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Physical, chemical and microscopic characterization of a new starch from chayote (*Sechium edule*) tuber and its comparison with potato and maize starches

J. Jiménez-Hernández, J.A. Salazar-Montoya, E.G. Ramos-Ramírez *

Department of Biotechnology and Bioengineering. CINVESTAV-IPN, Av. IPN 2508, P. O. Box 14-740, C. P. 07360, México 14 D.F., Mexico

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Abstract

In this work, the chayote tuber starch (CHS) was isolated and its chemical composition and its physical and microscopic characteristics were determined, and compared with potato (PS) and maize (MS) starches. The starch content in chayote tubers (728 g kg^{-1} dry weight) was similar to potato tubers (700 g kg^{-1} dry weight), with a high level of purity (>98%), while its phosphorous content was higher (0.15%) than PS (0.08%) and MS (0.01%). Starch granules were oval, irregular, truncated and rounded with sizes between 7 and 50 μm with smooth surfaces. CHS dispersions (1% and 4%, w/w) showed higher viscosity (75 and 1715 mPa s), than PS (350% and 50% lower) and MS (715% and 600% lower). The gelatinization temperature (65 to 74 °C) was similar in CHS and PS. The pasting properties (RVA) of the starches suggest that CHS showed better characteristics than the commercial potato and maize starches. Therefore, CHS could be used as a thickening agent and a substitute to PS in food dispersions where a high viscosity is needed.

Keywords: *Sechium edule*; Starch; Physical properties; Chemical and microscopic characteristics

1. Introduction

Chayote (*Sechium edule*) Jacq. Swartz, is a native cucurbit plant of México and Central America (Lira, 1996), which has been cultivated in small-scale in some countries like England, France and Spain. This plant produces fruits of different sizes and forms, green stalks, tender leaves and tubers, all of them edible. Chayote has been significant in the autochthonous diet since pre-Columbian times and it is an important export crop of some Latin American countries (Lira, 1996). Its cultivation in México has been focused to fruit production, which produces about 100,620.25 tons/year (SAGARPA, 2004). However, there is no published or official data on tuber production and the integral use of this resource. In this study, the average production of chayote tuber in México was calculated as 1084.5 tons/year, considering the number of hectares cultivated (2065.5 Ha), the number of plants per hectare (125 plants) and number of tubers produced per plant (2 tubers), as well as the average weight of the tuber (2.1 kg). These data shows that chayote tubers can be a potential source of raw material.

The importance of the chayote tuber lies on its high starch content (136 g kg^{-1} tuber fresh weight), which is similar to that reported for the potato tuber (140 g kg^{-1} tuber fresh weight) (Aung, Ball, & Kushad, 1990; Aung, Fouse, & Kushad, 1991; Lira, 1996). Very little information is available on the fine structure and physical and chemical properties of chayote tuber, similar to other under-utilized tropical tubers. Consequently, it is necessary that these starches should be studied in order to obtain and report their structural parameters, information which is required to gain competitiveness in an international-scale industry (Jakakody, Hoover, Liu, & Weber, 2005; Lira, 1996).

Some tropical tubers such as sagú (*Canna edulis*), zulu (*Maranta sp.*), guapo (*Myrosma cannifolia*) and chayote

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* Corresponding author. Tel.: +52 55 50613800; fax: +52 55 5061 3313.
E-mail address: eramos@cinvestav.mx (E.G. Ramos-Ramírez).

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(*S. edule*), that contain starch as a main component, have been used for fresh consumption; however, pure starches are difficult to extract from these tubers and their properties are unknown (Pérez, Lares, & González, 1997; Rincón, Padilla, Araujo, & Tillett, 1999). Therefore, it is valuable to determine the physicochemical characteristics of these starches and to explore its potential applications in the food industry.

The principal sources of refined starch are maize (79%), potato (9%) and tapioca (7%). These starches are used extensively in the manufacture of food and other applications due to their structural and physicochemical characteristics (Han & Saskatoon, 1998; Jakakody et al., 2005). The usage of potato starch is preferred over other starches, as in many foods, in adhesive and oil-field applications as well as in papermaking, because it can give a high consistency on pasting, and have advantage in film-forming and binding characteristics. The hydration behavior of potato starch differs from cereal starches, and suggests its application in many formulated foods that require a high stability and a long shelf life (Ganga & Corke, 1999).

Starch extraction from different sources can provide new raw material, with special properties for specific uses in the chemical and food industry (Moorthy, 2002). Therefore, the aim of this work was to isolate and study the chemical composition and the physical and microscopic characteristics of chayote tuber starch, and to compare its parameters versus potato and maize starches.

2. Materials and methods

2.1. Materials

Fresh tubers of chayote (*S. edule*) (Fig. 1) – medium size without any mechanical injuries – were purchased in a local market (La Merced, Mexico City). For the determination of edible yield the tubers were washed and peeled off with a commercial potato peeler, and then weighed (OHAUS balance, USA). The peeled off portion was called the "edible portion" and its yield (%) was calculated as a ratio between the edible portion weight and whole tuber weight. Fresh potato (*Solanum tuberosum*) tubers *var. Alpha* were used for comparing the physical characteristics and the chemical composition with chayote tubers. Maize (MS) and potato (PS) starches also were purchased from Sigma (México), and glycerol (99% purity) from Baker (México).

