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Physicochemical properties and digestibility of common bean (*Phaseolus vulgaris* L.) starches

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ABSTRACT

Physicochemical properties and digestibility of pinto bean, red kidney bean, black bean and navy bean starches were analyzed. All the common bean starches had oval and spherical granules with average diameter of 25.3–27.4 μm. Amylose contents were 32.0–45.4%. Black bean starch showed the highest peak viscosity, breakdown, final viscosity and setback, whereas red kidney bean starch showed the lowest pasting temperature, peak viscosity, breakdown, and setback. Pinto bean starch showed the highest onset and peak gelatinization temperatures, and the lowest gelatinization temperature range; whereas navy bean starch exhibited the lowest values. Amylopectin of red kidney bean had the highest molecular weight (M_w) and z-average gyration radius (R_z), whereas black bean amylopectin had the lowest values of M_w and R_z. The proportions of DP 6–12, DP 13–24, DP 25–36, and DP ≥ 37 and average branch-chain lengths were 23.30–35.21%, 47.79–53.53%, 8.99–12.65%, 6.39–13.49%, and 17.91–21.56, respectively. All the native bean starches were highly resistant to enzyme digestion.

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1. Introduction

Legumes are the second major food source for human next to cereal and play an important role in the human diet of developing countries (Singh, Kaur, Sandhu, & Guraya, 2004; Tharanathan & Mahadevamma, 2003). Common beans (*Phaseolus vulgaris* L.) are the main legumes consumed in the world, which are widely cultivated and have high nutritional quality; they are an excellent sources of starch and protein and are fairly good sources of dietary fiber, minerals, vitamins, and polyunsaturated fatty acids (Chung, Liu, Pauls, Fan, & Yada, 2008; Ovando-Martínez, Bello-Pérez, Whitney, Osorio-Díaz, & Simsek, 2011; Tharanathan & Mahadevamma, 2003).

Starch is composed of two main components, essential linear amylose and highly branched amylopectin, which are organized into a semi-crystalline granular structure. According to the enzyme digestion rate, starch could be classified into rapidly digestible starch (RDS), slowly digestible starch (SDS), and resistant starch (RS) (Englyst, Kingman, & Cummings, 1992). The most desirable feature of common beans is their starches containing significant amounts of SDS and RS, which result in low glycemic index (GI) response (Tharanathan & Mahadevamma, 2003). Consumption of low GI foods could prevent diabetes, heart disease, cardiovascular disease, obesity, and even certain cancers (Rizkalla, Bellisle, & Slama, 2002).

In the past decades, much attention has been paid on starch and flour properties of various bean varieties from either commercial or newly released source (Chavan, Shahidi, Hoover, & Perera, 1999; Chung et al., 2008; Hoover & Ratnayake, 2002; Kaur & Sandhu, 2010; Ovando-Martínez et al., 2011; Ratnayake, Hoover, Shahidi, Perera, & Jane, 2001). There is a great interest on the relationship between starch digestibility and its structural and physical characteristics of common bean starches. A systemic study on relationship between structural characteristics and functional properties of starches from different common beans could provide important information for optimizing industrial applications. The objective of this study was to investigate physicochemical properties and starch digestibility of various common bean starches.

2. Materials and methods

2.1. Materials

Four common beans (*P. vulgaris* L.), pinto bean, red kidney bean, black bean, and navy bean, were purchased from local supermarket;

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starches were isolated from these beans using a wet-milling process reported by Li, Jiang, Campbell, Blanco, and Jane (2008). Corn starch and potato starch were purchased from Sigma Chemical Co. (St. Louis, MO). All chemicals were reagent grade and obtained from Sigma–Aldrich Co. (St. Louis, USA).

2.2. Starch granule morphology

Starch samples were coated with palladium-gold. Images of starch granules were obtained using a scanning electron microscope (SEM) (JSM-6360LV, Japan Electron Optics laboratory Co., Ltd).

2.3. Starch granule size distribution

Size distribution of starch granules was measured using a laser light scattering particle size analyzer (Mastersizer 2000, Malvern Instruments Ltd., England) following the method described by Singh et al. (2004). 30 starch granules were randomly selected and measured for calculating the mean diameter of the granule.

2.4. Amylose content

Iodine affinity (IA) of starch that was defatted with 85% methanol solution was determined by using a potentiometric autotitrator (702 SM Titrino, Brinkmann Instrument, Westbury, NY). Amylose content was calculated by dividing the IA of starch by 20% (Takeda & Hizukuri, 1987).

