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Structural and physicochemical characteristics of starch from sugar cane and sweet sorghum stalks

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ABSTRACT

The starch present in sugar cane and sorghum juice has been considered a problem to the sugar industry. The objective of this work was to study the structural and physicochemical characteristics of the starch present in sugar cane and sweet sorghum. Sugar cane and sweet sorghum starches presented small granules (maximum 5.9 and 7.9 μm), A-type diffraction pattern, high degree of relative crystallinity (44.4 and 42.0%), and low amylose content (17.5 and 16.4%), respectively. Sugar cane starch presented more uniformity in granule shape and size, more homogeneity in amylose chain length, higher number of long lateral chains of amylopectin, and higher susceptibility to enzymatic digestion. Besides being in higher amount in the juice, sweet sorghum starch presented lower values for thermal properties of gelatinization, as well as higher swelling factor, which can cause more problems during processing. Additional studies are needed to evaluate the variety and maturity influence on these properties.

1. Introduction

The sugar (sucrose) and alcohol (ethanol) industry has become an important part of the agro-industrial sector in certain parts of the world. Although sugar cane is widely utilized as raw material for sugar and alcohol production, the use of alternative feedstocks has been tried experimentally. Sweet sorghum can be employed as a complementary option during sugar cane off-season.

Starch is one of the main products of photosynthesis in superior plants, stored in chloroplasts, in the form of granules, as energy storage reserves when photosynthesis is not occurring (Bello-Pérez, Montealvo, & Acevedo, 2006). Starch content in sugar cane juice stalk ranges from 1.6 to 2.6 g/kg (Figueira, Carvalho, & Sato, 2011), depending on season of the year, plant variety, diseases, maturity, processing, method of analysis (Imrie & Tilbury, 1972), climatic conditions, stress, and type of soil (Eggleston, Montes, Monge, & Guidry, 2007b). In recent years higher concentrations of starch in sugar cane have been delivered to factories, mainly because of the processing of unburned sugar cane, environmental conditions, and the use of new varieties with higher amounts of this polymer (Eggleston et al., 2013; Zhou et al., 2008).

The presence of starch in sugar cane poses a great problem, since it affects negatively the quantity and quality of sugar processes and products (Zhou et al., 2008). The increased use of sweet sorghum in agro-industries may aggravate these problems, because this plant species has even higher starch content than sugar cane. In sweet sorghum juice starch content ranges from 76 to 154 g/kg, depending on plant variety, harvest period, and maturity (Zhao, Steinberger, Shi, Han, & Xie, 2012).

Starch is a polysaccharide composed of two macromolecules: amylose, which has a linear chain structure made up of glucose units linked through α-1,4 bonds, and amylopectin, which has a branched chain structure made up of glucose units linked through α(1–4) and α(1–6) bonds. The morphology, chemical composition, and molecular structure of starches are unique for each particular plant species (Bello-Pérez et al., 2006). The adverse effects of starch in sugar cane and sweet sorghum processing are mainly related to the behavior of starch granules during their hydration and heating (Zhou et al., 2008).

Even in small amounts in the juice, the presence of starch can cause problems due to viscosity increase in sugar cane and sorghum mills and refineries. The starch in juice is not soluble, but with the heat applied during clarification and evaporation, starch granules progressively swell, and rupture releasing amylose and amylopectin, which results in an amorphous viscous solution. On cooling, the amylose chains association, a phenomenon known as

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retrogradation, influences the distribution of starch in factory and refinery products (Zhou et al., 2008). According to Eggleston et al. (2013), however, some insoluble starch has been also observed in syrup and raw sugars. This warrants further investigations to determine if it is soluble starch, insoluble granules, or both, which are detrimental to the filtering process.

Starch can raise the cost of production by reducing crystallization and centrifugation rates, increases molasses production in the process of sugar concentration (Kampen, Tan, & Cuddihy, 1998; Zhou et al., 2008), reduces filterability, delays sugar crystal growth and causes its distortion (Roberts, Godshall, Carpenter, & Clarke, 1976), and occludes into the sucrose crystal (Zhou et al., 2008).

