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Physical–chemical and functional properties of maca root starch (*Lepidium meyenii* Walpers)

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ABSTRACT

The starch of maca (*Lepidium meyenii* Walpers) presented oval and irregular morphology, with granule size between 7.4 and 14.9 μm in length and 5.8 and 9.3 μm in diameter. The isolated starch showed the following features: purity of 87.8%, with 0.28% lipids, 0.2% fibre and 0.12% fixed mineral residue, and no protein detected; the ratio between the amylose and amylopectin contents were 20:80; the solubility at 90 °C was 61.4%, the swelling power was 119.0 g water/g starch and the water absorption capacity was 45.9 g water/g starch; the gel turbidity rose 44% during the storing time; the gelatinization temperature was 47.7 °C and the transition enthalpy 6.22 J/g; the maximum viscosity reached 1260 UB at 46.4 °C, with breakdown, setback and consistence of 850, 440 and −410 UB, respectively. The low gelling temperature and the stability during gel refrigeration could be adequate for foods requiring moderate temperature process, but not for frozen food.

1. Introduction

Maca (*Lepidium meyenii* Walpers) is a native plant in the Andes region and belongs to the *Brassicaceae* family. This root is grown in altitudes varying between 3700 and 4450 m (Vilches, 1998). The maca root is considered a high nutritional value food, similar to that of cereal grains, as it has protein contents between 10% and 18%, carbohydrates between 59% and 76%, as well as a high number of free amino acids and considerable mineral contents, such as Fe, Mn, Cu, Zn, Ca, Na and K, yet with discrete lipid portion, between 0.2% and 2.2% (Dini, Migliuolo, Rastrelli, Saturnino, & Stchettino, 1994; Quiros, Epperson, Hu, & Holle, 1996). The roots are consumed in juices, soups, extracts and processed foods enriched with maca flour, but its availability in pills helped its commercialisation in the international market, especially in Europe and Asia with functional and medicinal claims (Cícero, Bandieri, & Arletti, 2001; Gonzales et al., 2001; Quiros et al., 1996; Vilches, 1998).

Starch is the reserve carbohydrate synthesised by superior plants and constitutes the main source of energy of most living organisms (Núñes-Santiago, Bello-Pérez, & Tecante, 2004). Its presence in roots and tubers such as cassava (*Manihot esculenta*), potato (*Solanum tuberosum*), Peruvian carrot (*Arracacia xanthorrhiza*), as well as in seeds and cereal grains mainly contribute to the texture properties of some foods and as raw material in some industrial applications as thickener, colloidal stabilizer, gelling agent, adhesive and water holding agent (Evans & Haisman, 1997; Godfrey & West, 1996; Lii, Tsai, & Tseng, 1996).

Starch is a polymer composed of about 1 part of amylose and 3 parts of amylopectin. Between 70% and 80% of roots and tubers composition is basically 16–24% starch and 4% lipids and proteins. The size of the granule varies from 1 to 110 μm, depending on the starch source, the granules deriving from tubers being larger than those from cereals (Bemmiller & Whistler, 1996; Hoover, 2001; Núñes-Santiago, Bello-Pérez, & Tecante, 2004; Tester, Karkalas, & Qi, 2004).

Starch degradation *in vitro* owing to amylolytic enzymes varies depending on the starch and the gelatinization grain origin. In the vegetable tissues, the susceptibility to the enzymatic attack is influenced by factors such as the amylose:amylopectin ratio, the crystalline structure, the particle size and the presence of enzymatic inhibitors (Zhang & Oates, 1999).

The starches major physical–chemical and functional properties for feeding ends and other industrial applications are gelatinization, retrogradation, solubility, water absorption power, syneresis and their rheological behaviour in pastes and gels. These physical–chemical and functional properties are influenced by the shape, molecular structure and botanical source of native starches in the different vegetable sources (Svegmark & Hermansson, 1993; Wang & White, 1994).

In the present study, the aim was to investigate some physical–chemical and functional properties of the starch extracted from maca (*L. meyenii* Walpers) roots as parameters of potential use in food products. Comparatively, more widely known starches such

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as cassava and Peruvian carrot were employed, both also native from the central and Andean regions of South America.

2. Materials and methods

2.1. Materials and reagents

The maca roots (*L. meyenii* Walpers) were acquired in the State of Arequipa, Peru, 4 days after-harvest; they were washed in 1% sodium hypochlorite solution and dried at ambient temperature. After cleaning, the roots were stored in polyethylene bags and frozen at −18 °C until their use.

All the reagents employed were purchased either from Sigma Chemical Co., or Aldrich Chemical Co.

