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Physical and chemical properties of starch and flour from different common bean (*Phaseolus vulgaris* L.) cultivars

Propriedades físicas e químicas do amido e de farinhas de diferentes cultivares de feijão (Phaseolus vulgaris L.)

Milene Marquezi[1], Vanessa Maria Gervin[1], Lucas Bertoldi Watanabe[1], Priscila Zaczuk Bassinello[2], Edna Regina Amante[1]*

[1] *Universidade Federal de Santa Catarina (UFSC), Centre for Agricultural Sciences, Department of Food Science and Technology, Florianópolis/SC - Brazil*

[2] *Embrapa Arroz e Feijão, Santo Antonio de Goiás/GO - Brazil*

***Corresponding Author**

Edna Regina Amante, Universidade Federal de Santa Catarina (UFSC), Centre for Agricultural Sciences, Department of Food Science and Technology, Rodovia Admar Gonzaga, 1346, CEP: 880034-001, Florianópolis/SC - Brazil, e-mail: eamante@cca.ufsc.br

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Summary

The physical, chemical and pasting properties of the flour and isolated starches from six different bean cultivars (*Phaseolus vulgaris* L.) were investigated in order to obtain information for application in new products. The protein and total starch contents of the bean flours ranged from 17.72 to 20.27% and from 39.68 to 43.78%, respectively. The bean starches had low amounts of proteins, lipids and ash and showed an amylose content ranging between 45.32 and 51.11% and absolute density values between 1.55 and 1.78 g.cm^{-3}. The bean starch granules were round to oval with a smooth surface. Results viscoamylographic profiles of the starches and flours showed the possibility of selecting cultivars for specific applications according to these characteristics.

Keywords: *Common bean; Starch; Viscoamylographic profile; Composition.*

Resumo

As propriedades físicas, químicas e de pasta da farinha e do amido isolado de seis diferentes cultivares de feijão (*Phaseolus vulgaris* L.) foram investigadas a fim de obter informações para aplicações em novos produtos. Os teores de proteína e de amido da farinha de feijão variaram de 17,72 a 20,27% e de 39,68 a 43,78%, respectivamente. Os amidos de feijão possuem pequenas quantidades de proteínas, lipídeos e material mineral. O teor de amilose variou entre 45,32 e 51,11% e a densidade absoluta, de 1,55 a 1,78 g.cm^{-3}. Os amidos de feijão apresentaram formato arredondado a ovoide, com superfície lisa. Resultados do perfil viscoamilográfico dos amidos e das farinhas mostraram a possibilidade de selecionar cultivares para aplicações específicas, segundo estas características.

Palavras-chave: *Feijão; Amido; Perfil viscoamilográfico; Composição.*

1 Introduction

Beans (*Phaseolus vulgaris* L.) are members of the Fabaceae family, which include legumes, and are amongst the oldest foods, dating back to the earliest records of human history. *Phaseolus vulgaris* L. is the most widely cultivated species of the genus, accounting for about 95% of the world production (LAJOLO et al., 1996; EMBRAPA, 2010). According to FAO (2014), the five major bean producing countries are Myanmar, India, Brazil, Mexico and the United States, which together account for over 65% of world production. Beans are produced in a variety of environments and cropping systems in various regions, that is, Latin America, Africa, the Middle East, East Asia, Europe and North America (JONES, 1999). This grain has a high protein content, complex carbohydrates, dietary fibre, minerals and B vitamins, and is consumed worldwide (LAJOLO et al., 1996).

The presence of starch as a major constituent in beans and also the presence of proteins in high proportions, lead to discussions about the rheological behaviour and explanations for these properties. The grains are prepared for consumption by cooking, which is responsible for softening, and starch gelatinization has an important influence on the rheological properties of beans derivatives.

Starch contributes greatly to the textural properties of many food products and has many industrial applications such as thickening agent, colloidal stabilizer, gelling, filler agent, water retention and as an adhesive. Knowledge of the granule composition and starch rheological properties is of significant importance for the food industry, which seeks to maintain and enhance the properties of its products during the storage periods (BOBBIO; BOBBIO, 1995). The growing demand for starches for industrial applications has created interest in new sources of these polysaccharides. The applications of starch in food systems are mainly governed by the properties of gelation, pasting, solubility and digestibility (SOBUKOLA; ABODERIN, 2012).

