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Comparison of the chemical composition and functional properties of *Phaseolus lunatus* prime and tailing starches

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Abstract

A physicochemical characterization was made of the tailing starch isolated from the legume *Phaseolus lunatus* L. Proximate composition was: 1.33% protein, 3.64% fibre, 0.18% fat, 1.10% ash and 93.8% carbohydrates as nitrogen-free extract. Total dietary fibre content was 22.0%, soluble fibre was 2.28%, and insoluble fibre was 19.7%, as determined using the Prosky AOAC 71, 1017 (1988) method. Amylose, as quantified by differential scanning calorimetry, (DSC) was 35.2%. Gelatinization temperature range, as determined by DSC, was from 67.9 to 89.1 °C, with 75.2 °C being the peak temperature. Transition enthalpy was 10.70 J/g. Swelling power ranged from 5 g water/g starch at 60 °C, to 13.89 g water/g starch at 90 °C. Solubility, analyzed within the same temperature range was from 3 to 14.82%. Syneresis, in a 6% gel stored at 4 °C for 24 h, was 20.6 ml water/50 ml gel. Clarity, expressed as transmittance, was 9.71%. Initial paste temperature was 82.5 °C, breakdown was 72 BU, consistency was 65 BU, and setback was −7 BU.

Keywords: *Phaseolus lunatus*; Tailing starch; Dietary fiber; Functional properties

1. Introduction

The baby lima bean (*Phaseolus lunatus* L.), known as "ib" in Mexico, is well distributed in Latin America, the southern United States, Canada, and many other regions worldwide. It is a reasonably drought-tolerant legume with reported yields as high as 1500 kg/ha (Kay, 1979), and is known to be an efficient organic fertilizer (Sullivan & Davenport, 1993). Though a rich protein (24%) and starch (63%) source, the presence of anti-nutritional factors and toxins in *P. lunatus* L. have limited its consumption (Chel-Guerrero, Pérez-Flores, Betancur-Ancona, & Dávila-Ortiz, 2002). In response, a wet-fractionation process has been proposed as a means of detoxification, but has also been proven as a viable technology for integral use of this seed (Betancur-Ancona, Camelo-Matos, Chel-Guerrero, & Dávila-Ortíz, 2001). Wet-fractionation produces protein concentrates, fibre-rich fractions, and two starch fractions. The first starch fraction, called prime starch, is the purest, and the second, called tailing starch, contains small granules, fractured granules, insoluble protein, and cell wall material (Czuchajowska, Otto, Paszczynska, & Baik, 1998a).

Little research has been done on tailing starches, which have been considered as an inevitable waste product in the wet-fractionation processing of seeds and grains (Otto, Baik, & Czuchajowska, 1997a, 1997b). Given the demand in the food industry for new functional ingredients, it is well worthwhile characterizing this starch with a view towards establishing its possible uses and adding value to this legume seed. The objective of this study was to investigate the physicochemical and functional properties of the tailing starch fraction of *P. lunatus* L. and compare these with the prime starch.

2. Materials and methods

2.1. Seeds and chemicals

The *P. lunatus* L. seeds used in this study were from the February 2000 harvest in the community of Calkiní,

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Campeche, México. The commercial corn starch used was Maizena™, acquired from Productos de Maíz, S.A. (Guadalajara, Jalisco, México).

All chemicals were reagent grade from J.T. Baker (Phillipsburg, NJ), and enzymes were Sigma (Sigma Co., St. Louis, MO, USA).

2.2. Isolation of prime and tailing starches

A total of 10 kg baby lima bean seeds was used in this study. All impurities and damaged seeds were discarded, the remaining, sound seeds milled in a Mykros impact mill, and the resulting flour passed through 20-mesh screen.

Baby lima bean seeds were processed using the wet-fractionation method reported by Betancur-Ancona et al. (2001). Briefly, 1 kg of 20-mesh flour was suspended in distilled water at a 1:6 ratio. The pH was adjusted to 11 with 1N NaOH and the dispersion stirred for 1 h at 400 rpm with a mechanical agitator (Caframo Rz-1). Wet-milling was then done in a Kitchen-Aid mill, separating the fibre solids from the starch and protein mix by using 80- and 150-mesh sieves. The residue was washed 5 times with 200 ml of distilled water. The protein-starch suspension was allowed to sediment for 30 min at room temperature to recover the starch fractions; then the solubilized protein was separated. The starch fraction was then washed three times by resuspending it in distilled water, leaving it to settle for 30 min and siphoning off the liquid. The resulting starch fraction was centrifuged at 1425 g for 12 min, mechanically separating the tailing fraction (upper) from the prime fraction (lower). Both these fractions were then dried at 60 °C for 24 h in an air convection oven (Imperial V), weighed and milled in a Ciclotec mill, until it could be passed through a 20-mesh screen.