2.2. Starch extraction

The starch from maca roots was extracted using a slight modification of the method described by Singh and Singh (2001). Roots were manually peeled, cut into small cubes (approx. 3 cm^3) and were ground with water in a blender for 5 min. The homogenate was filtered through muslin cloth. The residue left on the muslin cloth was washed with distilled water. Filtrate was collected in a glass beaker and the residue in the muslin cloth was discarded. The supernatant liquid was decanted, the starch layer was reslurried in distilled water and, again, starch was allowed to settle. This was repeated for 8–10 times until the supernatant became transparent. The starch cake was collected and dried at a temperature of 40 °C in a hot air cabinet drier.

2.3. Physical–chemical properties of starch

2.3.1. Scanning electron micrographs

The size and shape of the starch granule were observed by means of a backscattering electron microscope model Joel JSM 840 (IF-USP). Starch samples were coated with gold by the "sputtering" process, by an Edwards Sputter Coater 150B metalizer. The granules measurement was reported as the averages of the diameters and lengths taken from 30 granules per field.

2.3.2. Determination of the chemical composition

The chemical composition was determined in the roots and in the starch extracted from maca, following the AOAC (1990) and local norms (Instituto Adolfo Lutz., 1985); the total starch analysed by the method described by Areas and Lajolo (1981) and the total carbohydrates were estimated by difference. The dietary fibre (DF) content was determined by the enzymatic–gravimetric method (Prosky, Asp, Schweizer, Devries, & Fuerda, 1992). The total sugars were measured by the phenol–sulfuric reaction (Dubois, Gilles, Hamilton, Rebers, & Smith, 1959) and the reducing sugars by the 3,5-dinitrosalicylic acid reagent (DNS) described by Bernfeld (1951).

2.3.3. Amylose content (%)

The starch amylose content extracted was determined following the Morrison and Laignelet method (1983) with some modifications. A volume of 5.0 ml of UDMSO (dimethyldisulfide and urea at 6 M, 9:1) were added to a 40 mg isolated starch sample; the suspension was vigorously shaken and incubated in a boiling bath for 30 min, placed in a stove at 100 °C for 90 min. A 0.5 ml aliquot of this solution was diluted to 50 ml with distilled water and 1.0 ml I_2–KI (2 mg I_2, 20 mg KI/ml). Finally, the absorbance at 635 nm was measured in a UV–Vis B582 spectrophotometer. The amylose content was determined from a standard curve, using amylose and amylopectin solutions.

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

The maca starch granules swelling power and solubility were triply determined following the method proposed by Leach, McCowen, and Schoch (1959). Aqueous suspensions of 2% starch (w/v) were heated in a water bath at constant temperatures and shaking, for 30 min. Each suspension was cooled and centrifuged at 3000*g* for 15 min; the decanted was weighed and the supernatant was placed in a vacuum stove at 120 °C for 4 h. The data obtained were used to calculate the water absorption capacity, the swelling power and the solubility of the starch granules.

2.3.5. Turbidity

The maca starch gels turbidity was measured as described by Perera and Hoover (1999), by means of a 1% aqueous suspension placed in water bath at constant temperature (90 °C) and constantly shaken for 1 h. The paste was cooled at ambient temperature and stored at 4 °C for 5 days; turbidity was measured at every 24 h, measuring the absorbance at 640 nm in a spectrophotometer (Micronal B582) from time zero.

2.3.6. Stability to freezing and refrigeration

The conditions established for determining stability to freezing and refrigeration were adapted from Eliasson and Ryang (1992). A starch suspension at 6% was heated up to 95 °C for 15 min; it was next cooled to 50 °C and kept at this temperature for 15 min. Aliquots of 50 ml were placed in centrifuge tubes and these were conditioned at three temperatures: ambient, 4 °C and −10 °C, for 5 days. After every 24 h, the samples were centrifuged at 8000*g* for 10 min and later the amount of water expelled during storage was measured.

2.4. Thermal properties

2.4.1. Starch paste properties

The maca starch paste properties were determined according to the method described by Wiesenborn, Orr, Casper, and Tacke (1994), using a viscoamylograph (Brabender PT-100. Germany). An aqueous suspension of 8% starch (dry basis) was heated from 25 to 95 °C at a 1.5 °C/min range and kept at 95 °C for 20 min, and later cooled up to 50 °C at the same temperature range and kept at this second temperature for 20 min. The results obtained from the amylogram were used to calculate the maximum viscosity, consistence, breakdown and setback in Brabender Units (BU).