Taking into consideration the relevance of the sugar sector in the modern world, studies that characterize in detail the fraction starch both in sugar cane and sweet sorghum are important, since they can provide valuable data for future researches on the control of processes and products. Although some studies characterize sugar cane starch partially (Figueira et al., 2011; Kampen et al., 1998; Park, Martens, & Sato, 1985; Stevenson & Whayman, 1976), to the best of our knowledge, no studies specifically focusing on starch in sweet sorghum stalks have been published so far. Therefore, the objective of the present study was to carry out a comparative assessment of the structural and physicochemical characteristics of starch from sugar cane and sweet sorghum feedstocks.

2. Materials and methods

Sugar cane (RB 867515), third cut in July 2011, was used to extract the juice by pressing the stalks. Sweet sorghum (donated by a private company) were harvested in March 2011, 127 days after planting, and the stalks were pressed to obtain the juice. Both juices were evaluated for starch content according to Copersucar (2001). The starch present in the juice was extracted according to Park et al. (1985) with modifications. The juice was filtered (0.045 mm) and centrifuged at 9000 × *g* for 15 min at 5 °C. The suspension was centrifuged five consecutive times until the supernatant was clear. The method proposed by Stevenson and Whayman (1976) was employed to remove colored compounds. The starch solution was centrifuged with absolute ethanol and distilled water, and the precipitate was collected and dehydrated in an air circulation oven at 30 °C for 12 h. The dry starch was ground in a mortar with a pestle and sieved (0.25 mm).

After isolation, the purity of the starches was evaluated by determining total starch content using the method proposed by Rickard and Behn (1987). The percentage purity of the starches was calculated by dividing the starch content by the weight of the sample. Amylose content was determined using the amylose/amylopectin Megazyme kit (Megazyme International Ireland Limited, Bray, Ireland).

The molecular weight distribution profiles of the starches were determined by gel permeation chromatography (GPC) using a GE XK 26/70 column (2.6 cm diameter × 70 cm height) packed with Sepharose CL-2B gel. The samples were prepared according to the method proposed by Song and Jane (2000). A 4-mL aliquot containing 12 mg starch was injected in the column and eluted in the ascending mode. A solution containing 25 mM NaCl and 1 mM NaOH was used as eluent at a flow rate set to 60 mL/h. Fractions of 125 drops (approximately 4 mL) were collected and total sugar content (CHO) was analyzed using the phenol–sulfuric method (Dubois, Gilles, Hamilt, Rebers, & Smith, 1956) modified to be measured at 490 nm using an absorbance microreader, and the blue value (BV, iodine staining) method at 630 nm (Juliano, 1971).

The appearance of the granules was assessed using a scanning electron microscope (DSM 940 A, Carl Zeiss Inc., Oberkochen, Germany) with an amperage of 80 mA and acceleration voltage of 5 kV. The samples were attached to stubs with double-sided adhesive tape, and the starches were fixed and coated with a thin layer of gold using a sputter coating station (Balzers Med 010, Unaxis Balzers Ltd., Liechtenstein) for 3 min.

The size of starch granules was determined using an optical microscope (Nikon Eclipse E 200, Nikon, Inc., Melville, NY, USA) connected to a digital camera. The samples were diluted with a solution of 50% glycerol in water. The selected images were analyzed using the software Image Tool© (Wilcox, Dove, McDavid, & Greer, 2002). Following the recommendation of Vigneau, Loisel, Devaux, and Cantoni (2000), five slides were mounted and 100 measurements of starch granule size were taken per slide, in a total of 500 measurements. Due to the irregular shape of starch granules, the larger and the smaller diameters were measured. The results were used to construct histograms representing the frequency distribution for the groups of quantitative data.

To obtain the X-ray diffraction profiles, starch humidity was balanced in a desiccator containing saturated $BaCl_2$ solution (25 °C, aw = 0.9) for 36 h. The patterns of X-ray diffraction were determined in an X-ray diffractometer (Miniflex II, Rigaku, Tokyo, Japan) using copper radiation, at a scanning speed of 2° per min, angle 2θ ranging from 4° to 50°, 40 kV, and 40 mA. The relative crystallinity of starch was quantitatively determined following the method proposed by Nara and Komiya (1983) and using the Origin 7.5 software (Microcal Inc., Northampton, MA, USA). The data were smoothed with the Adjacent Averaging tool and plotted in graphs between 2θ angles ranging from 4° to 30°.

