelling resistant structures during pasting. The high proportion of very long chains also reflect the hypothesis that banana amylopectin can retrograde and reassociate on cooling faster than other starch amylopectins. It is known that retrograded starch is less accessible to amylases and digests slower or less completely. Retrogradation studies support the view that banana amylopectin retrogrades at a substantially faster rate than corn or potato amylopectin leading to less digestible starch.

Our work revealed some potentially useful, and we think fairly unique, aspects of banana starch related to its nutritional value. We believe that banana starch is unique enough, both nutritionally and functionally, to warrant investigation into its potential commercial uses in processed foods and become a commercially viable starch product.

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