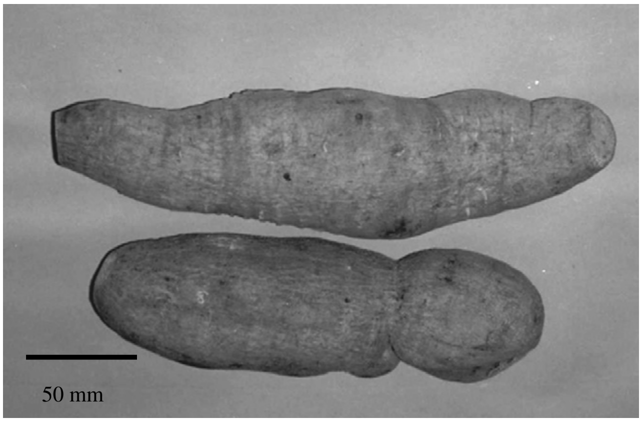

Fig. 1. Chayote (*Sechium edule*) tubers cultivated in México.

2.2. Physical characteristics and edible yield from tubers

The physical characteristics determined were morphology, size and weight. Morphology was evaluated describing the external appearance and apparent color; the color was registered using the Küppers (1996). Size (length) was measured with a vernier caliper (Mitutoyo, Japan).

2.3. Starch isolation

The starch was isolated from chayote tubers according to a modification of the technique described by Ganga and Corke (1999). Chayote tubers were peeled off and cut in 1 to 2 cm cubes, mixed with 2 volumes of distilled water, and homogenized in a blender model 853-10 (Osterizer, México) for 1 min at maximum speed. The obtained dispersion was transferred to a beaker where it remained motionless for 20 min. Subsequently, the dispersion was decanted (fraction A), and the supernatant (fraction B) containing the pulp was homogenized again in a blender with distilled water (2:1; pulp:water) and it was left to rest for 40 min (called "residue"). The starch-containing sediment (fraction A) was homogenized in a blender for 1 min at maximum speed and left to rest for 30 min. Then this fraction was filtered using a 250-μm-mesh sieve (Montinox, México). The solid remnants in the sieve (pulp) were eliminated, while the filtrate (starch) was washed until the washing water was translucent, which indicated that the starch had been extracted. On the other hand, the fraction A was decanted and the sediment residues (starch) were sieved and also were washed with distilled water until the washing water was translucent. Subsequently, starch-containing fractions were mixed and the product was dried in an incubator model 132000 (Boekel, USA) at 40 °C during 24 h, and finally ground in an analytical mill (IKA, Germany) and sieved at 250 μm. The chayote tuber starch (CHS) samples were stored in hermetic plastic containers at room temperature (21–24 °C) for further chemical and physical analysis.

2.4. Chemical composition

Moisture, proteins, crude fiber, ashes, phosphorus and carbohydrates (total and soluble) were determined using the methods described in the AOAC (1995). Starch content was determined by the enzymatic method described by Rose et al. (1991), which consists in solubilizing the starch in an alkaline medium (pH 9) and subsequently neutralizing (near to pH 5.1), and digesting it with a mixture of α-amylase (EC. 3.2.1.1) and amyloglucosidase enzymes (EC. 3.2.1.3) (200:1 w/w, respectively). The determinations were performed in fresh tubers and all starches (<8% moisture) studied.

2.4.1. Amylose content

The amylose content in the studied starches was determined using the colorimetric method reported by McGrance, Cornell, and Rix (1998), which consisted in solubilizing starch in dimethylsulfoxide and gelatinized it at 85 °C, after that was stain with iodide solution and left to rest for 10 min. The sample was read at 600 nm wavelength. The starch content (100%) could be considered as the sum of amylose and amylopectin. The amylose/amylopectin ratio was also calculated.

2.5. Morphology of starch granules

The morphology of granules in CHS, PS and MS was studied with a scanning electron microscope model SEM JSM-35C (Jeol, Japan). The starch granules were placed separately on double-sided adhesive tapes, which were attached to a support and then introduced into the etching unit model Desk-II (Denton Vacuum, USA.), in order to cover them with a 250 Å gold layer. Finally, the granules were observed in the microscope with 15 kV voltages.

2.6. Pasting properties

Pasting properties of starches were measured on a Rapid Visco Analyzer (RVA-4), using the RVA General Pasting Method (Newport Scientific Pty. Ltd., Warriewood, Australia). Starch samples were processed according to the Ragaee, El-Sayed, and Abdel-Aal (2006) method. The parameters determinate were: pasting temperature (pT, the temperature where viscosity first increases by at less 25 mPa s over 20 s period), peak time (PT, the time at which peak viscosity occurred), peak viscosity (PV, the maximum hot paste viscosity), holding strength or trough viscosity (TV, the trough at the minimum hot paste viscosity), final viscosity (FV, the viscosity at the end of the test after cooling to 50 °C and holding at this temperature), breakdown (BV, peak viscosity-holding strength or trough viscosity) and setback (SV, final viscosity-holding strength). All these parameters were calculated from the pasting curves, using the software Thermocline version 2.2 Newport Scientific Pty. Ltd. (Warriewood, Australia).