The enzymatic digestibility of starch was assessed using the methods described by Zhang and Hamaker (1998) and Benmoussa, Suhendra, Aboubacar, and Hamaker (2006) with some alterations. A 5-mL aliquot of distilled water was added to 200 mg starch. After 20 min in a boiling water bath the material was cooled to 40 °C and 25 mL of porcine pancreatic α-amylase (A-3176, Sigma Chemical Co., St. Louis, MO, USA) in Tris–maleate buffer solution pH 6.9 were added at the proportion of 5 units/mL. The suspension was incubated at 37 °C and at each selected experimental time (10, 20, 40, 60, 90, and 120 min) a 1-mL aliquot was collected. The reaction was interrupted by heating the mixture at 98 °C for 10 min and the content of reducing sugar was determined using the method described by Somogyi (1945).

The thermal properties of both starches were evaluated using a differential scanning calorimeter (Pyris 1 DSC, Perkin-Elmer, Norwalk, CT, USA). An aliquot of 3 mg of starch was placed in high-pressure stainless steel pan (P/N 0219-0062) and deionized water was added using a microsyringe to yield a starch:water ratio of 1:3. The pans were sealed and equilibrated for 24 h at room temperature before the analysis. The equipment was calibrated with indium and an empty pan was used as reference. The scanning was carried out at a heating rate of 5 °C/min and temperature ranging from 30 to 130 °C. Based on the thermograms, the following gelatinization parameters were obtained: onset temperature (T_o), peak temperature (T_p), final temperature (T_f), temperature range ($\Delta T = T_f - T_i$), and enthalpy (ΔH). The swelling factor of starch granules was evaluated according to the direct method proposed by Tester and Morrison (1990), at 50, 70, and 90 °C.

3. Results and discussion

3.1. Starch content in feedstock juices

The starch content in sugar cane juice was 356 ± 20 mg/L, considerably lower than the amount found in sweet sorghum juice, which was 1147 ± 9 mg/L. Andrzejewski, Eggleston, Lingle, and Powell (2013) reported that the stalk starch content was

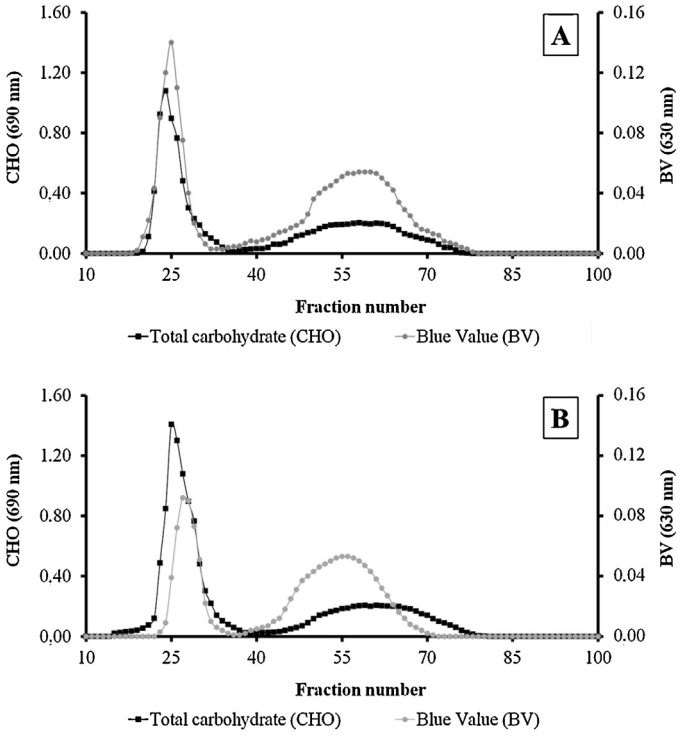

Fig. 1. Gel permeation chromatography profile on Sepharose CL-2B. (A) Sugar cane starch; (B) sweet sorghum starch.