2.3. Granule size and microscopic appearance

Starch granule size and shape were determined using the method of McMasters (1964), using a Kyowa optical microscope with ocular graduations for observation and direct measurement. Observations were made by placing samples of 100 ml of 1% starch suspension on slides. Granule observation was made in the total area occupied by the sample on the slide, measuring axial and equatorial diameters for 300 granules.

2.4. Chemical composition

2.4.1. Proximate composition

Nitrogen, fat, ash, fibre and moisture content were determined according to the AOAC official procedures (methods 954.01, 920.39, 923.03, 962.09, and 925.09, respectively) (AOAC, 1997). Nitrogen content (N_2) was determined with a Kjeltec Digestion System (Tecator, Sweden), using cupric sulfate and potassium sulfate as catalysts. Protein content was calculated as nitrogen $\times 6.25$. Fat content was obtained from a 1 h hexane extraction. Ash content was calculated from the weight of the sample after burning at 550 °C for 4 h. Moisture content was measured, based on sample weight-loss after oven-drying at 110 °C for 2 h. The carbohydrate content was estimated as nitrogen-free extract (N.F.E.).

2.4.2. Amylose content

Amylose content was estimated using the calorimetric method of Mestres, Matencio, Pons, Yadij, and Flliedel (1996). Briefly, 8 mg samples were weighed into medium pressure, stainless steel containers. A solution of L-α-Lysophosphatidylcoline (LPC) at 2% w/w in water was added to each container. The cell was then sealed and stabilized for 1 h. Each cell was then placed in a DSC-7 differential scanning calorimeter (Perkin-Elmer Corp., Norwalk, CT), along with a cell containing 50 μl of distilled water as a reference. These were heated from 35 to 160 °C at a rate of 10 °C/min, kept at 160 °C for 2 min, and then cooled to initial temperature at the same rate. The sample was then reheated under the same conditions. Energy data were automatically collected during the analysis. A container was also prepared with amylose, which was processed in the same way as the starch samples. Enthalpies were determined for the sample (ΔH_1) and the amylose (ΔH_2), and amylose content calculated using the following formula:

$$\text{Amylose content (\%)} = 100 \times \text{amylose weight} \times \Delta H_1/(\Delta H_2 \times \text{sample weight}).$$

2.4.3. Total (TDF), soluble (SDF) and insoluble (IDF) dietary fiber

The dietary fibre fractions were determined using the Prosky (1988) method. 1 g (d.b.) (W_1) starch samples were weighed into four Erlenmeyer flasks. To each of these, 50 ml of phosphate buffer (0.08M, pH 6) was added, and the pH adjusted to 6 with 0.325 N HCl or 0.275 N NaOH. These were placed in a water bath at 100 °C for 10 min. Then, 0.1 m α-amylase (Sigma A-3306) was added to each and they were left to incubate at the same temperature for 15 min with constant agitation. The flasks were then cooled rapidly and the sample adjusted to pH 7.5. They were then placed in a water bath at 60 °C for 10 min, a 0.1 ml protease solution added to each (Sigma P-3910, 50 mg in 1 ml phosphates buffer), and left to incubate at the same temperature for 30 min. The flasks were cooled and the samples adjusted to pH 4. They were then returned to the water bath at 60 °C until reaching this same temperature. After adding 0.3 ml amyloglucosidase (Sigma A-9913) to each, the samples were left to incubate for 30 min under constant agitation. Then, 95% ethanol at the

same temperature was added at a 1:4 sample:ethanol ratio, and this was left in the water bath for 1 h. The samples were filtered in crucibles for fibre at a constant weight into which a 1 g cap of celite had been placed previously. The flasks were rinsed three times with 20 ml of 78% ethanol, twice with 10 ml 95% ethanol, twice with 10 ml acetone. The crucibles were then placed in a stove at 130 °C for 1.5 h, and weighed (W_2). Two of the crucibles were placed in a furnace at 550 °C for 4 h (W_3), and crude protein was determined using the contents of the remaining two (W_4). Calculations were done using this formula:

$$\%\mathrm{TDF} = (W_2 - W_3 - W_4 - W_5) \times 100/W_1$$

where W_5 is the reagent target weight.

2.4.4. Insoluble (IDF) and soluble dietary fibre (SDF)

The same Prosky (1988) method was used to quantify IDF, the one difference being that alcohol was not added to precipitate the SDF. Calculation of the IDF percentage in the samples was done in the same way as for TDF. The SDF was calculated by subtracting the IDF value from the TDF value.