Few studies can be found on bean starch. Accordingly, the purpose of this study was to characterize the physicochemical traits of the starches and flours from different bean cultivars and to relate these characteristics with the other properties in order to seek applications for the starches studied.

2 Materials and methods

2.1 Materials

The bean cultivars were provided by EMBRAPA (Goiás, Brazil) and are among the most economically important crops in Brazil, consisting of the commercial groups known as red, carioca, and black beans. The cultivars analysed were BRS Embaixador and BRS Pitanga (red), BRS Estilo and Pérola (carioca) and BRS Campeiro and BRS Esplendor (black).

The beans were grown in the experimental fields of Embrapa Rice and Beans in Santo Antônio de Goiás, State of Goiás, Brazil, and harvested between September and October, 2011. 100 g portions of the grains were stored in a cool and dry place in polyethylene bags until the time of analysis.

2.2 Sample preparation

After a preliminary cleaning and the removal of any broken and damaged seeds, the dried beans were washed with mild soap and distilled water, and dried in an oven at 45 °C for 5 h, to reduce possible interference in the analysis. The beans were ground in an analytical microprocessor (Q298A21, Quimis®, Brazil) and the resulting flour sieved (60 mesh) to obtain a homogeneous powder. The samples of bean flour were vacuum packed in polyethylene bags and stored at room temperature until the time of analysis.

2.3 Starch isolation

The starch was isolated from the beans using the procedure of Rupollo et al. (2011) with modifications. The grains (300 g) were left in a 0.16% sodium sulphite solution for 24 h at 4 °C, and then ground in a domestic blender. The mass was filtered through filter cloth and the suspension left in a beaker to decant. The supernatant was removed, and the decanted starch layer re-suspended in distilled water and centrifuged (Hermle Z200A, Labortechnik®, Germany) at 1200 *g* for 20 minutes. The upper non-white layer was scraped off. This procedure was repeated until only starch was left, which was collected and dried in an oven (De Leo®, Brazil) at 40 °C for 12 h.

2.4 Chemical analysis

The starch and flour samples were analysed for their moisture, protein (N x 6.25), fat and ash contents according to the methodologies of the Association of Official Analytical Chemists – AOAC (HORWITZ, 2005). The starch content of the bean cultivars was determined by a polarimetric method according to the methodology of the Ministry of Agriculture, Rural Development and Fisheries (PORTUGAL, 2000), and the amylose content of the starch samples was determined using the method of Williams et al. (1970).

2.5 Absolute density

The absolute density of the starch granules was determined using a pycnometer by the displacement of xylene at 30 °C, according to Schoch and Leach (1964).

2.6 Granule morphology

The starch samples (previously dried in an oven at 40 °C) were compared by scanning electron microscopy (SEM) as to the size and shape of the granules. Each of the six powdered samples was fixed to an aluminium support using double-sided tape and metalized with a 350 Å thick gold layer in a Polaron E5000 vacuum device with magnification of x700.

2.7 Pasting properties

The pasting properties of the bean flours and isolated starches were determined using a Rapid Visco Analyser (RVA 4500, Perten Instruments®, Sweden), with initial and final temperatures of 50 °C and 95 °C, and maintaining at 95 °C for 10 min, simulating the domestic cooking of beans A sample suspension (3.0 g in 25 mL distilled water) adjusted to 0% moisture, was used for both the flours and the isolated starches. The samples were held at 50 °C for 1 min., heated to 95 °C during 7.5 min, and then held at 95 °C for 10 min before cooling to 50 °C during 3 min. The parameters, including pasting temperature, peak viscosity, breakdown, final viscosity and setback, were recorded.

2.8 Statistical analysis

All the analyses were carried out with three repetitions, the results submitted to an analysis of variance (ANOVA) and the averages compared applying the Tukey test at 5% significance. The ASSISTAT 7.7 statistical program was used.

3 Results and discussion

3.1 Chemical composition

The definition of the optimum range for different applications requires knowledge of the chemical and physical characteristics of the raw material. Table 1 shows the values obtained for the chemical composition of the bean flour and starch samples.