2.4.2. Differential scanning calorimetry (DSC)

For determining the starch gelatinization temperature, a DSC was employed, (model 822^e, Mettler Toledo, Simple Robot, TSO 801R0, operated by EXSTAR6000 Software), using the technique described by Ruales and Nair (1994), somewhat adapted. To 3.0 mg starch samples (dry basis) 70% distilled water were added to form a suspension. The capsule was hermetically sealed and balanced at ambient temperature for 1 h before being heated in the equipment. The calibration of the system was conducted with metallic indium and an empty aluminum capsule taken as reference. The samples were analysed between 10 and 120 °C at a heating range of 10 °C/min. The starch samples thermal transitions were defined as T_o (initial temperature), T_p (peak temperature), T_f (final temperature) and ΔH_{gel} concerning the gelatinization enthalpy. The enthalpies were automatically calculated from the starch samples on a dry mass basis.

2.4.3. Texture properties of the starch gel

The maca starch gel texture properties were determined from the texture analysis profile (TAP) using a TA/XT2 equipment (Stable Microsystems, Surrey, England). A starch suspension at 6%

was heated up to 95 °C for 15 min, later cooled to 50 °C and kept at this temperature for 15 min. The paste formed was transferred in 40 ml portions in 50 ml beaker flasks and cooled at ambient temperature; they were later stored at 4 °C for 24 h. The gels formed in the flasks were directly used in the texture analysis, and each gel was penetrated 10 mm by a cylindrical probe of P/25 diameter. Two strength–time curves were obtained with 1.0 mm/s speed, during the penetration cycles. From the texture profile curve, fracturability, hardness, cohesiveness, adhesiveness, springiness, gumminess and chewiness were calculated. The TPA analyses were triply conducted.

3. Results and discussion

3.1. Granule size by scanning electron micrographs

The maca starch granule morphology and distribution are shown in Fig. 1. The maca starch granules presented oval and irregular morphology with a distribution between 7.4 and 14.9 μm in length and 5.8 and 9.3 μm in diameter. The morphology observed was similar to that of biri (*Canna edulis*) and oca (*Oxalis tuberosa*) starch, also known as Andean roots, with sizes between 35 and 101 μm, and 22 and 55 μm, respectively (Santacruz, Koch, Svensson, Ruales, & Eliasson, 2002).

Some authors have demonstrated the influence of the temperature variation in the cultivation of sweet potato, wheat and maize, concerning the starch granule size and have observed the decrease in size and, consequently, changes in the starch granules physical–chemical properties (Lu, Jane, Keeling, & Singletary, 1996; Noda, Kobayas, & Suda, 2001; Singh, Seib, & Bernardin, 1994). As to maca starch, probably the environmental conditions (temperatures from 4 to 7 and −10 °C) for cultivating the root could influence the starch granule morphology and size. Yet, there are neither records of the cultivation of this product in other environmental conditions, nor studies concerning the maca starch properties, which does not allow for confirmation of this hypothesis.

Table 1
Chemical composition of maca root and starch

Components	(%) Dry basis	
	Maca root	Maca starch
Crude protein	17.69 ± 1.96	NI*
Lipids	3.61 ± 0.04	0.28 ± 0.03
Carbohydrates	72.78 ± 0.2*	99.06 ± 0.02*
Fibre soluble	8.50 ± 0.32	NI*
Fibre insoluble	23.24 ± 0.07	0.2 ± 0.01
Total starch	23.17 ± 1.06	87.83 ± 0.87
Total sugar	18.87 ± 0.35	1.53 ± 0.52
Sugar reducing	13.10 ± 0.17	1.21 ± 0.65
Amylose	ND*	20.45 ± 0.91
Amylopectin	ND*	79.54 ± 0.91
Ash	5.93 ± 0.18	0.12 ± 0.01

ND*, not determined; NI*, not identify.
* Determined for difference.

3.2. Chemical composition

The results referring to the maca starch chemical composition are shown in Table 1. The isolated starch presented 0.28% lipids, 0.2% fibre and 0.12% fixed mineral residue, but it was not possible to quantify the protein content because of its low content. The isolated starch purity was 88%, which represents high purity when compared to the purity of some *Pachyrhizus ahipa* varieties (56–59%) and those similar to the red sweet potato (87%) (Osundahunsi, Fagbemi, Kesselman, & Simón, 2003; Torruco-Uco & Betancur-Ancona, 2007).

The maca starch presented 20.5% amylose and 79.5% amylopectin (Table 1), this result differs for maize starches (28.3% and 71.7%), red sweet potato (34.2% and 65.8%), malanga (*Xanthosoma saggitifolium*) (24% and 76%) and makal (*Xanthosoma yucatanensis*) (22.4% and 77.6%) (Charles, Chang, Ko, Shiroth, & Huang, 2005; Moorthy, 2002; Osundahunsi et al., 2003; Torruco-Uco & Betancur-Ancona, 2007).