2.7. Flow behavior

The flow behavior of CHS, PS and MS dispersions at 1% and 4% (w/w) concentrations was determined with a concentric cylinder viscometer model RV2 (Haake, Germany), which includes an interface (rheocontroller), a temperature bath (Haake C) and a measuring head (MK-500). Starch dispersions were prepared at 90 °C with distilled water on a hot plate stirrer model 524C (Barnstead Int., USA), with a vigorous stirring for 15 min and subsequently left to cool and rest for 24 h at room temperature before the rheological determinations were performed. The analysis was done at 25 °C with a shear rate of 2000 s^{-1} using the MV1 geometry. The Ostwald de Waele's model was used for obtaining the rheological parameters (η_{ap}, apparent viscosity; n, flow behavior index; K, consistency coefficient; and R^2, correlation coefficient) with the Standard Rotational-C PG-140 software (Haake, Germany).

2.8. Thermal properties

Thermal property determinations were performed with a differential scanning calorimeter model DSC 2010 (TA Instruments, USA). The equipment was calibrated with indium (In), and 3 mg of the dry sample (8% moisture) with 9 μL of deionized water placed in an aluminum pan. Each pan was sealed and left to rest for 1 h at room temperature (21–24 °C) and later placed in the analysis device in order to be scanned between 0 and 200 °C, with a heating ramp of 20 °C/min. An empty aluminum pan was used as reference during the determinations. The thermal parameters obtained from thermograms were: onset temperature (T_o), peak temperature (T_p), conclusion temperature (T_c) and gelatinization enthalpy (ΔH_{gel}). The parameters were determined using the Thermal Analyst Controller Differences 9900 software, and the gelatinization temperature range (R) was calculated as $T_o - T_c$.

2.9. Statistical analysis

The data were analyzed with ANOVA and a posteriori tests (Duncan and Tukey) in order to determine statistically significant differences ($p < 0.05$) among the samples, using the SPSS ver. 12.0 statistical software. Results were the average of three determinations.

3. Results and discussion

3.1. Physical characteristics and edible yield of chayote tuber

The natural external appearance of chayote (*S. edule*) tubers showed a rough surface with transversal lines (Fig. 1) and a more elongated (280–430 mm) form than potato (70–300 mm) tubers, similar to the previously reported by Lira (1996). Physical characteristics and edible yield of chayote tubers were compared with those of potato. The color of chayote and potato tubers, according to the Küppers (1996), was in the orange color field described with the keys N_{30} A_{70} M_{40} and N_{30} A_{60} M_{30}, respectively.

Chayote tubers weighed between 480 and 930 g, which suggest that they are medium sized, considering that these tubers could sometimes weigh more than 2100 g. The weight for potato tubers *var. Alpha* was 50–250 g. Edible yield in chayote tubers (86%) was similar (87.97%) to one reported (Pérez et al., 1997) on wild zulu (*Maranta sp.*) tubers from South American, which indicates that both tubers have a thin peel and suggests a clear possibility of commercial application in the same way that potato tubers.

3.2. Chemical composition

The chemical composition of chayote and potato tubers is summarized in Table 1. No statistically significant difference between the compositions of the tubers was found. Similar values were reported (Aung et al., 1991; Lira, 1996; Wolfgang, Detmold, & Hans-Peter, 1999) previously for each tuber. The similar starch content in chayote and potato tubers (72.80% and 70.01%, respectively) indicates that chayote tuber could be considered as a novel starch source high in starch, rivaling potato.

The chemical composition (Table 2) of the analyzed starches (CHS, PS and MS) presented statistically significant differences ($p < 0.05$), except in carbohydrates content. The moisture content of all analyzed samples was <10%, which is acceptable (Wolfgang et al., 1999), because commercially up to 20% of moisture is allowed in starch as raw material. Regarding the lipid and protein content, MS presented highest values (0.68 and 0.50% respectively); according to previous studies (Badui, 2001; Beynum & Roels, 1985; Hoseney, 1991; Lovedeep, Narpinder, & Navdeep, 2002) the high content of these components in the starch is related with cereal the source. In agreements to tubers, the lipid and proteins contents for CHS (0.16% and 0.29%) and PS (0.18% and 0.20%) were lower than MS.

No statistical differences ($p < 0.05$) were found in the carbohydrate total content between the three studied starches (CHS, PS and MS). Additionally, the test results of soluble sugars (low molecular weight) showed an absence of these compounds in all the starches; therefore, likely samples consist only of oligosaccharides and polysaccharides (sugars of high molecular weight). Moreover, the absence of soluble sugars suggests that the tuber was at optimal harvesting stage (Moorthy, 2002; Wolfgang et al., 1999), because the concentration of these sugars before or after the harvesting stage is higher. In addition, the isolated starch (CHS) presented high purity degree (>98%) like MS and PS, which are reactive grade.