The protein content of the bean flours ranged from 17.72 to 20.27%, indicating a high amount of protein in this legume and its potential as a dietary protein source. BRS Pitanga, Pérola and BRS Esplendor showed higher levels of protein compared to the other cultivars. Similar results were found by Saha et al. (2009), where thirty-five different genotypes of *Phaseolus vulgaris* L. were studied and the protein content ranged from 18.66 to 26.17%. The values found for moisture, ash and lipids of the bean flours were close to those found by Ramírez-Cárdenasi et al. (2008) who studied five varieties of beans, and the results ranged from 10.69 to 15.38%, 3.36 to 4.22% and 1.27 to 1.94%, respectively.

The total starch content of the bean flours ranged from 39.68 to 43.78%, the BRS Esplendor flour containing a lower starch content than the others (Table 1). These values are close to those found by Pujolà et al. (2007), where the starch contents of nine *Phaseolus vulgaris* L. cultivars ranged from 41.4 to 52.3%. Chung et al. (2008a) also found similar values, ranging from 36.8 to 40.3%.

Since they are the two major components of the raw material, in addition to the technological properties, the determination of the starch and protein contents might help direct the development of new products. The results obtained for the cultivars in the different groups and in the same group for this and other studies revealed that the chemical composition can vary according to the location planted, the cultivation process and environmental factors.

The protein (0.90 to 2.11%), ash (0.22 to 0.36%) and lipid (0.52 to 0.90%) contents of the isolated starches were as indicated in brackets, showing starches of low-grade purity. The starch is usually extracted by processes that allow for the permanence of contaminants such as proteins, lipids and ash. Although in small quantities, these contaminants can interfere with the physicochemical and functional properties of the starch (LEONEL; CEREDA, 2002). Thus, the purity of the starch can be expressed according to the ash, lipid and protein contents of the raw material coming from the extraction process.

The total starch content ranged from 83.60 to 91.04% in the isolated bean starches. These values are close to those found by Ovando-Martínez et al. (2011) for the Black 8025 (91.69%) and Pinto Durango (88.56%) cultivars when they were grown under irrigated and rain fed conditions. The starch yields from BRS Embaixador (26.10%) and BRS Pitanga (19.38%) were higher than those from BRS Estilo (17.15%), Pérola (16.75%), BRS Campeiro (18.26%) and BRS Esplendor (17.12%).

Table 1. Chemical composition of the bean flours and starches.

Sample	Total starch (%)	Protein (%)	Moisture (%)	Ash (%)	Lipids (%)
Bean flour					
BRS Embaixador	42.31 ± 0.96^{b}	18.91 ± 0.08^{c}	8.21 ± 0.13^{d}	3.67 ± 0.09^{c}	1.10 ± 0.04^{b}
BRS Pitanga	42.30 ± 0.30^{b}	20.27 ± 0.04^{a}	8.60 ± 0.16^{c}	3.74 ± 0.09^{bc}	1.15 ± 0.12^{b}
BRS Estilo	43.65 ± 0.46^{a}	17.72 ± 0.33^{d}	10.53 ± 0.14^{a}	3.44 ± 0.08^{d}	1.56 ± 0.07^{a}
Pérola	42.91 ± 0.28^{ab}	19.91 ± 0.54^{ab}	9.65 ± 0.13^{b}	3.76 ± 0.01^{bc}	1.23 ± 0.04^{b}
BRS Campeiro	43.78 ± 0.24^{a}	19.46 ± 0.15^{bc}	9.62 ± 0.19^{b}	3.91 ± 0.01^{b}	1.20 ± 0.02^{b}
BRS Esplendor	39.68 ± 0.24^{c}	19.92 ± 0.24^{ab}	8.78 ± 0.01^{c}	4.10 ± 0.04^{a}	1.25 ± 0.03^{b}
Bean starch					
BRS Embaixador	83.60 ± 0.02^{c}	1.68 ± 0.06^{b}	13.48 ± 0.08^{a}	0.35 ± 0.04^{ab}	0.90 ± 0.11^{a}
BRS Pitanga	87.90 ± 0.14^{b}	2.11 ± 0.11^{a}	8.81 ± 0.11^{b}	0.36 ± 0.02^{a}	0.86 ± 0.04^{ab}
BRS Estilo	90.30 ± 0.14^{a}	1.07 ± 0.05^{cd}	7.85 ± 0.16^{b}	0.24 ± 0.01^{c}	0.54 ± 0.05^{c}
Pérola	90.03 ± 0.05^{ab}	0.90 ± 0.00^{e}	8.29 ± 0.31^{b}	0.22 ± 0.03^{c}	0.55 ± 0.08^{bc}
BRS Campeiro	91.04 ± 2.12^{a}	0.94 ± 0.04^{de}	7.26 ± 1.93^{b}	0.24 ± 0.05^{c}	0.52 ± 0.17^{c}
BRS Esplendor	89.66 ± 0.21^{ab}	1.13 ± 0.06^{c}	8.33 ± 0.03^{b}	0.26 ± 0.03^{bc}	0.62 ± 0.16^{abc}