2.5. Functional properties

2.5.1. Differential scanning calorimetry (DSC)

Calorimetric characteristics (temperature gelatinization and transition enthalpy) were determined with a DSC-7 (Perkin-Elmer Corp., Norwalk, CT), using the technique described by Paredes-López and Hernández-López (1991). Five milligrams (d.b.) of starch was weighed into an aluminium cell and the moisture level adjusted to 70% by adding de-ionized water. The cell was then hermetically sealed and left to equilibrate for 1 h at room temperature. It was then placed in the calorimeter and heated from 50 to 120 °C at a rate of 5 °C/min, using an empty container as reference. Under these conditions, gelatinization temperature was determined by automatically computing initial temperature (Ti), maximum peak temperature (Tp), final temperature (Tf), and gelatinization enthalpy (ΔH) from the resulting thermogram.

2.5.2. Solubility, swelling power (SP) and water absorption capacity (WAC)

The solubility and swelling power patterns were determined using the method of Schoch (1964) as modified by Sathe and Salunkhe (1981). Briefly, 40 ml of a 1% starch suspension (w/v) was prepared in a previously tared, 50 ml centrifuge tube. A magnetic agitator was placed in the tube, and it was kept at a constant temperature (60, 70, 80 or 90 °C) in a water bath for 30 min. The suspension was then centrifuged at 2120 g for 15 min, the supernatant decanted and the swollen granules weighed. Of the supernatant, 10 ml were dried in an air convection oven (Imperial V) at 120 °C for 4 h in a crucible to constant weight. Percentage of solubility and swelling power were calculated using the following formulas:

$$\%\ \text{Solubility} = \text{dry weight at } 120\ ^\circ\text{C} \times 400/\text{sample weight}$$

$$\text{Swelling Power} = \text{weight of swollen granules} \times 100/\text{sample weight} \times (100 - \%\ \text{solubility})$$

Water absorption capacity was measured using the method of Anderson, Conway, Pheiser, and Griffin (1969). The same conditions as in the method above were used, except that this property was expressed as the weight of the gel formed per sample, divided by treated sample weight.

2.5.3. Syneresis

Syneresis was carried out using the Tjahjadi and Breene (1984) method, modified for the present study. This method measures the volume of water freed by a starch gel (6% w/w) when stored at 4 °C for 24 h. Briefly, 400 ml of 6% (d.b.) starch suspension was heated to 95 °C at a rate of 1.5 °C/min, held at this temperature for 15 min, then cooled to 50 °C at the same rate and held at this second temperature for another 15 min. From this suspension, 50 ml portions were transferred to centrifuge tubes, and these left to cool to room temperature. The tubes were then capped and placed in a refrigerator at 4 °C for 24 h. After this period, the tubes were centrifuged at 10 000 g for 15 min in a refrigerated centrifuge (Beckman model J2-HS), and the volume separated from the gel measured.

2.5.4. Starch gel clarity

This property was measured using the method of Bello-Pérez, Agama-Acevedo, Sánchez-Hernández, and Paredes-López (1999). The transmittance of a 1% starch paste at 650 nm was measured using a spectrophotometer (Beckman DU-650, CA, USA), with de-ionized water as the target. Starch suspensions (1%) in tubes with threaded caps were placed in a water bath at 100 °C for 30 min, agitated in a vortex every 5 min, and left to cool to room temperature. From these, the percentage of transmittance was determined (%T).

2.5.5. Paste properties

These properties were evaluated following the method of Wiesenborn, Orr, Casper, and Tacke (1994), using a viscoamylograph (Brabender PT-100, Germany). Briefly, 400 ml of 6% (d.b.) starch suspension were heated to 95 °C at a rate of 1.5 °C/min, held at this temperature for 15 min, then cooled to 50 °C at the same rate and held at this second temperature for another 15 min and finally cooled to 30 °C at the same

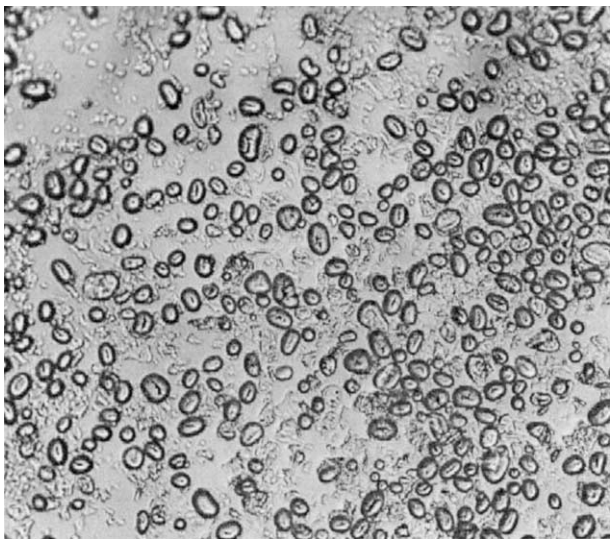

Fig. 1. Microphotograph of *Phaseolus lunatus* tailing starch granules.

rate. Maximum viscosity, consistency, breakdown and setback were calculated in Brabender Units (BU) from the resulting amylograms.