2.5. Thermal properties

Thermal properties of starch were analyzed using a differential scanning calorimeter (DSC-7, Perkin–Elmer, Norwalk, CT) equipped with an intracooling II system. Starch (3 mg, dry basis) was mixed with water (9 μl), sealed in an aluminum pan, and equilibrated at 25 °C for 2 h. The equilibrated sample was scanned from 10 to 110 °C at a heating rate of 10 °C/min and an empty pan was used as the reference.

2.6. Pasting properties

Starch pasting properties were determined by using a Rapid ViscoAnalyzer (RVA) (Newport Scientific, Sydney, Australia). Each starch suspension (8%, db, w/w; 28 g total weight) was equilibrated at 50 °C for 1 min, heated to 95 °C at a rate of 6 °C/min, maintained at 95 °C for 5 min, and cooled to 50 °C at a rate of 6 °C/min. A rotating paddle speed of 160 rpm was used for the entire experiment except the paddle speed of 960 rpm was used for the first 10 s.

2.7. Molecular weight and gyration radius of amylopectin

Molecular weight and gyration radius of amylopectin were analyzed using a high-performance size exclusion chromatograph equipped with multi-angle laser scattering and refractive index detectors (HPSEC-MALS-RI) following a method described by Yoo and Jane (2002).

2.8. Branch chain-length distribution of amylopectin

Amylopectin was separated from amylose using gel-permeation chromatography and precipitated using excess ethanol. The collected amylopectin was dispersed using 90% dimethyl sulfoxide (DMSO) and debranched using isoamylase. The branch chain-length distribution of amylopectin was determined using a capillary electrophoresis following a method of Jiang, Campbell, Blanco, and Jane (2010).

2.9. In vitro digestibility of starch

In vitro digestibility of raw common bean starch was determined according to a method of Englyst et al. (1992) modified by Sandhu and Lim (2008).

In vitro digestibility of cooked starch was following the method described by Englyst et al. (1992) with minor modification. Starch (0.50 g, db) in10 mL of sodium acetate buffer (0.1 M, pH 5.2) was cooked in a boiling water-bath for 30 min with stirring. The cooked starch was cooled down to 37 °C, mixed with an enzyme solution (2.5 mL) consisting of pancreatin extract and amyloglucosidase, and incubated in a water-bath at 37 °C. The rapidly digestible starch (RDS) was defined as the total starch digested within the first 20 min, and the slowly digestible starch (SDS) was the starch digested between 20 and 120 min (Englyst et al., 1992). The resistant starch content was calculated as follows:

$$(\%)\text{RS} = \frac{\text{total starch} - \text{RDS} - \text{SDS}}{\text{total starch}} \times 100\%$$

2.10. Statistical analysis

All analyses were performed in duplicate. The mean and standard deviation were reported for each sample. Statistical analyses were carried out with Duncan's multiple test ($p < 0.05$) using statistical software SAS 8.1 (Institute Inc., USA).

3. Results and discussion

3.1. Morphological properties of starches

SEM micrographs of the bean starch granules are shown in Fig. 1. All the common bean starches showed similar granular shapes of round and oval with indentation, which were different from corn and potato starch granules. The surface of all common bean starch granules appeared to be smooth with no evidence of any fissure (Fig. 1). The results are in agreement with previous report (Jane et al., 1999; Hoover & Sosulski, 1991; Hoover & Ratnayake, 2002). Starch granules from different botanical origins differ in morphology. The difference in the granule morphology may be attributed to the biological origin, biochemistry of the amyloplast and physiology of the plant (Hoover & Sosulski, 1991).

Size distributions of the common bean starch-granules are summarized in Table 1. The average granule diameters of the common bean starches ranged from 25.3 to 27.4 μm. Mean granule diameters of the starches in this study followed the following order: potato > red kidney bean > navy bean > pinto bean > black bean > corn (Table 1). Granule size is determined by the biological source from which the starch is isolated (Lindeboom, Chang,

Table 1
Mean granule diameter and amylose content of starch.

Sample	Particle size distribution (μm)	Mean granule diameter (μm)	Amylose content (%)
Pinto bean starch	10.0–60.3	26.0 ± 0.1^{d}	32.0 ± 0.6^{b}
Red kidney bean starch	11.5–60.3	27.4 ± 0.2^{b}	32.4 ± 0.9^{b}
Black bean starch	10.0–60.3	25.3 ± 0.1^{e}	45.4 ± 0.8^{a}
Navy bean starch	10.0–60.3	26.6 ± 0.1^{c}	43.2 ± 1.4^{a}
Corn starch	5.0–45.7	16.3 ± 0.1^{f}	31.5 ± 1.1^{b}
Potato starch	11.5–120.2	45.1 ± 0.2^{a}	24.3 ± 0.3^{c}

Results are mean ± standard deviations of duplicate analysis. Values followed by different letter in the same column are significantly different ($p < 0.05$).