Table 1
Chemical composition of chayote and potato tubers

Components (g/100 g d.w)	Chayote	Potato
Moisture	81.30 ± 0.19	80.06 ± 1.36
Carbohydrates	85.50 ± 0.01	85.1 ± 0.85
Starch	72.80 ± 0.6	70.01 ± 2.64
Fiber crude	0.17 ± 0.08	0.21 ± 0.03
Proteins	10.35 ± 0.02	10.07 ± 0.08
Lipids	0.33 ± 0.06	0.39 ± 0.02
Ash	3.65 ± 0.17	4.04 ± 0.25

Average values of three measurements. (For $n = 3 \pm$ s.d.).

Table 2
Chemical composition of chayote tuber starch (CHS), potato starch (PS), and maize starch (MS)

Characteristics (%)	CHS	PS	MS
Moisture	7.02 ± 0.15^{b}	8.52 ± 0.10^{c}	4.90 ± 0.32^{a}
Protein$^{(nX6.25)}$	0.29 ± 0.00^{b}	0.20 ± 0.00^{a}	0.50 ± 0.00^{c}
Carbohydrates	98.56 ± 2.95^{a}	98.97 ± 1.15^{a}	98.42 ± 1.83^{a}
Lipid	0.16 ± 0.00^{a}	0.18 ± 0.00^{a}	0.68 ± 0.02^{b}
Ash	0.46 ± 0.04^{c}	0.34 ± 0.00^{a}	0.38 ± 0.00^{b}
Phosphorus	0.15 ± 0.00^{c}	0.08 ± 0.03^{b}	0.01 ± 0.00^{a}
Amylose	12.90 ± 0.64^{a}	25.90 ± 0.43^{b}	29.30 ± 0.17^{c}
Amylopectin	87.10 ± 0.23^{c}	74.10 ± 0.36^{b}	70.70 ± 0.64^{a}
Amylose/amylopectin ratio	0.13 ± 0.01	0.34 ± 0.05	0.41 ± 0.03
Ph	8.12 ± 0.37^{b}	7.66 ± 0.22^{b}	4.96 ± 0.51^{a}
Granule size (μm)	7–50	10–85	7–28

Average values of three measurements. (For $n = 3 \pm$ s.d.). The letters indicate statistically significant differences (Tukey $p < 0.05$) for each determination.

Considering that chayote is a starch-rich tuber such as potato, it could be a possible source of this polymer. In the same way, during the homogenization step, chayote tubers showed a similar behavior that those reported in potato (Wolfgang et al., 1999), because of their similar appearance. This may have advantages in the industrial starch extraction process, because the mechanical forces that can be applied in the starch extraction process will be lower in relation to those required for cereals such as maize and wheat (Wolfgang et al., 1999).

The contents of ash (0.46%) and phosphorus (0.15%) were higher for CHS than PS (0.34% and 0.08%, respectively) and MS (0.38% and 0.01%). Generally, starch ashes are mainly composed of phosphorus, sodium, potassium, magnesium and calcium (Beynum & Roels, 1985). In the starch, the phosphorus content is as the phosphate groups, which are bounded to the amylopectin molecules and confer a polyelectrolyte nature to the chains. Beynum and Roels (1985) suggested that this ionic nature allows starch dispersions to develop high viscosity. In the same way, Wolfgang et al. (1999), have proposed that the thickening capacity of starch is associated with the high content of phosphate ester groups and they have reported an average phosphorus content of 0.079% of starch in potato, which is lower than (0.15%) CHS. Therefore, it could be that the high phosphate content of chayote starch is also the responsible parameter of high viscosity developed by these starch dispersions.

The amylose/amylopectin ratio was <0.5 in all studied starches (Table 2), which indicates a predominance of amylopectin (CHS, 0.13; PS, 0.34; and MS, 0.41); CHS showed the highest content of amylopectin. The literature suggests (Beynum & Roels, 1985) that starches with an amylopectin high content could form gels with a low trend to retrogradation. CHS presented an alkaline pH value (8.12), while in PS this value was close to neutrality (7.66) and in MS it was acid (4.96), which indicated that there is a higher degree of ionization in CHS dispersions. The degree of ionization has a significant effect in the hydration behavior of starches in order to permit the interaction between water molecules and amylopectin and amylose chains, this effect is increased in higher pH values (Pérez et al., 1997).

Considering the quality standards of Thai cassava starch (Sriroth, Piyachomkwan, Wanlapatit, & Oates, 2000), which is classified in several grades, according to customer's need, CHS could be placed in grade 1. This means that the starch qualifies as low in moisture content