2.6. Statistical analysis

All physical and chemical analyses were carried out in triplicate, and a statistical study done to determine central tendency and dispersion for the results. A Student *t* statistic with a significance level of 5% (Statgraphics plus 2.1 statistical computer software) was applied to determine the differences between means.

3. Results and discussion

3.1. Granule size and microscopic appearance

The granules of *P. lunatus* tailing starch had an oval to spherical form, similar to that reported by Gujska, Reinhard, and Khan (1994) for pinto and navy bean tailing starches, and by Otto et al. (1997a, 1997b) for garbanzo bean and pea tailing starches. Fig. 1 shows the small and damaged tailing starch granules, as well as the irregular forms, from cell wall material. These are characteristic of tailing starch, and have been reported by other authors (Otto et al., 1997a, 1997b)

The smallest diameter for granules of *P. lunatus* tailing starch ranged from 20 to 45 μm (Fig. 2A). Granules with 25 μm diameters accounted for 40% of the total and those with 30 μm diameters for 37%, together forming the majority of granules. Granules of less than 20 μm and more than 40 μm were the minority. The range for the largest diameter was wider, between 20 and 50 (m (Fig. 2B). Granules of 30 μm size accounted for 36% of the total population, the majority, and granules of 45 μm and larger accounted for only 3%, the lowest proportion. This coincides with the grain longitude reported by Czuchajowska, Klaczynski, Paszczynska, and Bailk (1998) for garbanzo bean starch. The smallest average diameter was 26.7 μm and the largest 34 μm, this latter being similar to sizes reported by Betancur et al. (2001) for *P. lunatus* prime starch.

3.2. Chemical composition

3.2.1. Proximate composition

As can be seen in Table 1, the *P. lunatus* prime starch recovered during the fractionating process used was extremely pure (98.6% as N.F.E.). The tailing starch, in contrast, had high protein (1.33%), crude fibre (3.64%) and ash (1.10%) content, indicating that it was composed of a mix of cell wall material, protein, and starch. Similar contents have been reported for tailing starches from the Alaska and Latah varieties of smooth peas (4.55 and 10.2% protein, respectively), from the Scout variety of wrinkled pea (1.21% ash) and garbanzo bean (2.08% ash) (Czuchajowska, Otto et al., 1998; Otto et al., 1997a), and for wheat (2% protein, 0.3% ash)

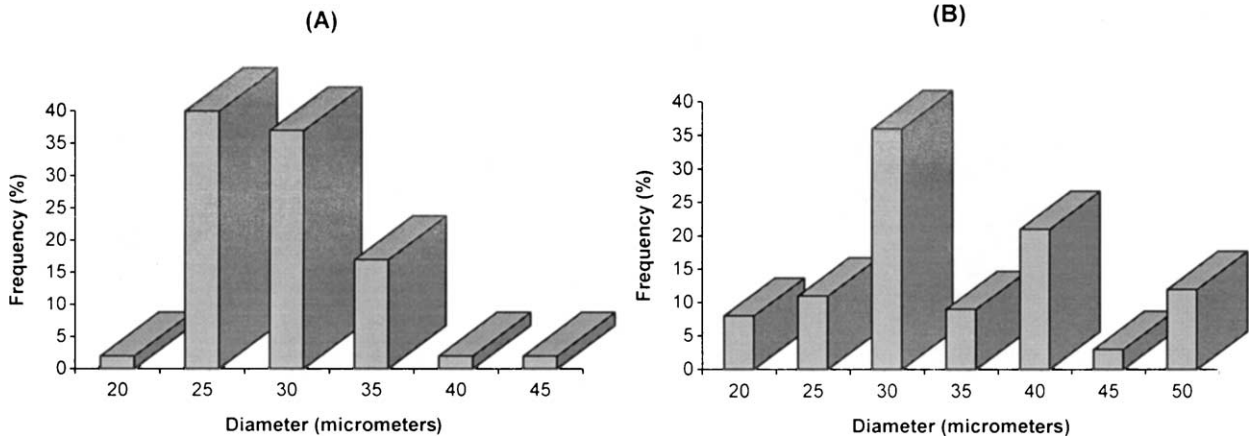

Fig. 2. Smallest (A) and largest (B) diameters distribution of *Phaseolus lunatus* tailing starch granules.