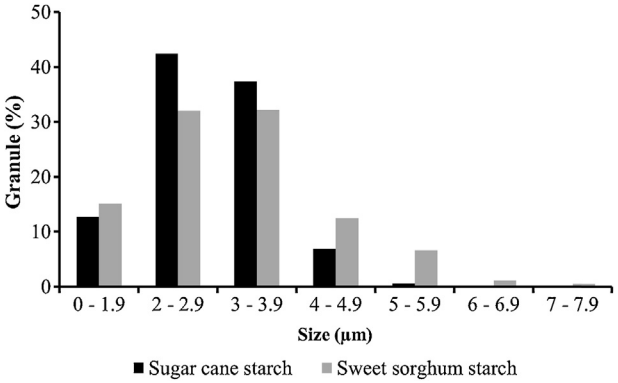

Fig. 2. Distribution of sugar cane and sweet sorghum starch granule size.

200 ± 6 mg/L in sugar cane juice and 835 ± 3 to 1691 ± 436 mg/L in three sweet sorghum mature hybrids juice. The amount of starch, however, is a function of variety, maturity, part(s) of the plant, and analytical method.

3.2. Structural and physicochemical characterization of isolated starches

3.2.1. Composition and macromolecular size distribution

The isolated starches presented high purity considering that the starch contents were 99.1% in sugar cane and 98.9% in sweet sorghum, indicating a good extraction process.

In sugar cane starch, amylose content was 17.5%, within the range reported in other studies, of 15% (Whayman & Willersdorf, 1976), 19% (Vignes, 1974), and 20% (Kampen et al., 1998). Amylose content in sweet sorghum starch was 16.4%, but in the literature this parameter is reported only for grains, ranging from 11.2 to 22.5% (Benmoussa et al., 2006; Singh, Sodhi, & Singh, 2010). Considering that most conventional sources of starch used in agro-industries contain 20–30% amylose (Jane, 2009), the raw materials used in our study presented relative low amounts of this compound. The content and the fine structure of the starch macromolecules have great influence on starch physicochemical (Lindeboom, Chang, & Tyler, 2004) and functional properties (Jane, 2009).

Fig. 1 shows the gel permeation chromatograms of sugar cane and sweet sorghum starches. The first peak corresponds to amylopectin fraction and the second one corresponds to amylose fraction, showing a significant response to BV.

The first peak (amylopectin) of sugar cane starch (Fig. 1A) showed lower total carbohydrate (CHO) content and higher reaction to iodine (BV) compared to sweet sorghum starch (Fig. 1B). The ratio BV/CHO for the amylopectin peak was 1.30 for sugar cane starch and 0.06 for sweet sorghum starch. Higher BV/CHO ratios in the amylopectin fraction may suggest a higher number of long lateral chains in the molecule of this polysaccharide (Rocha, Demiate, & Franco, 2008), since these long branch-chains, similarly to amylose, can bind iodine and raise iodine affinity (Jane et al., 1999).

The chromatograms of sugar cane and sweet sorghum starches presented differences regarding the second peak (amylose), since CHO and BV curves were more uniform (at the same interval) for the former, indicating higher homogeneity of the molecular mass in this fraction.

Although amylose and amylopectin contents were similar (difference of approximately 1%) in both sources, evaluating their gel permeation chromatography profiles it was possible to observe differences in the length of amylose chains and lateral chains of amylopectin, which also form helicoids that absorb iodine.

3.2.2. Shape and size of starch granules

Sugar cane and sweet sorghum starch granules, observed under a scanning electron microscope, were small, with varied shapes, smooth surface, and no apparent fissures.

Although the predominant shape of granules in sugar cane starch is spherical, some of them were irregular, tending to oval or semi-spherical, or even truncate. Similar shapes were reported by Figueira et al. (2011) and Stevenson and Whayman (1976), who mentioned irregular shapes, but predominantly spherical and oval granules.

Sweet sorghum starch granules were less spherical and more angular, predominantly presenting an irregular polyhedral shape. Other authors observed spherical and polyhedral shapes in sweet sorghum starch obtained from grains of American (Benmoussa et al., 2006) and Indian (Singh et al., 2010) varieties, respectively.

The mean smaller diameters of sugar cane (2.8 ± 0.8 μm) and sweet sorghum (2.8 ± 1.0 μm) starch granules were the same, but the mean larger diameters of sugar cane (3.1 ± 0.8 μm) and sorghum starch (3.6 ± 0.8 μm) were different, reinforcing the fact that the latter are irregular in shape. The size of granules found in the literature for sugar cane starch is equally small, since this parameter was reported to range from 1 to 3 μm (Figueira et al., 2011), 1 to 5 μm (Stevenson & Whayman, 1976), and 1 to 6 μm (Park et al., 1985).