In different cultivations of sweet potato, the starch content varies from 43% to 79% and in it the amylose content goes from 17% to 22% (Madhusudhan, Susheelemma, & Tharanathan, 1992). This can be influenced by the botanical source, the climatic conditions and

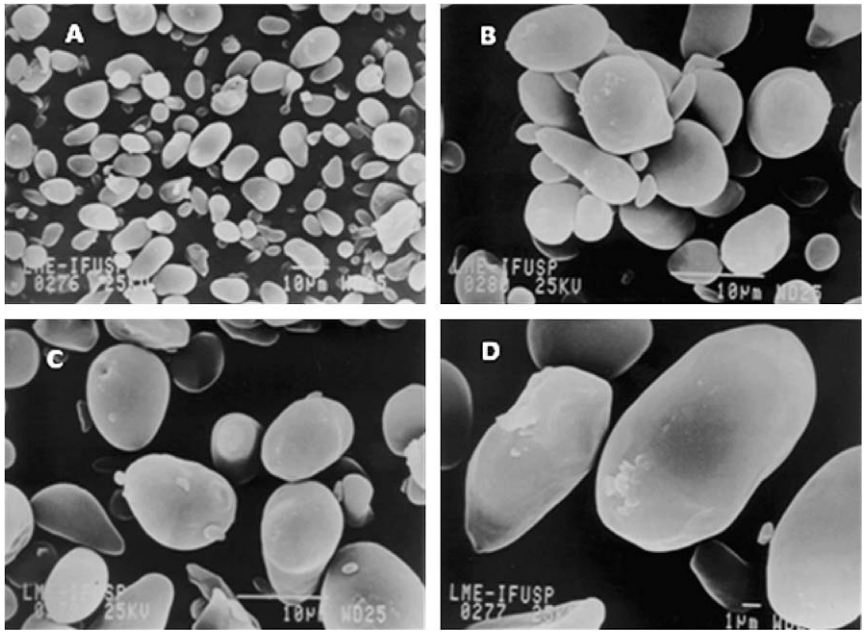

Fig. 1. Scanning electron micrographs (SEM) of maca starch. A: (×550, bar = 10 μm); B: (×1400, bar = 10 μm); C: (×1500, bar = 10 μm); D: (×3000, bar = 1 μm).

types of soil during cultivation, as well as the harvest time, being that a late potato harvest may reduce it from 22% to 18% (Noda et al., 2004).

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

The swelling power (SP), the water absorption capacity (WAC) and the solubility of maca starch are directly correlated to the increment in temperature. Fig. 2A, B (SP), and C (WAC) show the swelling power, the water absorption capacity and the solubility of the maca starch granules, respectively. As can be seen from the figures, low levels of SP were verified; WAC and solubility at temperatures of 30 and 40 °C can be observed, with gradual swelling of the granule from 50 to 90 °C. The swelling power of the maca starch granules at 90 °C was 119.0 g water/g starch, the water absorption capacity was 45.9 g water/g starch and 61.4% solubility; these data are high if compared to the cassava starch (Fig. 2B), or with the data observed by Betancur-Ancona, Chel-Guerrero, Camelo Matos, and Davila-Ortiz (2001), which was 58.8 g water/g starch. Equally high are the values of some maize varieties (13.7–20.7 g water/g starch) (Sandhu & Singh, 2007) and different potato varieties (36.5–40.5 g/g) (Singh, McCarthy, & Singh, 2006).

Starches such as amylose in reduced proportion show high swelling power and low solubility when heated in excess water. The crystalline molecular structure of starch is broken and the water molecules are bonded to the free hydroxyl groups of amylose and amylopectin by hydrogen bonds, which could cause an increment in the absorption capacity and solubility (Singh, Singh, Kaur, Sodhi, & Gill, 2003).

3.4. Turbidity

The gelatinized maca starch suspensions presented relative stability during storage, showing a small reduction in absorbance after the first day (from 0.51 to 0.49 nm) with a small increase after the second storing day (Fig. 3). It can also be observed in the figure that maca starch is more stable than Peruvian carrot starch and similar to cassava starch (Fig. 3). In potato starches, turbidity gradually increased in the first 5 days of storage at 4 °C, varying from 1.25 to 1.85 nm from the 1st to the 5th storing day (Kauar, Singh, & Sodhi, 2002). Sandhu and Singh (2007) observed a progressive increase in gel turbidity from 1.6 to 2.2 nm in maize varieties, during storage between 0 and 120 h.