Table 1
Chemical composition of *Phaseolus lunatus* prime and tailing starches (% d.b.)

Component (%)	Prime starch	Tailing starch
Protein	0.12±0.01[a]	1.33±0.04[b]
Fat	0.54±0.01[a]	0.18±0.00[b]
Fibre	0.67±0.02[a]	3.64±0.07[b]
Ash	0.14±0.01[a]	1.10±0.03[b]
NFE	98.53±0.07[a]	93.74±0.18[b]

[a,b] Different letters in the same row indicate statistical difference ($P<0.05$).

(Krishnarau & Hoseney, 1994). These components are present in tailing starch because of the difficulty of separating highly hydratable fine fibre during the wet-fractionation process, and the strong adherence of insoluble protein to the starch (Otto et al., 1997b).

3.2.2. Amylose content

Amylose content was higher in the tailing starch fraction (35.2%) than in the prime fraction (32.6%) (Table 2). This coincides with those seen in other legume starches, though the amylose contents in both the *P. lunatus* L. starch fractions were lower than reported for other legumes (e.g. 48.1% in garbanzo bean tailing starch, 52.6% in smooth pea c.v. Latah tailing starch and 57% in smooth pea tailing starch c.v. Alaska; Czuchajowska, Otto et al., 1998). It was also observed that amylose content was correlated with granule size in that it was lower in the tailing starch fraction than in the prime starch fraction, the latter tending to have a higher amylaceous component content (Szczodrak & Pomeranz, 1992). This high amylose content in the prime and tailing starches of *P. lunatus* L. makes it potentially useful in resistant starch production, be it through heat treatment of isolated starch or inclusion in a food system requiring some heat processing.

3.2.3. Total (TDF), soluble (SDF) and insoluble (IDF) dietary fibre

The definition of dietary fibre used in the present study is the endogenic material of the cell wall that is undigested by the gastrointestinal secretions of humans (Cheung & Chau, 1998). Tailing starch is composed of this material and insoluble protein (Czuchajowska, Otto et al., 1998). This was confirmed in the microscopic and proximal analyses of the *P. lunatus* tailing starch. Total dietary fibre (TDF) content was 22.0%, similar to the 26.2% reported for pea tailing starch (Czuchajowska et al., 1998), the insoluble portion (IDF) was 19.7%, and the soluble portion (SDF) was the remaining 2.28% (Table 2). In contrast, TDF for the prime fraction was 1.25%, with 0.20% IDF and 1.05% SDF. This low TDF content, and the lower IDF percentage, are due to the high purity of this starch fraction. The cell wall material and insoluble fibre removed from this fraction are what increase the IDF proportion in the tailing starch fraction. This same trend has also been reported for smooth pea cv. Latah (26.2% TDF) and garbanzo bean (51.9% TDF), in which TDF in the prime fraction is only at trace levels (Otto et al., 1997b; Czuchajowska, Otto et al., 1998).

The *P. lunatus* tailing starch is a potential source of natural dietary fibre. This is especially salient, given that resistant starch is mainly produced from high amylose content corn starch through chemical and thermal treatments (Tovar, 1992) and that one of the most popular of these products has a 30% TDF and less than 1% fat content (Huang, 1996).

The tailing starch fraction is also potentially useful in health applications because of its high TDF content, and especially its insoluble fibre fraction. These are helpful in the treatment of some disorders as their consumption leads to a decrease in postprandial glucose and improvement of the lipid profile in humans, as well as the inhibition of cancer in epithelial cells (Asp, 1994; Cheung & Chau, 1998; Skrabanja, Liljeberg, Hedley, Kreft, & Björck, 1999).

3.3. Functional properties

3.3.1. Gelatinization temperature

The initial and peak gelatinization temperatures of the *P. lunatus* L. starch fractions showed lower initial temperatures and higher peak temperatures in the tailing fraction than in the prime fraction (Table 3). This is similar to the behaviour reported for other legume starches (Czuchajowska, Otto et al., 1998). In enthalpy transitions, low values are related to amylose-rich star-

Table 2
Amylose, total dietary fibre, soluble dietary fibre and insoluble dietary fibre content of *Phaseolus lunatus* L. prime and tailing starches (% d.b)

Component	Prime starch	Tailing starch
Amylose	32.6±0.10[a]	35.2±0.20[b]
Total dietary fibre	1.25±0.11[a]	21.96±0.20[b]
Insoluble dietary fibrer	0.20±0.09[a]	19.68±0.07[b]
Soluble dietary fibrer	1.05±0.20[a]	2.28±0.28[b]

[a,b] Different letters in the same row indicate statistical difference ($P<0.05$).