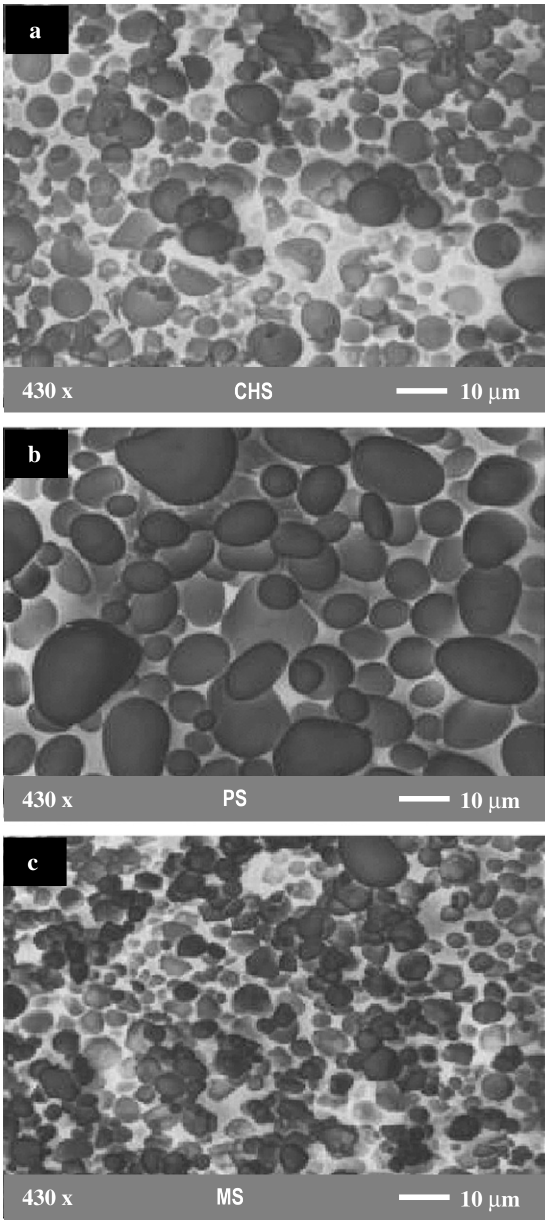

Fig. 2. Scanning electron micrographs 430x of granules from, (a) chayote tuber starch (CHS), (b) potato starch (PS) and (c) maize starch (MS).

(< 13%), high in purity (> 97.5) and low in protein content (< 0.3%); however, the ash content for CHS is higher (> 0.05) than commercially acceptable in the highest grade starch. This category is the best in the Thai quality standards.

3.3. Morphology of starch granules

According to various authors (Badui, 2001; Beynum & Roels, 1985; Hoseney, 1991; Lovedeep et al., 2002), the morphology and size of starch granules are related to their source; thus, granule morphology is used as taxonomic criterion to identify the vegetable source of this polysaccharide. Fig. 2 shows the morphology of the CHS, PS and MS granules. Granule size (Table 2) was within the range of 7–50 μm for CHS, 10–85 μm for PS and 7–28 μm for MS. Granules from all studied starches showed oval, rounded or truncated forms, and some granules were broken; in this study the granule surfaces were observed smooth and without pores. The presence of broken and truncated granules was higher in CHS than in the other studied starches, which suggests that probably starch isolate method was too strong during the homogenization step; therefore, it is necessary to take care in time and speed of this process. Actually, the presence of broken and truncated granules is not considered in the quality standard of starches (Sriroth et al., 2000; Wolfgang et al., 1999).

The granule size suggests some possible applications, for example those smaller than 60 μm are used in the production of cosmetic products due to their high water absorption capacity (Paredez-López, Shevenin, Hernández-López, & Carabez-Trejo, 1989; Zhao & Whistler, 1994), and also as encapsulating agent for flavors, colorants and essences (Lovedeep et al., 2002). Therefore CHS, because of its granule size adequate (7–50 μm), could be considered as a useful and interesting polymer in the alimentary industry.

3.4. Pasting properties

The pasting properties (RVA) of starch dispersions are presented in Table 3. As expected for tubers, the shapes of the pasting curve were similar between PS and CHS, with differences in the peak high (Fig. 3). The studied samples (CHS, PS and MS) presented statistically significant differences ($p < 0.05$) during heating and cooling behavior in presence of water excess. However, fortunately the pasting properties for CHS were advantageous over the PS. CHS had the highest peak viscosity (PV = 14746 mPa s), and the highest values for breakdown (BV) and final viscosity (FV). Trough viscosity (TV) was similar in all samples (Table 4). Peak time (PT) and pasting temperature (pT) were similar in PS and CHS, except for MS, which required a longer time (6.08 min) to reach maximum viscosity. This RVA

Table 3
Pasting properties (RVA) of chayote tuber starch (CHS), potato starch (PS) and maize starch (MS)

Simples	pT (°C)	PT (min)	PV (mPa s)	TV (mPa s)	FV (mPa s)	BV (mPa s)	SV (mPa s)
CHS	67.75 ± 1.36^{a}	3.59 ± 0.26^{a}	14746 ± 787^{c}	2329 ± 166^{a}	4939 ± 118^{b}	12417 ± 853^{c}	2610 ± 87^{b}
PS	65.83 ± 1.01^{a}	2.97 ± 0.15^{a}	9412 ± 61^{b}	1987 ± 210^{a}	4253 ± 136^{a}	7424 ± 148^{b}	2455 ± 213^{b}
MS	78.55 ± 3.79^{b}	6.08 ± 0.79^{b}	4959 ± 101^{a}	3231 ± 307^{b}	4237 ± 168^{a}	1724 ± 75^{a}	1037 ± 101^{a}

Average values of three measurements. (For $n = 3 \pm$ s.d.). The letters indicate statistically significant differences (Duncan $p < 0.05$) for each parameter. pT, Pasting temperature; PT, peak time; PV, peak viscosity; TV, trough viscosity; FV, final viscosity; BV, breakdown viscosity and SV, setback viscosity.