Values followed by the same letters in the same column and for the same sample (bean flour or bean starch) do not differ significantly according to the Tukey test with 5% probability.

3.2 Amylose content and absolute density

Table 2 shows the results obtained for the amylose content and absolute density of the bean starch granules. The amylose content was high, ranging from 44.97 to 51.11%. Chung et al. (2008a) found lower values than those presented in the present work. According to these authors, the amylose content for three cultivars ranged from 38.0 to 41.5%. In comparison with other legumes, the values obtained for the six cultivars were higher than those found for mung bean cultivars (30.4 to 34.6%) (SINGH et al. 2004), lentils (23.5 to 24.7%), chickpeas (23.0 to 23.3%) and peas (23.9 to 24.1%) (HOOVER; RATNAYAKE, 2002).

The amylose content may vary from starch to starch with respect to the amount, size, shape and association mode of the granule, which determines the extent and crystal structure type (WHISTLER; DANIEL, 1993). The amylose and amylopectin contents of legumes may partially explain the reduced glycemic responses produced by these foods. The starch granules contain large amounts of amylose (24-65%), responsible for the retrogradation phenomenon, while most other food carbohydrate sources contain no more than 25 to 30% (LAJOLO; GENOVESE; MENEZES, 1996).

In the present study starches with varying densities were found, but there were no significant differences in density between cultivars. When compared to other botanical starch sources, the density of the BRS Estilo starch was closer to those of the banana plantain (1.5280 g.cm^{-3}) (SILVA; SILVA, 2005), sweet potato (1.4794 g.cm^{-3}) (BATISTUTI et al., 1993) and yam (1.522 g.cm^{-3}) starches (DURANGO et al., 2009).

Table 2. Amylose content and absolute density of the isolated bean starches.

Starch Samples	Amylose (%)	Absolute density (g.cm^{-3})
BRS Embaixador	45.32 ± 0.12^{c}	1.78 ± 0.35^{a}
BRS Pitanga	48.16 ± 0.40^{b}	1.77 ± 0.16^{a}
BRS Estilo	51.11 ± 0.57^{a}	1.55 ± 0.15^{a}
Pérola	49.25 ± 0.12^{b}	1.72 ± 0.10^{a}
BRS Campeiro	44.97 ± 0.31^{c}	1.72 ± 0.09^{a}
BRS Esplendor	48.76 ± 0.80^{b}	1.66 ± 0.05^{a}

Values followed by the same letters in the same column do not differ significantly according to the Tukey test with 5% probability.

3.3 Starch granule characteristics

The size and shape of bean starch granules vary according to species and the size distribution varies with the stage of plant development (LEONEL, 2007). Figure 1 shows the scanning electron micrographs of the different native bean starch granules studied here.