Table 3
Gelatinization temperature of *Phaseolus lunatus* prime and tailing starches

Starch	*Ti* (°C)	*Tp* (°C)	*Tf* (°C)	ΔH (J/g)
Prime[c]	69.14[a]	73.87[a]	78.54[a]	10.70[a]
Tailing	67.86[b]	75.18[b]	89.14[b]	10.46[b]

[a,b] Different letters in the same row indicate statistical difference ($P<0.05$).

[c] Betancur-Ancona et al. (2001).

ches, such as legume tailing starches. The values for the *P. lunatus* tailing starch were reduced due to its other components, the interactions between them, its total starch content, granule size and mechanical damage to granules. This phenomenon is also mentioned by Czuchajowska, Otto et al. (1998), Czuchajowska, Klaczynski et al. (1998) and Szczodrak and Pomeranz, (1992).

The fact that gelatinization temperatures for the prime and tailing starch fractions of *P. lunatus* were similar to those of cereals commonly used in industrial processes (e.g. corn = 62–73 °C, and rice = 68–78 °C), is not a disadvantage in terms of the energy output required to gelatinize them in cooking processes (Betancur et al., 2001; Swinkels, 1985).

3.3.2. Swelling power, water absorption capacity and solubility

At lower temperatures, the swelling power values for the *P. lunatus* tailing starch were higher than for the prime fraction (Fig. 3). This trend inverted as temperature increased, with 13.89% swelling for the tailing fraction at 90 °C, statistically ($P < 0.05$) smaller than the 19.90% for the prime fraction. This has also been reported for the starch fractions of garbanzo beans and peas (Czuchajowska, Otto et al., 1998). This is likely due to a tight correlation between starch granule diameter, gelatinization temperature and amylopectin chain length distribution, and a negative relation with amylose content (Sasaki & Matsuki., 1998). The latter is present in high proportions in *P. lunatus* tailing starch, meaning that the small tailing starch granules tend not to retain absorbed water whereas the prime starch granules absorb water and swell as temperature rises (Fig. 4). Also, the fibre, insoluble protein and damaged starch that are present in greater proportions in the tailing starch can absorb large quantities of water but do not retain it when heated, resulting in low swelling values when this starch is heated. Starch swelling power is also said to be a function of amylopectin content as amylose is a diluent and a swelling inhibitor (Cheng, Tsai, & Tseng, 1996).

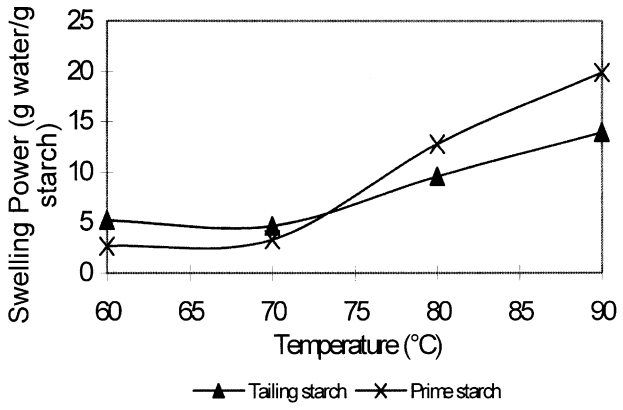

Fig. 3. Swelling power pattern of *Phaseolus lunatus* prime and tailing starches.

Solubility in the tailing starch fraction was higher ($P < 0.05$) (14.82% at 90 °C) at the tested temperatures than in the prime fractions (12.35% at 90 °C) (Fig. 5). This may result from exuding of amylose from both fractions when the starch granules are gelatinized, and since amylose content is lower in the prime fraction its solubility percentage decreases.

The high swelling and water absorption capacity of the *P. lunatus* prime starch make it a potential additive in sausage-type meat products, as these properties are essential for proper texture in these foods (Carballo, Barreto, & Jímenez-Colmenero, 1995).

3.3.3. Syneresis

Syneresis was expressed as the volume of water separated from the formed gel under storage at 4 °C for 24 h. The *P. lunatus* tailing starch had a value of 20.6 ml water/50 ml gel, meaning it is highly unstable in refrigeration relative to corn starch gels, which show no syneresis at concentrations greater than 7%. The high syneresis of legume starches is related to their amylose content, which precipitates when gelatinization begins, causing rigidity when the gels are cooled and stored (Chel-Guerrero & Betancur, 1998).