3.5. Stability to freezing and refrigeration

Syneresis characterises the starch stability to freezing and refrigeration as shown in Fig. 4. The paste presented high stability when stored at ambient temperature and under refrigeration (4 °C), not presenting syneresis. However, the paste showed low stability to freezing in the storing period (−10 °C) and, therefore, high syneresis (4.5%) when compared to cassava and Peruvian carrot starch (Fig. 4). Starches with high amylose value influence the gelatinization and retrograding properties. Starches with high amylose content such as potato (20.1–31.0%), maize (22.4–32.5%), taro (28.7–29.9%) and cassava (18.6–23.6%) present high syneresis, due to the large amount of water expelled during the retrograding process (Gunaratne & Hoover, 2002; Singh et al., 2003). The low syneresis in starch pastes is attributed to the low amylose content, and also to the possible aggregation and to the amylose crystallization occurring during the first storing hours, whilst in amylopectin it would occur at later stages (Miles, Morris, Oxford, & Ring, 1985; Singh et al., 2006).

The paste retrogradation is indirectly influenced by the structural arrangement of the starch chains within the amorphous and crystalline regions of the non-gelatinized granule, acting in the granule breakdown during gelatinization and also in the interactions occurring within the starch chains during the gel storage (Perera & Hoover, 1999).

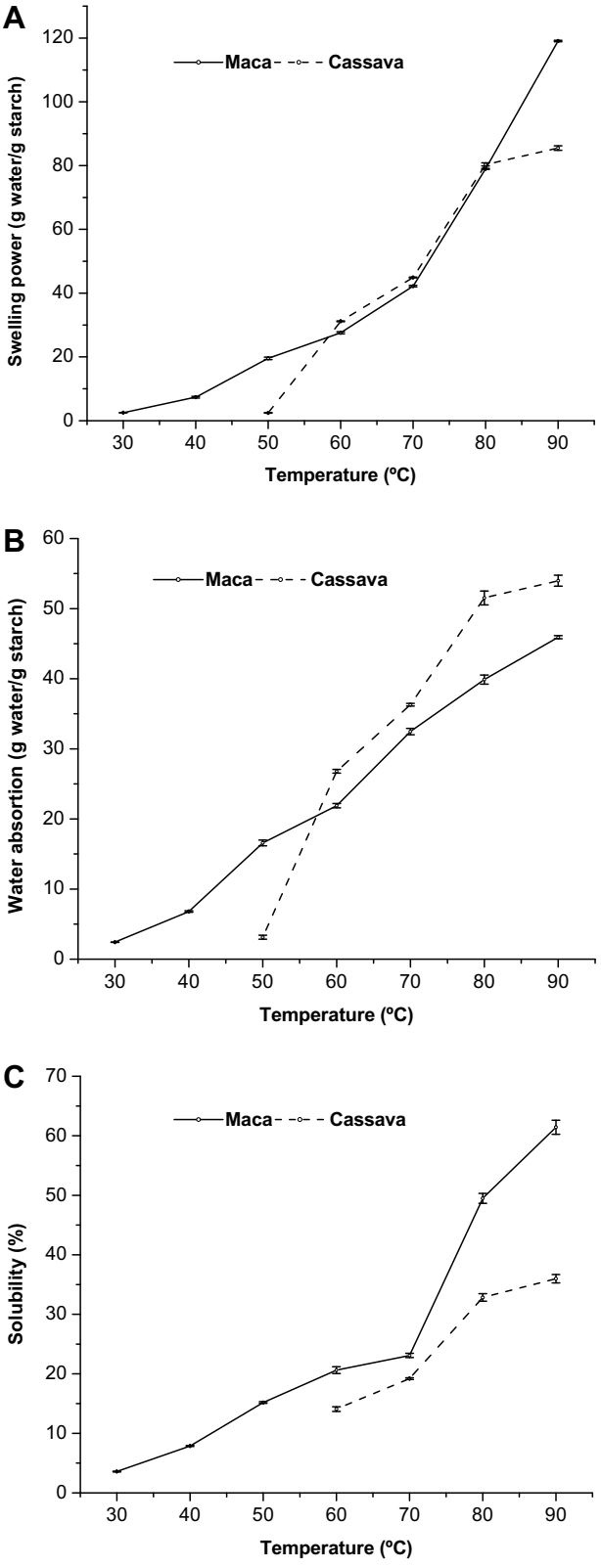

Fig. 2. Comparative hydration curves of starches of maca and cassava as a function of the temperature. A: Swelling power; B: Water absorption capacity; C: Solubility (%).