The size distribution of the granules showed different sizes and shapes, but most of the bean starch granules were spherical or ellipsoid, in agreement with other studies (SINGH et al., 2004; RUPOLLO et al., 2011; VANIER et al., 2012). The sizes of the ellipsoid starch granules ranged from 29.61 to 35.94 μm in length and from 18.99 to 24.01 μm in width. Of the ellipsoid granules,

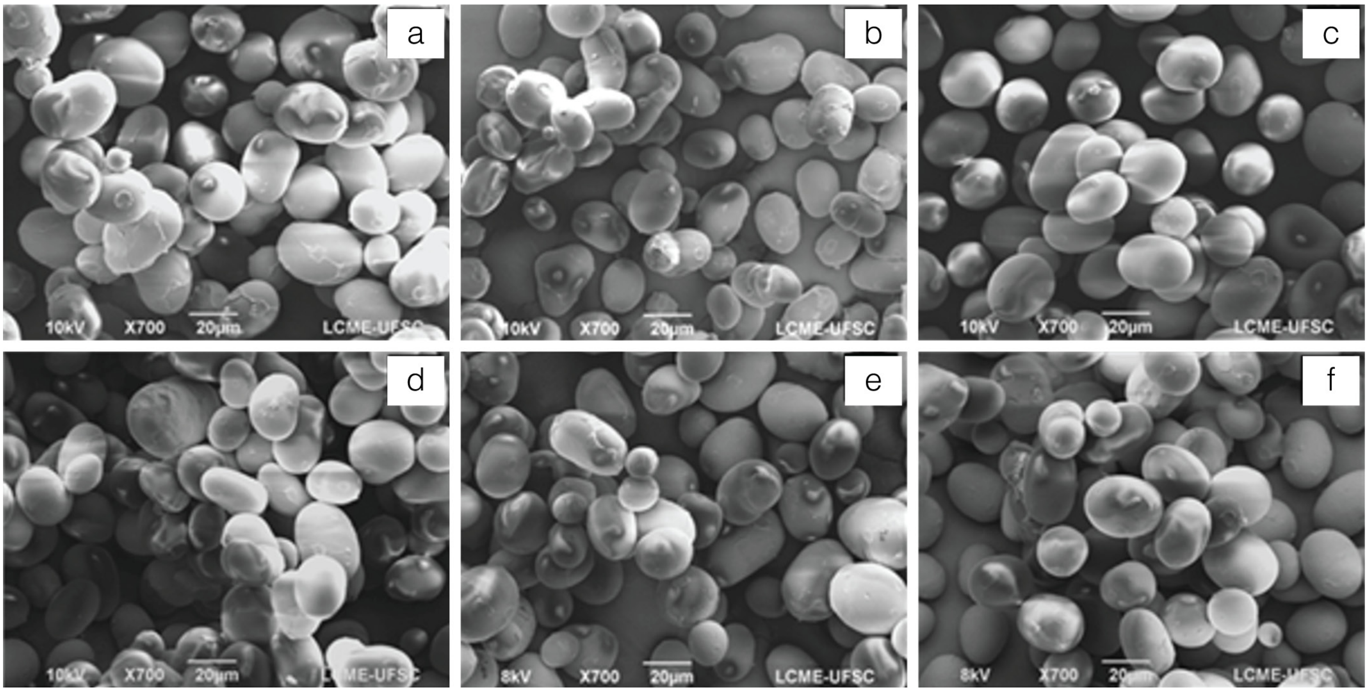

Figure 1. Scanning electron micrographs (x700) of the isolated bean starches: BRS Embaixador (a); BRS Pitanga (b); BRS Estilo (c); Pérola (d); BRS Campeiro (e); BRS Esplendor (f).

the BRS Embaixador ones were the largest and the BRS Pitanga ones were the smallest.

These values are in agreement with those presented by Ovando-Martínez et al. (2011), who found values from 22.61 to 24.88 µm in length and 17.87 to 18.74 µm in width for the ellipsoid granules of the cultivars Black 8025 and Pinto Durango. Chung et al. (2008a) found higher values for the starch granules from the bean cultivars Majesty, Red Kanner and Boating (red colour group) with values ranging from 24 to 47 µm in length and from 23 to 32 µm in width for the ellipsoid granules of these cultivars.

In comparison with starches from other botanical sources, the diameters found for the bean starches were larger than those for cassava starch, (LEONEL, 2007) - from 14.39 to 15.34 µm) and for banana plantain starch (SILVA; SILVA, 2005) - from 9.5 to 12.12 µm). However, the values are similar to those of arrowroot starch, which ranged from 22.05 to 29.54 µm (LEONEL, 2007).