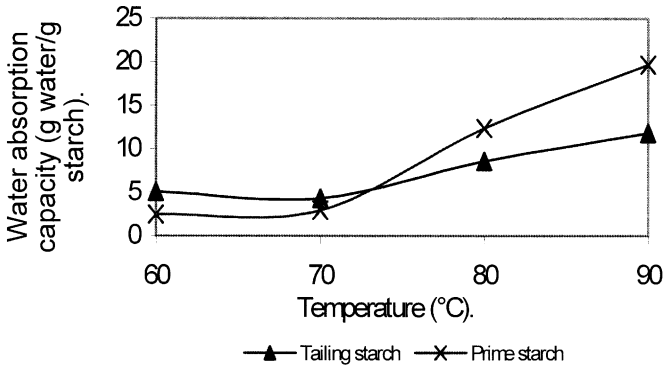

Fig. 4. Water absorption capacity of *Phaseolus lunatus* prime and tailing starches.

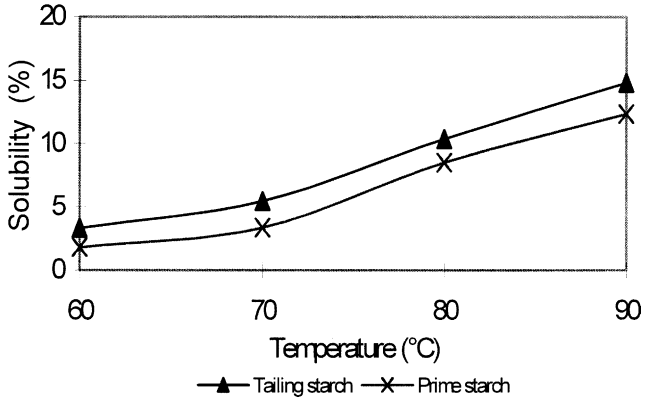

Fig. 5. Solubility pattern of *Phaseolus lunatus* prime and tailing starches.

Because of its instability under refrigeration, the *P. lunatus* tailing starch is not recommended for use in products that require conservation at low temperatures, such as sauces and baked goods, especially if the cooling chain must be broken for product use.

3.3.4. Starch gel clarity

The transmittance of the prime starch (25.29±0.36) was higher ($P<0.05$) than that of the tailing starch (9.71±0.24). The lower clarity in the gels formed from the tailing starch is mainly due to the presence of suspended particles, which are characteristic of this fibrous fraction (Czuchajowska, Otto et al., 1998). Degree of swelling of a starch also directly influences gel clarity (Hoover & Senanayake, 1995). The swelling of the *P. lunatus* prime fraction was greater than the tailing fraction, meaning that the degree of transmittance increased in the pure starch portion.

The clarity of a starch gel directly influences the shine and colour of products that contain it as a thickener. The low clarity of the *P. lunatus* L. tailing starch limits its use as a thickening agent in soups or mayonnaises, while the more transparent primary fraction could be used in sauces (Chel-Guerrero & Betancur, 1998).

Table 4
Paste properties of *Phaseolus lunatus* prime and tailing starches

Parameter	Prime starch	Tailing starch
Initial gelatinization temperature (°C)	90	82.5
Maximum viscosity (BU)	680	387
Viscosity at 95 °C (BU)	680	250
Maximum viscosity temperature (°C)	95	96
Viscosity at 95 °C for 15 min (BU)	650	315
Viscosity at 50 °C (BU)	800	380
Viscosity at 50 °C for 15 min (BU)	840	380
Breakdown (BU)[a]	30	72
Consistency (BU)[b]	150	65
Setback (BU)[c]	120	−7

[a] Breakdown, Maximum viscosity (BU)—viscosity at 95 °C for 15 min (BU).
[b] Consistency, viscosity at 50 °C (BU)—maximum viscosity (BU).
[c] Setback, viscosity at 50 °C (BU)—Viscosity at 95 °C for 15 min (BU).

3.3.5. Paste properties

Paste properties in the *P. lunatus* tailing starch began at 82.5 and at 90 °C for the prime fraction (Chel-Guerrero & Betancur, 1998) (Table 4). This agrees with the