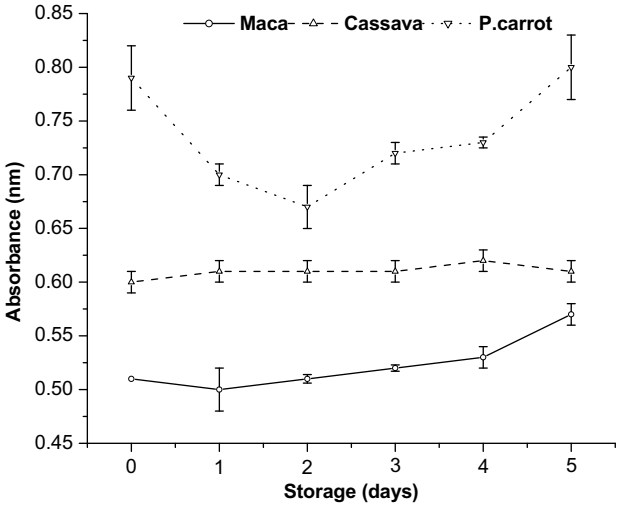

Fig. 3. Effect of storage time on the turbidity starch compared with other starches.

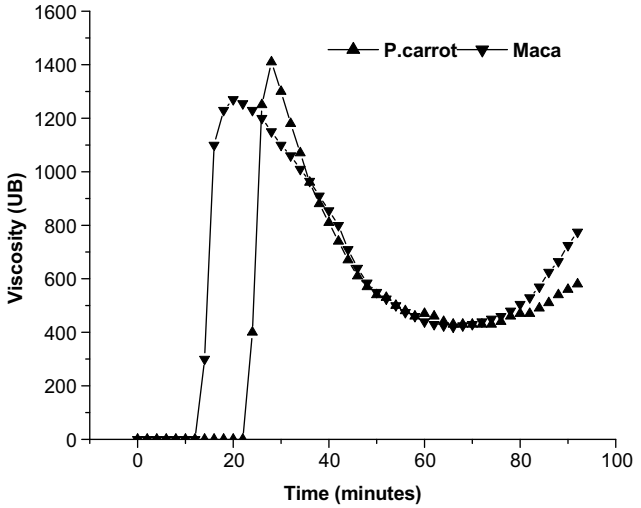

Fig. 5. Viscoamylogram of maca and Peruvian carrot starches.

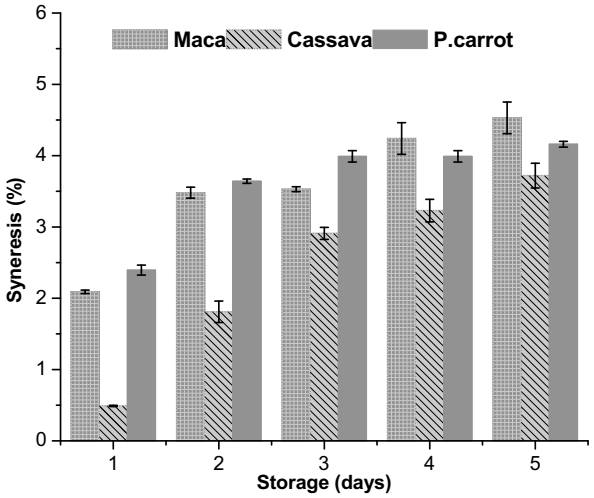

Fig. 4. Refrigeration stabilities of maca starch compared with cassava and Peruvian carrot starches.

Table 2
Paste properties of maca and Peruvian carrot starches

Parameters	Starch	
	Maca	P. carrot
Peak viscosity (BU)	1260	1400
Viscosity at 95 °C (BU)	780	610
Peak viscosity temperature (°C)	46.4	62
Viscosity at 95 °C for 20 min (BU)	410	470
Viscosity at 50 °C (BU)	850	580
Breakdown (BU)[a]	850	930
Consistency (BU)[b]	−410	−820
Setback (BU)[c]	440	110

BU, Brabender units.
[a] Breakdown: peak viscosity (BU) – viscosity at 95 °C for 20 min (BU).
[b] Consistency: viscosity at 50 °C (BU) – peak viscosity (BU).
[c] Setback: viscosity at 50 °C (BU) – viscosity at 95 °C for 20 min (BU).

3.6. Thermal properties

3.6.1. Paste properties

The paste properties are influenced by several factors, such as granule size, the amylose/amylopectin ratio, molecular characteristics of the starch and the conditions of the thermal process employed to induce gelatinization (Zhou, Robards, Glennie-Holmes, & Helliwell, 1998).