3.4 Pasting characteristics

Figure 2 shows the pasting profiles of the bean flours and starches. The viscoamylographic properties of the bean flours showed similar profiles, with the viscosity increasing with temperature but not decreasing on returning to 50 °C, as expected. None of the samples showed a reduction in viscosity during the heating period at 95 °C, which reveals that the starch granules gelatinized, and other compounds, such as protein and fibre may have contributed to paste stability. Similar profiles were observed

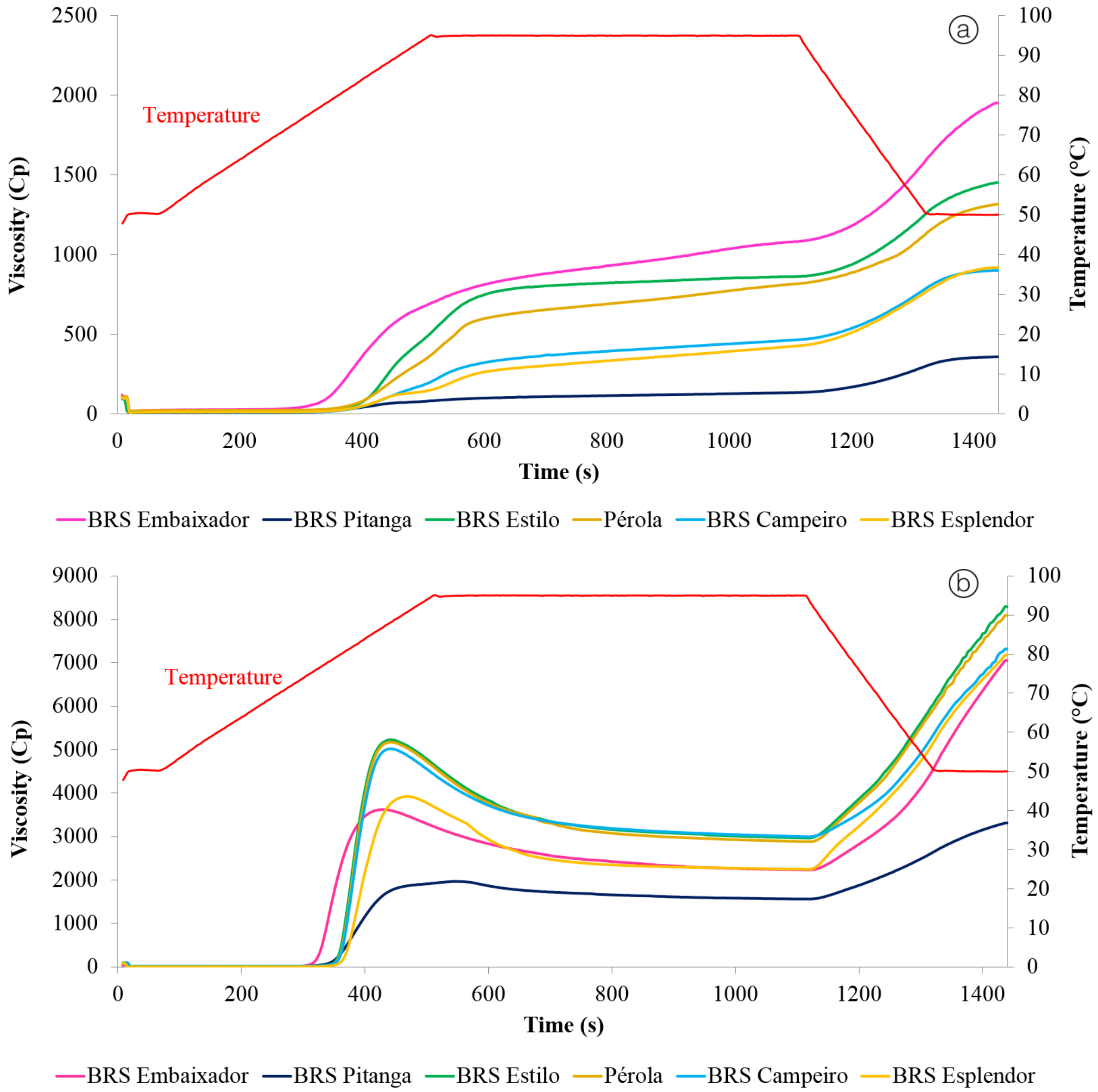

Figure 2. Viscoamylograms of the bean flours (a) and starches (b). The labels indicate the different cultivars.

for the common bean from Canada (CHUNG et al., 2008a) and for the mung bean and fava flours (LIU et al., 2006).