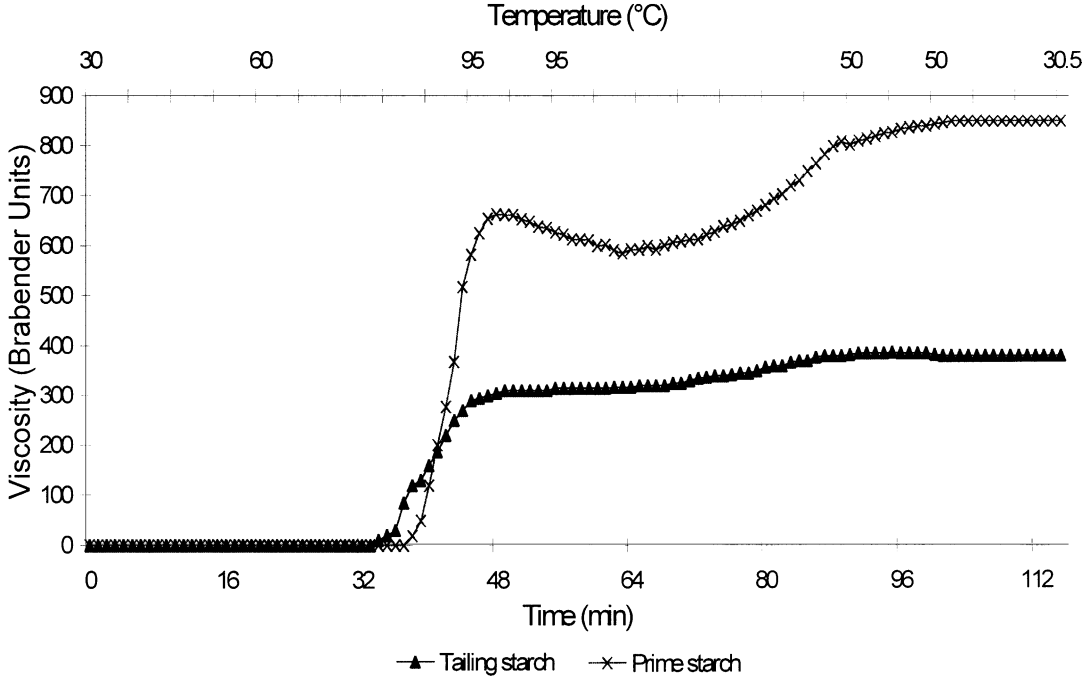

Fig. 6. Viscoamylograph of *Phaseolus lunatus* prime and tailing starches.

high amylose content reported in the tailing starch of garbanzo beans and peas, and also in *P. lunatus* tailing starch (Czuchajowska, Otto et al., 1998).

The viscosity of the *P. lunatus* tailing starch was almost constant throughout the heating and cooling periods, with a constant shear stress, whereas the viscosity of the prime starch increased considerably during the cooling (Fig. 6). Again, these coincide with reported behaviour for garbanzo bean and pea prime and tailing starches (Czuchajowska, Otto et al., 1998). A positive correlation has been suggested between the starch content of the tailing fraction and developed viscosities, which is related to the swelling power of the starch fractions (Czuchajowska, Otto et al., 1998a; Czuchajowska, Klaczynski et al., 1998). Additionally, the *P. lunatus* tailing starch has a moderate swelling power, causing the amylogram peak for the obtained paste to be lower. Thus, weakening from the cooling is less, because the granules do not swell so much that they become fragile, as reported for root and tuber starches. The negative setback value for the tailing starch fraction suggests high stability in the heating and cooling processes. That its breakdown value is higher than that for the prime starch indicates that it has less stability during heating, and its lower consistency value indicates greater stability than for the primary starch fraction during cooling (Villacrés & Espín, 1996).

Its high stability during the heating and cooling processes, with constant shear stress, demonstrates that the *P. lunatus* tailing starch has possible uses in products requiring sterilization, such as baby food. This is especially important since the viscosity of most commercial native starches decreases sharply during these processes, as is the case with yucca starch, a widely commercially used starch in Latin America and Asia (Villacrés & Espín, 1996).

4. Conclusions

The granule of *P. lunatus* tailing starch was oval to spherical, with an average largest diameter of 34 μm and an average smallest diameter of 26.7 μm. This fraction has higher contents of protein, fibre, ash and amylose than the primary fraction, a trait also reported for other legume tailing starches. It also had a higher percentage of total dietary fibre (22.0%), of which the greater part was insoluble dietary fibre (19.68%). Gelatinization temperature and solubility of the tailing fraction were also higher than for the prime fraction, though the opposite was true for swelling power, water absorption capacity, syneresis and clarity of the gels formed from the two fractions. The viscosity of the tailing fraction was low but stable throughout the heating and cooling processes, contrasting with that of the prime fraction, which was high but varied with temperature modifications. The characteristics of the *P. lunatus* tailing starch fraction indicate that it is a good source of dietary fibre which can be included in products subjected to thermal processing. Its use will increase fibre content due to the production of resistant starch, and provide the health benefits attributed to a fibre-rich diet. It has the added benefit that, when incorporated into food systems it behaves like a starch, easing food production and improving sensory characteristics.

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