Fig. 5 and Table 2 show the rheological behaviour of maca starch and Peruvian carrot starch measured in the Brabender Viscoamilograph. The figure shows that the maca starch profile presents similarities to that of Peruvian carrot (Fig. 5). During the heating from 25 to 95 °C (for 40 min) the maca starch paste presented a maximum viscosity peak of 1260 Brabender Units (BU) after 20 min of heating; at this peak, the temperature was 46 °C. Considering the maca starch gelatinization temperature, at 95 °C it presented 780 BU, and after 20 min at the same temperature, the viscosity fell to 410 BU, rising to 850 BU at the end of the cooling cycle, at 50 °C. The breakdown value of the maca starch paste is high (850 BU) when compared to that of makal (−8 BU), cassava (306 BU) and maize (22 BU) starches (Torruco-Uco & Betancur-Ancona, 2007), but is lower than that of Peruvian carrot (930 BU). The consistency of the maca starch paste presents a negative value (−410 BU), a very low value as compared to makal, cassava and maize (180 and 282 BU, respectively) (Betancur-Ancona et al., 2001; Torruco-Uco & Betancur-Ancona, 2007) and Peruvian carrot (−820 BU). The setback value was 440 BU, which is considered high in the case of cassava, makal and maize (−231, 172 and 304 BU, respectively) (Betancur-Ancona et al., 2001). Low consistence and setback values increase stability paste in mechanical processes and reduce the tendency in retrograding during cooling, this being the case of starches with high swelling power and consequently high viscosity, such as the potato, cassava and waxy starches (Osundahunsi et al., 2003). The granules of these starches markedly swell when cooked in water and the forces turn fragile due to the mechanical shaking, resulting in instability during cooking (Sandhu & Singh, 2007). Conversely, starches rich in amylose present granules with limited swelling due to the internal stiffness of strongly associated linear molecules, and the granules of these starches do not swell enough to form viscous pastes when cooked in water under normal conditions (Sandhu & Singh, 2007).

3.6.2. Diferencial scanning calorimetry (DSC)

The maca starch gelatinization temperature presented a low value, with a 45.7 °C initial temperature (T_o), the gelatinization peak temperature (T_p) was 47.7 °C, the final temperature (T_c) was 51.16 °C, and the gelatinization enthalpy (ΔH_{gel}) was 6.22 J/g, results shown in Table 3 and Fig. 6.

Table 3
Gelatinization properties of cassava, maca and Peruvian carrot starches

Variety	T_o (°C)	T_p (°C)	T_c (°C)	ΔH_{gel} (J/g)
Cassava	61.54	64.82	69.45	9.85
Maca	45.7	47.7	51.16	6.22
Peruvian carrot	59.54	61.95	65.86	10.48

T_o, onset temperature; T_p, peak temperature; T_c, final temperature; ΔH_{gel}, enthalpy gelatinization.

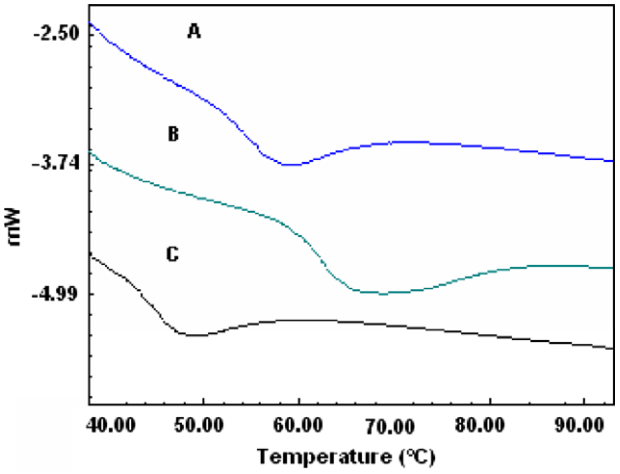

Fig. 6. DSC endotherm curves of gelatinization of starches from different: (A) Peruvian carrot; (B) cassava; (C) maca.