Similar viscoamylographic profiles were observed for the starches of the six cultivars (Figure 2b) and BRS Estilo, Pérola and BRS Campeiro showed superposition of their profiles. The BRS Embaixador, BRS Pitanga and BRS Esplendor starches were less viscous.

Table 3 shows the differences in the parameters evaluated in the viscoamylographic profiles of the flours and isolated bean starches. The maximum viscosity obtained during the heating cycle indicated how high or low the viscosity of the sample could go, which in turn depended on the structure of the starch granules, their proportion of amylose and amylopectin, and the probable combinations that could be made with other ingredients. This parameter becomes important, for example, when the flour is intended for application in the preparation of soups, cakes and other foods in which such properties are required. With respect to this property, the highest peak viscosity for the isolated starch is compared with that of the bean flour.

The final viscosities and setbacks of the bean flours ranged from 355.5 to 1948.5 cP, and from 221.5 to 873.0 cP, respectively. The high values of the trough viscosity for the bean flours are consistent with those of the starch counterparts, which were also high. Comparing the starches, the bean flours of all the cultivars showed a low tendency to retrogradation. As already mentioned, this is because the flour is composed of various substances and the high protein and fibre contents may have contributed to the stability of the paste. Thus, these flours could be used to thicken creamy soups and sauces due to their high viscosities - except for BRS Pitanga - and low tendencies to retrograde. In addition, they could be used in the preparation of breads and creams, since the occurrence of retrogradation in these foods is undesirable and should be avoided.

The pasting temperatures of the bean flours and isolated starches ranged from 86.72 to 95.23 °C and from 71.25 to 75.65 °C, respectively. The high pasting temperature observed for the bean flour demonstrates that, due to the inclusion of other components, such as proteins, fibres and lipids, there was greater resistance to gelatinization, requiring higher temperatures.

The peak viscosities of the isolated starches ranged from 1973.67 to 5233.00 cP, and only BRS Pitanga showed a value below 3000 cP. The trough viscosities ranged from 1561.67 to 2995.00 cP, the final viscosities from 3320.67 to 8295.33 cP, and the setback viscosities from 1759.00 to 5328.67 cP.

Chung et al. (2008a), studying the starches from Canadian bean cultivars, found pasting temperatures ranging from 73.9 to 75.65 °C, peak viscosities ranging from 1980 to 2746 cP and final viscosities from 4802 to 6532 cP. Rupollo et al. (2011) found a peak viscosity of 2819 cP for beans hermetically stored at 5 °C and 2808 cP for the same beans stored at a normal temperature of 25 °C, with final viscosities of 4358 and 4040 cP, respectively, for these two types of storage. Chung et al. (2008b) studying the starches isolated from other legume cultivars, found peak viscosities during heating of from 1129 to 1371 cP, 1185 to 1359 cP and 755 to 1347 cP for pea, lentil and chickpea starches, respectively.

Table 3. Pasting properties of the bean flours and starches.