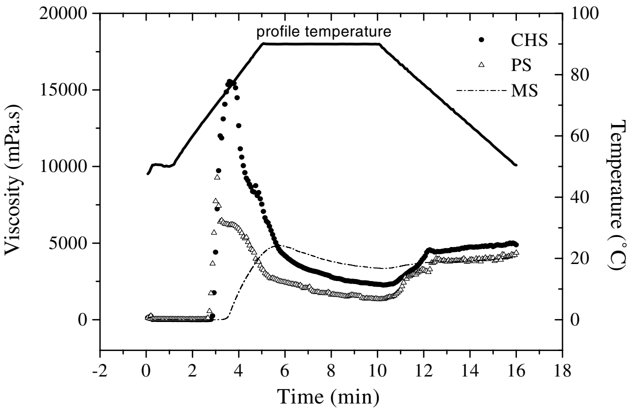

Fig. 3. Pasting curves (RVA) of chayote tuber starch (CHS), potato starch (PS) and maize starch (MS).

Table 4
Rheological parameters of dispersions of chayote tuber starch (CHS), potato starch (PS) and maize starch (MS) at 1% and 4%, w/w

Simples	[%]	η_{ap} (mPa s)	n^*	K (Pa s)^n	R^2
CHS	1	75.09 ± 0.43^c	0.52	1.59	0.98
PS	1	16.66 ± 0.67^b	0.89	0.03	0.97
MS	1	9.21 ± 0.49^a	0.54	0.18	0.83
CHS	4	1715.20 ± 0.63^c	0.39	4.89	0.97
PS	4	1141.70 ± 23.54^b	0.41	2.94	0.93
MS	4	14.63 ± 0.84^a	0.56	0.25	0.91

* Dimensionless. Average values of three measurements. (for $n = 3 \pm$ s.d.). The letters indicate statistically significant differences (Duncan $p < 0.05$) among the samples at the same concentration. The rheological parameters: η_{ap}, apparent viscosity; n: flow behavior index; K, consistency coefficient; and R^2, correlation coefficient.

behavior (Fig. 3) might be explained by a higher content of amylose, and a lipid complexed amylose chains (Jakakody et al., 2005), therefore the lower capacity of absorption and swelling of starch granules (Ragaee et al., 2006).

During the holding period (TV) of the viscosity test, the dispersions were subjected to a high temperature and mechanical shear stress, which further disrupt starch granules, according to Ragaee et al. (2006) this could result in alignment and leaching out of the amylose. In our data, the analyzed samples (CHS, PS and MS) did not have statistical differences for this parameter, no matter the differences between the characteristics according to Table 2 and Fig. 2. This period (which ends at 10 min of the pasting test for all the samples, Fig. 3) is commonly associated with a breakdown in viscosity (BV). High values of breakdown are associated with high peak viscosity (PV) and the degree of swelling of the starch granules during heating. This was the case of CHS, which had a higher peak viscosity (PV = 1476 mPa s) and breakdown (BV = 12417 mPa s) than all of the other samples, followed by PS peak viscosity (PV = 9412 mPa s) and breakdown (BV = 7424 mPa s). By this, according to Ragaee et al. (2006), the PV provides practical indication of the viscous load likely to be encountered by a mixing cooker.

It is possible that during the cooling, starch molecule re-association took place, especially between amylose chains, which resulted in a gel structure formation and, therefore increase in the final viscosity. This phase is commonly described as the setback region (SV) and is related to retrogradation, syneresis (Niba, Bokanga, Jackson, Schlimme, & Li, 2001; Ragaee et al., 2006; Varavinit, Shobsngob, Varanyanond, Chinachoti, & Naivikul, 2003) and amylose leaching degree (Jakakody et al., 2005). There were significant differences ($p < 0.05$) in SV between cereal starch (MS) and tuber starches (PS, CHS), where the tuber starches had higher values (2610 and 2455 mPa s, respectively). Then, the results of starch pasting properties suggest that CHS due to high PV and FV could be used as thickening agent in food dispersions, where a high viscosity could be needed.

3.5. Flow behavior

Starch dispersions (CHS, PS and MS) presented a non-Newtonian pseudoplastic-type behavior ($n < 1$) (Table 4), which was characterized by a decrease in viscosity by an increasing shear rate (Steffe, 1996). The apparent viscosity (η_{ap}) of starch dispersions (CHS, PS and MS) at 1% and 4% (w/w) concentrations was statistically different ($p < 0.05$). CHS dispersions presented higher apparent viscosity than PS and MS. In comparison with PS dispersions, CHS presented 350% more viscosity at 1% (w/w) and an increase of 50 % for starch dispersion at 4% (w/w). Regarding MS dispersion, CHS showed an increase in viscosity of 715% for 1% (w/w) and 600% in dispersion at 4% (w/w). In the present study, the CHS dispersions developed higher viscosity than PS and MS dispersions; therefore, it could be considered that chayote tuber is a good starch source and this material is a better thickening agent than PS, MS and other sources. CHS presented a highest content of phosphorus and amylopectin, which are probably the main reasons for the development of a higher viscosity than PS and MS (Badui, 2001; Beynum & Roels, 1985; Hoseney, 1991; Lovedeep et al., 2002).