The gelatinization temperature of maca starch was lower as compared to the gelatinization temperatures of cassava (61.5, 64.8 and 69.4 °C) and Peruvian carrot starches (59.5, 61.9 and 65.8 °C), employed as reference for comparing data (Table 3) In the literature, gelatinization temperature data can be found for different products, such as: maize (62.4, 66.3 and 72.9 °C) (Betancur-Ancona et al., 2001), white sweet potato (66.7, 70.7 and 74.8 °C), potato (60, 69 and 80 °C) and cassava (6.4, 69.3 and 84.1 °C) (Osundahunsi et al., 2003; Pérez, Breene, & Bahnassey, 1998). In maca starch, low gelatinization temperature indicates that the beginning of gelatinization requires less energy (ΔH_{gel} = 6.22 J/g) as compared to the Peruvian carrot and cassava starches (10.5 and 9.8 J/g), respectively, and the ones shown by Betancur-Ancona et al. (2001) for cassava (9.6 J/g) and maize (10.3 J/g), as well as for white sweet potato (10.5 J/g) (Osundahunsi et al., 2003).

Li, Berke, and Glover (1994) reported ΔH_{gel} in the 8.2 to 12.3 J/g range for different tropical maize starches, and explained that the variation of gelatinization energy could present differences amongst the bonding forces of the double helix forming the amylopectin crystallography, which resulted in different alignments of the hydrogen bonds within the starch molecules (Sandhu & Singh, 2007).

3.6.3. Texture properties of starch gel

The texture properties of maca gel and of the starches employed as reference (cassava and Peruvian carrot) were determined by a texture analyser and are shown in Table 4 and Fig. 7. The profile of the maca starch gel texture presented high fracturability (2.2 N) and hardness (4.1 N) and lower values of adhesiveness and cohesiveness when compared with cassava and Peruvian carrot starches (Table 4). The gel firmness is mainly caused by the starch gel retrograding, which is associated with the syneresis of water and amylopectin crystallization loss, starches with high paste viscosity result in gels with high stiffness and cracking (Miles et al., 1985). Starch gels presenting high stiffness tend to have high amylose content and long amylopectin chains (Mua & Jackson, 1997). In a potato starch variety, Singh and collaborators (2006) found high fracturability and hardness, attributing this property to the presence of a high percentile of wide granules and low amylose content.

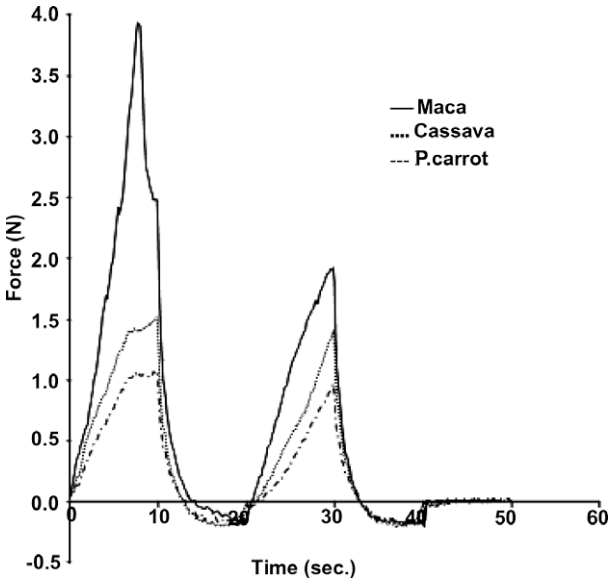

Fig. 7. Texture profile analysis (TPA) curves of starch gels from: (A) maca; (B) cassava; (C) P. carrot.

4. Conclusions

The physical–chemical and functional properties of maca starch (*L. meyenii* Walpers), a non-conventional source, suggest that this product may serve as a model ingredient for foods and other industrial applications that require processing at low temperatures and dispense freezing. The maca starch granules presented different sizes with granules between 7.4 and 14.9 μm in length and 5.8 and 9.3 μm in diameter, which are considered small. For the low amount of protein, the isolated starch could have a wide use for making high-glucose syrup. The 47.6 °C gelatinization temperature of this starch, together with a water absorption capacity of 45.9 g of water/g, swelling power of 119.0 g water/g and 61.4% solubility at 90 °C are of great importance in products subjected to low temperatures during processing. However, the high firmness and stability of the gel during refrigeration could be adequate as thickener, stabilizer and jellifying agent in refrigerated foods,

Table 4
Textural properties of starch gels from maca, Peruvian carrot and cassava

Starch	Fracturability (N)	Hardness (N)	Adhesiveness (Ns)	Cohesiveness	Gumminess (N)	Springiness (s)	Chewiness (Ns)
Maca	2.231	4.126	0.7925	0.506	2.085	0.912	1.901
P. carrot	1.760	0.879	1.986	0.582	0.947	0.850	0.805
Cassava	1.077	1.096	0.910	1.037	0.627	0.815	0.511

despite being inadequate in frozen foods due to the syneresis after retrograding. These values may credit maca as a source for new forms of starch for special purposes, although the low production of the plant for industrial ends is acknowledged.

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