Sugar cane and sorghum starch granules can be considered very small (up to 5 μm) or small (5–10 μm) using the classification proposed by Lindeboom et al. (2004). According to these authors, the size of starch granules from conventional sources ranges from less than 1 μm to more than 100 μm and this parameter is under genetic control, varying with the variety, environment, and also with maturity.

The graphs of distribution of sugar cane and sweet sorghum starch granule size (Fig. 2) show that both starches present more granules between 2.0 and 3.9 μm (79.8% and 64.2%, respectively). Nevertheless, sweet sorghum starch presented a higher percentage of smaller (up to 1.9 μm) and higher granules (>5 μm), i.e., a broader

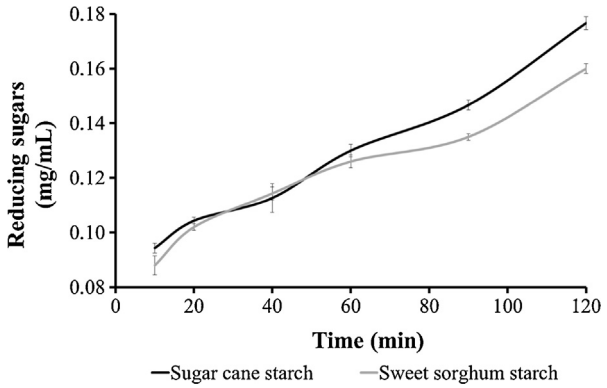

Fig. 3. Production of reducing sugars by hydrolysis of sugar cane and sweet sorghum starches with porcine pancreatic α-amylase.

variation in size. Starch granule size is of great importance, since it can affect starch gelatinization, swelling factor, solubility, pasting properties, enzyme susceptibility, and crystallinity (Lindeboom et al., 2004).

3.2.3. X-ray diffraction and relative crystallinity

X-ray diffractograms of sugar cane and sweet sorghum starches showed that both starches presented A-type crystalline pattern (Zobel, 1964), with a peak at the diffraction angle 2θ 15.2° with medium–strong intensity and others with strong intensity at the doublet 17.3°/18.0° and at 23.2°. A-type crystalline pattern, also present in cereals, is characterized by a double helix formed by packed amylose and amylopectin molecules in a monocyclic arrangement (Sajilata, Singhal, & Kulkarni, 2006).

Relative crystallinity of sugar cane and sweet sorghum starches was 44.4 and 42.0%, respectively, suggesting a high degree of crystallinity for both. According to Zobel (1988), the degree of crystallinity of starch granules can range from 15 to 45%, and amylopectin is the main factor responsible for this parameter. The relatively low amylose content (16.4–17.5%) and, consequently, high amylopectin content (82.5–83.6%) found in this study for both starches may account for their high degree of crystallinity.

3.2.4. Enzyme susceptibility

The quantity of reducing sugars produced by hydrolysis of both sugar cane and sweet sorghum starches with porcine pancreatic α-amylase (Fig. 3) was similar in the beginning of the process. However, after 60 min of hydrolysis sweet sorghum starch was less susceptible than sugar cane starch.

During enzymatic digestion (10–120 min) in the present study, the quantity of reducing sugars produced by hydrolysis of sugar cane starch increased by 100% (0.09–0.18 mg/mL). Park et al. (1985) evaluated the susceptibility of sugar cane starch to bacterial α-amylase. Starch isolated from sugar cane was digested with 100 SKB units of α-amylase (*Bacillus subtilis* or *B. licheniformis*) in phosphate buffer pH 6.0 for 24 h at room temperature. Within the period of 2–24 h, 0.2–1.2 mg/mL of reducing sugars were produced, increasing their production by 500%.

Also, during enzymatic digestion (10–120 min), the quantity of reducing sugars produced by hydrolysis of sweet sorghum starch increased by 78% (0.09–0.16 mg/mL) in this study. Zhang and Hamaker (1998) evaluated the enzymatic digestion of sweet sorghum starch obtained from grains only, under the same conditions used herein, and reported that the quantity of reducing sugars increased by 44% (2.5–3.6 mg/mL). Given that both starches presented similar contents of macromolecules and the same crystalline pattern, the lower enzymatic digestibility of sweet sorghum starch may be associated with the higher mean size of its granules.