Sample	Peak viscosity (cP)	Trough viscosity (cP)	Final viscosity (cP)	Setback viscosity (cP)	Breakdown viscosity (cP)	Pasting temperature (°C)
Bean flour						
BRS Embaixador	692.50 ± 1.50[a]	1075.50 ± 13.50[a]	1948.50 ± 1.50[d]	873.00 ± 12.00[a]	nd*	86.72 ± 0.42[d]
BRS Pitanga	82.50 ± 0.50[f]	134.00 ± 1.00[f]	355.50 ± 2.50[e]	221.50 ± 2.18[e]	nd*	95.23 ± 0,62[a]
BRS Estilo	505.33 ± 6.66[b]	863.67 ± 18.88[b]	1451.67 ± 17.21[b]	588.00 ± 8.89[b]	nd*	88.03 ± 0.28[c]
Pérola	365.67 ± 11.37[c]	817.33 ± 14.57[c]	1314.67 ± 23.29[c]	497.33 ± 11.06[c]	nd*	88.07 ± 0.57[c]
BRS Campeiro	199.00 ± 12.16[d]	465.00 ± 14.80[d]	897.66 ± 8.14[d]	432.67 ± 20.26[d]	nd*	88.05 ± 0.22[c]
BRS Esplendor	147.67 ± 5.51[e]	426.67 ± 2.31[e]	916.00 ± 13.23[d]	489.33 ± 14.15[c]	nd*	90.97 ± 0.19[b]
Bean starch						
BRS Embaixador	3632.33 ± 50.12[b]	2239.67 ± 105.83[b]	7055.33 ± 42.16[b]	4815.67 ± 64.52[c]	1392.67 ± 61.86[c]	71.25 ± 0.26[d]
BRS Pitanga	1973.67 ± 7.02[c]	1561.67 ± 29.14[c]	3320.67 ± 45.61[c]	1759.00 ± 43.92[e]	412.00 ± 27.87[d]	72.15 ± 0.26[c]
BRS Estilo	5233.00 ± 135,32[a]	2966.67 ± 323.57[a]	8295.33 ± 127.47[a]	5328.67 ± 200.78[a]	2266.33 ± 194.67[a]	74.32 ± 0,03[b]
Pérola	5175.67 ± 7.02[a]	2882.33 ± 24.58[a]	8088.33 ± 79.40[a]	5206.00 ± 98.09[ab]	2293.33 ± 27.54[a]	75.20 ± 0.43[a]
BRS Campeiro	5020.33 ± 230.67[a]	2995.00 ± 129.00[a]	7315.33 ± 342.46[b]	4320.33 ± 218.51[d]	2025.33 ± 101.89[a]	74.30 ± 0.43[b]
BRS Esplendor	3926.00 ± 83.23[b]	2250.67 ± 177.08[b]	7167.67 ± 181.44[b]	4917.00 ± 25.06[bc]	1675.33 ± 94.40[b]	75.65 ± 0.22[a]

Values followed by the same letters in the same column and for the same sample (bean flour or starch) do not differ significantly according to the Tukey test with 5% probability. *nd: not detectable.

A high viscosity is desirable for industrial uses where the goal is the thickening power and for this retrogradation must be controlled. The amylose content is one of the factors that influences starch retrogradation (BEMILLER; HUBER, 2010), a higher proportion of amylose traditionally being linked to a higher tendency to retrogradation, but the amylopectin content, intermediate materials, size and shape of the granules and the botanical source, also have a role in retrogradation (SINGH et al., 2003).

The high values for retrogradation of the isolated starches (1759 to 5328.67 cP) were linked to the high amylose values of the bean starches. The relationship between amylose and starch retrogradation was evident for BRS Estilo, which had the highest amylose percentage of all the cultivars, and therefore a greater tendency to retrogradation.

4 Conclusions

The results obtained for the physical and chemical characteristics and pasting properties of the flours and isolated starches from the bean cultivars studied showed that even cultivars of the same commercial group had significant differences. Starch is the major constituent of the beans, but the high protein contents make them a good source of protein in the diet. Thus, the flour could be used as a supplement for wheat flour, increasing the nutritional quality of bakery products. Furthermore, the low lipid content suggests the possibility of developing products with high protein and low fat contents made from beans. The isolated starches showed small amounts of protein, ash and lipids, which could interfere with the pasting properties. The bean flours of all the cultivars showed low setback values and high final viscosities and could be used to increment creamy soups and sauces. High viscosity starches from the different cultivars could be used in food products that require this feature as thickeners for creams, soups and puddings, although the high setback of these isolated starches, due to the high amylose content, would be a difficulty that would have to be overcome. Since it has a low setback, the starch from the BRS Pitanga bean could be used in stored products, such as bakery products. Knowledge of the pasting properties of beans is essential to provide references for the quality control of the raw materials in new products.

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