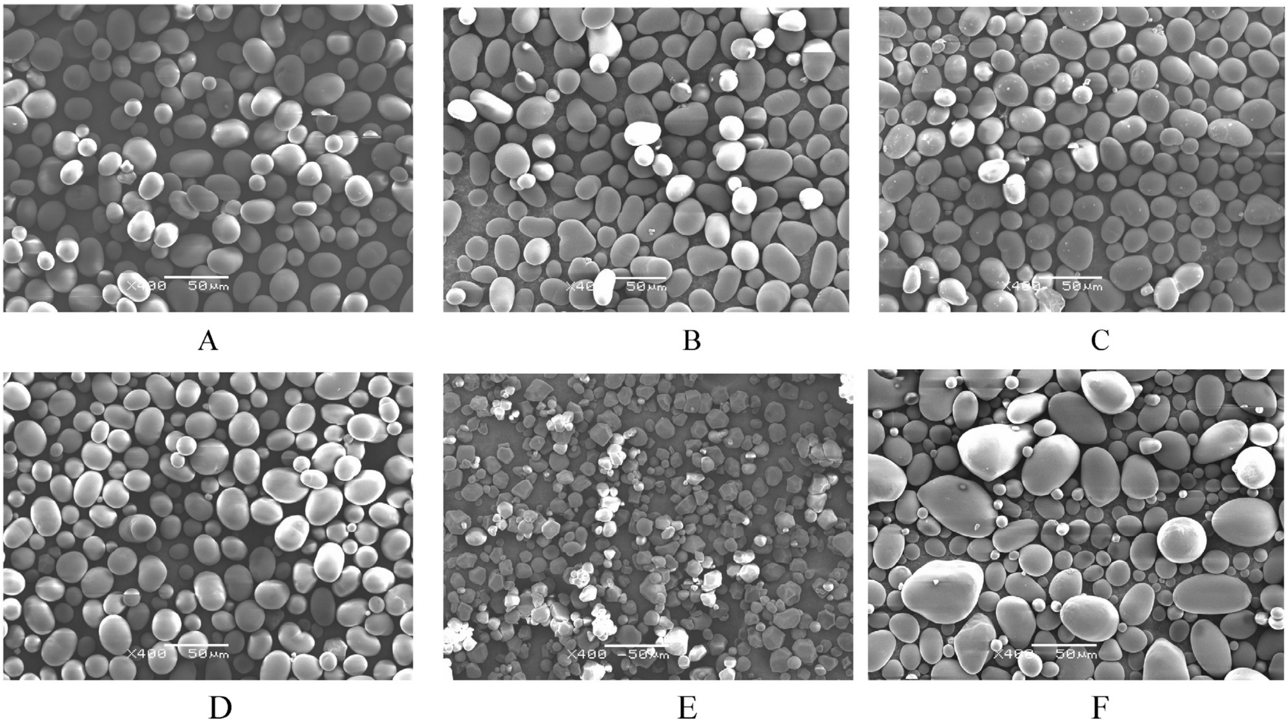

Fig. 1. Scanning electron microscopy (SEM) images of starches at 400× magnification. (A) Pinto bean starch. (B) Red kidney bean starch. (C) Black bean starch. (D) Navy bean starch. (E) Corn starch. (F) Potato starch.

& Tyler, 2004). The shape and size of starch granules has been reported to be varied with plant species and maturity (Jane et al., 1999; Hoover & Sosulski, 1991). Starch granule size and granule size distribution may affect its physicochemical properties, such as pasting, enzyme susceptibility and solubility (Kaur & Sandhu, 2010; Kaur, Sandhu, & Lim, 2010; Lindeboom et al., 2004; Sandhu & Lim, 2008).

3.2. Amylose content

It is known that amylose plays an important role in pasting and gelling properties, and initial gel hardness of cooked starch (Srichuwong, Sunarti, Mishima, Isono, & Hisamatsu, 2005). Significant differences ($p > 0.05$) were observed between different bean cultivars in amylose content (Table 1). The amylose contents of the common bean starches varied from 32.0% to 45.4%, the lowest being found in pinto bean starch and the highest in black bean starch (Table 1). These were within the range (21.2–65.0%) reported for other bean starches (Hoover & Sosulski, 1991). The amylose contents observed for all the common bean starches were higher than amylose contents of potato (24.3%) and corn starch (31.5%). The results were accordance with previous report (Singh, Singh, Kaur, Sodhi, & Gill, 2003). Among different starches, the amylose content is mainly generally controlled by genetic factors (*wx* gene, *du* gene). Some external factors, such as growing conditions, also affect the amylose content in the starch (Singh et al., 2003). Amylose content has a significant effect on functional and physicochemical properties, including pasting, retrogradation and swelling behavior of starch (Blazek & Copeland, 2008; Tester & Morrison, 1990).