One of the options used in sugar cane mills to eliminate the starch present in the juice is its digestion with amylases during syrup evaporation (Zhou et al., 2008). In this phase, starch is gelatinized, making its digestion easier. Since they are small, sugar cane starch granules also have a large surface area for the enzyme action and, moreover, present A-type crystalline pattern, which, according to Englyst, Kingman, and Cummings (1992), makes them even more susceptible to the enzymes. Nonetheless, this procedure is relatively expensive and not always effective (Zhou et al., 2008); furthermore, crude and refined sugar can present residual enzymatic activity, which may cause problems in products that contain these ingredients in their formulation (Eggleston, Montes, Monge, & Guidry, 2007a). In a subsequent study, Eggleston and Montes (2009) found that residual activity in sugars may occur when high temperature stable α-amylases are used, because they are very stable at high temperature and may not denature/inactivate after application, resulting in carry-over activity into raw sugar and molasses. In contrast, intermediate temperature stable α-amylases do not cause this.

3.2.5. Thermal properties

The analysis using differential scanning calorimetry (DSC) to evaluate starch gelatinization helps to explore and understand the granular structure, as well as verify and monitor the thermal properties and phase transitions of starch (Zhong & Sun, 2005). Gelatinization properties of sugar cane and sweet sorghum starches measured using DSC are summarized in Table 1.

Starch gelatinization generally occurs in a range of temperature characteristic for each plant species. This temperature range corresponds to the maximum viscosity, measured since the crystalline zones start to disappear until the end (Bello-Pérez et al., 2006).

The high temperatures traditionally used in the processes to obtain sugar and alcohol are responsible for the problems caused by starch. Given that the transition temperatures of sugar cane (67.3 and 84.4 °C) and sweet sorghum starch (65.8 and 80.8 °C) are below those used in the juice treatment (90 and 105 °C), both starches could theoretically have their gelatinization process completed, presenting increased viscosity. On the practical side, however, recent results (Eggleston et al., 2013) have shown that considerable amounts of insoluble (granular) starch is present in syrups and in some raw sugars, particularly those with high soluble starch content. Therefore, swollen, not completely swollen, and not swollen starch granules can differently affect enzyme applications and viscosity. Considering this new knowledge, a factor that may be contributing to the incomplete expansion of starch granules is the competition between sucrose and starch for water.

Table 1
Thermal properties of sugar cane and sweet sorghum starches.

Starch	Gelatinization properties				
	T_o (°C)	T_p (°C)	T_f (°C)	ΔT (°C)	ΔH (J/g)
Sugar cane	67.3 ± 0.4	75.2 ± 0.1	84.4 ± 0.3	17.0 ± 0.2	15.5 ± 0.2
Sweet sorghum	65.8 ± 0.3	72.4 ± 0.4	80.8 ± 0.5	15.0 ± 0.5	10.6 ± 0.3

T_o = onset temperature; T_p = peak temperature; T_f = final temperature; $\Delta T = T_f - T_o$, temperature range; ΔH = enthalpy.

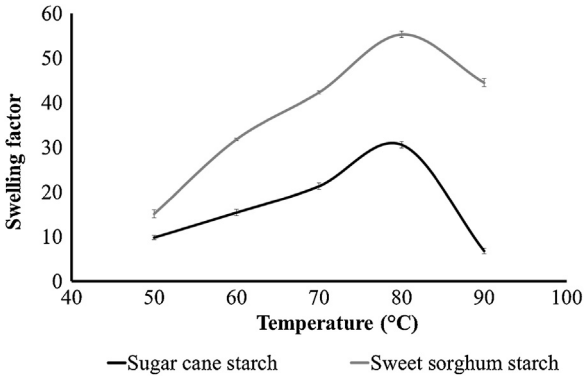

Fig. 4. Swelling factor of sugar cane and sweet sorghum starch granules at different temperatures.