Table 5
Thermal parameters of chayote tuber starch (CHS), potato starch (PS) and maize starch (MS)

Samples	T_o (°C)	T_p (°C)	T_c (°C)	R (°C)	ΔH_{gel} (J/g)
CHS	65.18 ± 1.26^a	68.66 ± 1.58^a	74.02 ± 1.96^a	8.84 ± 0.77^a	1.13 ± 0.07^a
PS	64.06 ± 0.54^a	67.80 ± 0.61^a	75.16 ± 2.21^a	11.10 ± 1.42^b	1.29 ± 0.11^b
MS	70.56 ± 0.24^b	74.48 ± 0.24^b	81.73 ± 0.77^b	11.17 ± 0.89^b	1.33 ± 0.04^b

Average values of three measurements. (For $n = 3 \pm$ s.d.). The letters indicate statistically significant differences (Duncan $p < 0.05$) for each parameter. Thermal parameters: onset temperature (T_o), peak temperature; (T_p), conclusion temperature; (T_c), gelatinization temperature range; (R), gelatinization enthalpy; (ΔH_{gel}).

3.6. Thermal properties

According to some authors (Hagenimana, Pu, & Ding, 2005; Yu & Christie, 2001), starch shows a very complex thermal behavior due to the physicochemical changes of the granules during gelatinization, thermal transition, crystallization, molecular degradation, among others. The thermal parameters of tuber starches (CHS and PS) presented statistically significant differences ($p < 0.05$) in relation to MS (Table 4). The endothermic peaks ($T_o - T_c$) for CHS and PS were between 64 and 75 °C, while the ones for MS appeared between 70 and 81 °C. These results are partially due to the differences in size, and chemical composition (mainly, phosphorus and lipid content) among the studied starches (tubers and cereals). Some authors (Badui, 2001; Beynum & Roels, 1985; Hoseney, 1991) have reported that starch composition depends on the source (tubers or cereals). Potato starch from different crops in India and Philippines had endothermic peaks between 60 and 73 °C (Ganga & Corke, 1999; Lovedeep et al., 2002), which were similar to the ones obtained in the present study. CHS showed enthalpy values (ΔH_{gel}) statistically lower ($p < 0.05$) than the other two studied sources (Table 5). The ΔH_{gel} indicate the presence of crystalline regions (attributed to amylopectin linear fraction and amylose fraction) (Banks & Greenwood, 1975; Beynum & Roels, 1985) and amorphous zones (mainly amylose). Some reports (Iturriaga, Lopez, & Añon, 2004) indicated that the presence of crystalline zones increases the amount of thermal energy required to initiate the starch melt, while the amorphous zones reduce the amount of energy. Therefore, CHS requires a lower temperature to gelatinize. This indicates that PS and MS present more crystalline regions than the chayote tuber starch because they showed higher values of ΔH_{gel} than CHS. These differences can be attributed to granule structure, amylose and amylopectin content, polymer arrangement, and gelatinization temperature, according to Lovedeep et al. (2002).

4. Conclusions

Chayote tubers are presented as a novel starch source, considering that they are larger than potato tubers with similar edible yield. The extracted starch (CHS) presented a high degree of starch purity (>98%). Starch dispersions of CHS, PS and MS presented a non-Newtonian pseudoplastic-type behavior. The CHS dispersions developed higher viscosities than PS and MS dispersions, which were attributed to the higher content of phosphorus and amylopectin in CHS. The thermal properties of this novel starch (CHS) source, showed that it is similar to the potato one ($p < 0.05$), although CHS presented a lower gelatinization enthalpy (ΔH_{gel}) than PS and MS. The shape and size of the CHS granules were comparable to those of MS granules, which could suggest some possible uses for CHS as encapsulating agent for many substances of commercial interest. In addition, the results of starch pasting properties suggest that CHS showed better characteristics than commercial potato and maize starches due to high PV and FV. Therefore, it is considered that CHS could be used as a thickening agent and a substitute to PS in food dispersions where a high viscosity could be needed.

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References

AOAC. (1995). Official methods of analysis. 15th Ed, Association of Official Analytical Chemists. Washington DC, USA, p. 780.

Aung, L. H., Ball, A., & Kushad, M. (1990). Developmental and nutritional aspects of chayote (*Sechium edule*, *Cucurbitaceae*). *Economic Botany, 44*(2), 157–164.

Aung, L. H., Fouse, D. C., & Kushad, M. (1991). The distribution of carbohydrates in the organs of *Sechium edule* Sw. *Journal of Horticultural Science, 66*(2), 253–257.

Badui, S. D. (2001). Quı´mica de los alimentos. In: Alhambra (Ed.), México D.F., 94–104.

Banks, W., & Greenwood, C. T. (1975). *The biogenesis of starch granules in higher plants*. New York: Appleton Crofts p. 853.

Beynum, G. M. A., & Roels, J. A. (1985). *Starch conversion technology*. New York, U SA: Marcel-Dekker p. 980.

Ganga, Z. N., & Corke, H. (1999). Physical properties of starch of Asian-adapted potato varieties. *Journal of Science Food Agriculture, 79*, 1642–1646.

Hagenimana, A., Pu, P., & Ding, X. (2005). Study on thermal and rheological properties of native rice starches and their corresponding mixtures. *Food Research International, 38*, 257–266.

Han, H. L., & Saskatoon, F. W. S. (1998). Cationization of potato and tapioca starches using an aqueous alcoholic-alkaline process. *Starch*, 487–492.

Hoseney, C. R. (1991). Principios de ciencia y tecnologı´a de cereales. Edit. Acribia. Zaragoza, España, p. 682.

Iturriaga, L., Lopez, B., & Añon, M. (2004). Thermal and physicochemical characterization of seven argentine rice flours and starches. *Food Research International, 37*, 439–447.

Jakakody, L., Hoover, R., Liu, Q., & Weber, E. (2005). Studies on tuber and root starches. I. Structure and physicochemical properties of innala (Solestemon rotundifolius) starches grown in Sri Lanka. *Food Research International, 38*, 615–629.

Küppers, H. (1996). Atlas de los colores. Edit. Blume, p. 161.

Lira, S. R. (1996). Chayote *Sechium edule* (Jacq.) Sw. Promoting the conservation and use of under utilized and neglected crops. 8. Institute of plants Genetics and Crops Plant Research, Gatersleben/International Plant Genetic Resources Institute. Rome, Italy. p. 43. In web page: http://www.ipgri.cgiar.org//publications/.

Lovedeep, K., Narpinder, S., & Navdeep, S. S. (2002). Some properties of potatoes and their starches. II Morphological, thermal and rheological properties of starches. *Food Chemistry, 79*, 183–192.

McGrance, S. J., Cornell, H. J., & Rix, C. J. (1998). A simple and rapid colorimetric method for the determination of amylose in starch products. *Starch, 4*, 158–163.

Moorthy, S. N. (2002). Physicochemical and functional properties of tropical tuber starches: a review. *Starch, 54*, 559–592.

Niba, L. L., Bokanga, M. M., Jackson, F. L., Schlimme, D. S., & Li, B. W. (2001). Physicochemical properties and starch granular characteristics of flour from various Manihot esculenta (Cassava) genotypes. *Journal of Food Science, 67*(5), 1701–1705.

Paredez-López, O., Shevenin, M. L., Hernández-López, D., & Carabez-Trejo, A. (1989). Amaranth starch-isolation and partial characterization. *Starch, 41*, 205–207.

Pérez, E., Lares, M., & González, Z. (1997). Some characteristics of Sagu (*Canna edulis* Kerr) and Zulu (*Maranta sp.*) rhizomes. *Journal of Agriculture Food Chemistry, 45*(7), 2546–2549.

Ragaee, S., El-Sayed, M., & Abdel-Aal (2006). Pasting properties of starch and protein in selected cereals and quality of their food products. *Food Chemistry, 95*, 9–18.

Rincón, A. M., Padilla, F. C., Araujo, C., & Tillett, S. (1999). *Myrosma cannifolia*, chemical composition and physicochemical properties of the extracted starch. *Journal of Science Food Agriculture, 79*, 532–536.

Rose, R., Rose, C. L., Omi, S. K., Forry, K. R., Durall, D. M., & Bigg, W. L. (1991). Starch determination by perchloric acid vs enzymes: evaluating the accuracy and precision of six colorimetric methods. *Journal of Agriculture Food Chemistry, 39*, 2–11.

SAGARPA (2004). Sistema de información agropecuaria de consulta. México D.F. In web page: http://www.siap.sagarpa.gob.mx.

Sriroth, K., Piyachomkwan, K., Wanlapatit, S., & Oates, C. G. (2000). Cassava starch technology: the Thai experience. *Starch, 52*, 439–449.

Steffe, J. F. (1996). *Rheological methods in food process engineering* (2nd ed.). East Lansing, MI: Freeman Press p. 796.

Varavinit, S., Shobsngob, S., Varanyanond, W., Chinachoti, P., & Naivikul, O. (2003). Effect of amylose content on gelatinization, retrogradation and pasting properties of flours from different cultivars of Thai rice. *Starch, 55*, 410–415.

Wolfgang, B., Detmold, W., & Hans-Peter, G. (1999). Potato starch technology. *Starch, 51*(7), 235–242.

Yu, L., & Christie, G. (2001). Measurement of starch thermal transitions using differential scanning calorimetry. *Carbohydrate polymers, 46*, 179–184.

Zhao, J., & Whistler, R. L. (1994). Spherical aggregates of starch granules as flavour carriers. *Food Technology, 48*(7), 104–105.