Both studied starches presented transition temperatures at higher values compared with cassava, potato, Peruvian carrot, barley, wheat, and certain varieties of maize starch (Hoover, 2001; Rocha et al., 2008; Song & Jane, 2000; Tester & Morrison, 1990). High transition temperatures indicate that the beginning of gelatinization requires more energy to occur. The relatively smaller size of sugar cane and sweet sorghum starch granules probably accounts for their high temperatures of gelatinization, as stated by Lindeboom et al. (2004). However, in addition to granule size, starch gelatinization is related to many other factors, including amylose content (Song & Jane, 2000), proportion and type of crystalline organization, and granule ultra-structure (Lindeboom et al., 2004).

The enthalpy of starch gelatinization (ΔH) is the energy necessary to transform the granule structure from a crystalline to an amorphous state (Hasjim, Li, & Dhital, 2013). This parameter was higher for sugar cane starch compared with sweet sorghum starch and corresponds to the higher relative crystallinity of the former. According to Vamadevan, Bertoft, and Seetharaman (2013), however, differences in thermal properties are specifically related to the melting of amylopectin crystallites. The length of the external chains of amylopectin has a major impact on gelatinization enthalpy and the internal structure of the same macromolecule (chain organization) has a major influence on transition temperatures. These authors also suggested that only the number of blocks that build the clusters and the inter-block chain length appear to be more involved in setting gelatinization temperature.

Although many of these ultra-structure properties were not evaluated in the present study, the high ΔH of sugar cane starch suggests that the long outer branches of amylopectin chains can form longer double helices that require higher levels of thermal energy for melting, as stated by Hoover and Ratnayake (2002).

3.2.6. Swelling factor

Intragranular water of starch suspensions heated to a certain temperature is measured by the swelling factor of starch granules. This swelling derives from gelatinization and influences the rheological properties of pastes and gels (Tester & Morrison, 1990). The swelling factors of sugar cane and sweet sorghum starch granules are presented in Fig. 4.

The swelling factor of sugar cane starch ranged from 9.8 to 30.6 between 50 and 80 °C. At 90 °C this parameter dropped to 6.8 due to the rupture of the granules caused by excessive swelling. Sweet sorghum starch presented a similar behavior, although the swelling factor was higher, ranging from 15.1 to 55.3 between 50 and 80 °C, and at 90 °C it dropped to 44.5.

The studied starches presented higher swelling factors compared with some conventional sources: maize – ranging from 0.4 to 6.0 between 50 and 80 °C (Tester & Morrison, 1990); oat – 9.2 at 80 °C (Tester & Karkalas, 1996); chickpea – ranging from 7.1 to 27.5 between 50 and 90 °C (Polesi, Sarmento, & Anjos, 2011).

Gelatinization and swelling properties are related to the perfection and ordering of amylopectin crystallites, length of the external chains of amylopectin, extent of branching, molecular weight and polydispersity, starch composition, and architecture of the granules (Tester, 1997). The higher relative crystallinity and the presence of a larger number of crystallites (formed by the association of long amylopectin chains) in sugar cane starch seems to increase its granular stability, thereby reducing the extent of granular swelling.

The formation of an amorphous viscous solution when starch granules are heated during clarification and evaporation phases is a major problem in the sugar industry, because it reduces the efficiency of boiling and increases the formation of molasses. Taking into consideration that sweet sorghum starch granules have a higher swelling factor than sugar cane starch granules, the former can cause more harmful effects in the industry. When this gelatinized system cools, principally the molecules of amylose can reassociate to form a gel network, causing more serious problems, such as the presence of starch in the final products (Zhou et al., 2008).

4. Conclusions

Sugar cane and sweet sorghum starches presented similar amylose/amylopectin ratio. However, sugar cane starch presented more uniformity in granule shape and size, more homogeneity in amylose chain length, and a higher number of long lateral chains of amylopectin compared with sweet sorghum starch. The higher susceptibility of sugar cane starch to enzymatic digestion seems to be associated with the smaller size of its granules (larger surface area). Additionally, sugar cane starch presented higher values of thermal properties of gelatinization, as well as lower swelling factor than sweet sorghum starch.

The introduction of sweet sorghum in the industrial process of the sugar industry can cause problems regarding viscosity, because of the higher quantity of starch in the juice obtained from this feedstock and the higher swelling factor of its granules compared with sugar cane starch. These results, however, are applicable to these experimental conditions and cannot be generalized. Further studies, using several varieties, environment conditions, and maturity stages, should be conducted to provide a more effective conclusion.

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