3.3. Thermal properties

Gelatinization of starch is the lose of double helical crystalline structure of the external chains of amylopectin (Chavan et al., 1999). The gelatinization temperatures(onset, T_o; peak, T_p; and conclusion, T_c), gelatinization temperature range (R, $T_c - T_o$) and enthalpy of gelatinization (ΔH) for starches from different common bean are presented in Table 2. Significant differences ($p < 0.05$) were observed in T_o, T_p and T_c among bean starches. The gelatinization temperatures of the common bean starches were in agreement with the previous report (Sandhu & Lim, 2008). The differences in gelatinization temperature may be attributed to the differences in amylose content, branch-chain length of amylopectin (Hoover, Hughes, Chung, & Liu, 2010; Jane et al., 1999; Singh et al., 2003), lipid complexed amylose chains (Hoover & Ratnayake, 2002) and granule architecture (crystalline to amorphous ratio) (Tester & Morrison, 1990). Pinto bean starch showed the highest T_o, T_p and the lowest R, whereas navy bean starch exhibited in contrast. The higher gelatinization temperature was an indication of more perfect crystals (Hoover & Sosulski, 1991) or a higher co-operative unit, that is, longer chains in the crystal or a larger crystal size (Hoover & Ratnayake, 2002). Noda et al. (1998) have postulated that T_o, T_p and T_c are influenced by the molecular architecture of the crystalline region, which corresponds to the distribution of amylopectin short chains (DP 6–11), and not by the proportions of crystalline region which correspond to the amylose/amylopectin ratio. Gelatinization temperature is negatively correlated with the amount of amylopectin short branch chains (DP 6–12) and positively correlated with amylopectin long branch chains (DP $\geq$37); short branch chains of amylopectin destabilize the crystalline lamellar structure, whereas the long branch chains of amylopectin could form longer double helices, which require higher temperatures for complete dissociation (Jane et al., 1999; Park, Ibanez, Zhong, & Shoemaker, 2007). The gelatinization temperatures, gelatinization temperature range ($T_c - T_o$) and enthalpy change of gelatinization (ΔH) of all the common bean starches were higher than that of potato starch and corn starch (Table 2). The enthalpy change (ΔH) of red kidney bean starch was higher than that of other bean starches. The gelatinization enthalpy change has been reported to be related to characteristics of the starch granule such as degree of crystallinity (Krueger, Knutson, Inglett, & Walker 1987) and granule size (Bogracheva, Meares, & Hedley, 2006). The

Table 2
Thermal properties of starch.

Sample	T_0 (°C)	T_p (°C)	T_c (°C)	R (°C)	ΔH/(J/g)
Pinto bean starch	67.6 ± 0.6[a]	73.6 ± 0.5[a]	79.7 ± 1.0[a]	12.1	14.3 ± 0.8[bc]
Red kidney bean	65.7 ± 0.7[b]	72.8 ± 0.1[ab]	80.2 ± 1.6[a]	14.5	14.9 ± 0.5[ab]
Black bean starch	64.4 ± 0.4[c]	72.0 ± 0.8[bc]	79.0 ± 0.7[a]	14.6	13.1 ± 1.0[bc]
Navy bean starch	63.8 ± 0.1[c]	71.7 ± 0.1[bc]	79.1 ± 0.1[a]	15.3	14.0 ± 0.1[bc]
Corn starch	66.1 ± 0.2[b]	71.0 ± 0.3[c]	75.8 ± 0.6[b]	9.7	12.8 ± 0.3[c]
Potato starch	59.0 ± 0.6[d]	63.6 ± 0.6[d]	69.5 ± 0.6[c]	10.5	16.1 ± 1.0[a]

Results are means ± standard deviations of duplicate analysis. Values followed by different letter in the same column are significantly different ($p < 0.05$). T_0, onset gelatinization temperature; T_p, peak gelatinization temperature; T_c, conclusion gelatinization temperature. R, gelatinization range ($T_c - T_0$); ΔH, enthalpy change of gelatinization.

Table 3
Pasting properties of starch.

Sample	Pasting temperature (°C)	Peak viscosity (RVU)	Trough viscosity (RVU)	Breakdown (RVU)	Final viscosity (RVU)	Setback (RVU)
Pinto bean starch	77.4 ± 0.4[bc]	139.3 ± 0.1[c]	115.8 ± 0.9[bc]	23.5 ± 0.9[cd]	216.4 ± 1.2[ab]	100.6 ± 0.3[a]
Red kidney bean starch	76.6 ± 0.3[c]	117.3 ± 0.3[d]	117.3 ± 0.5[bc]	0.0 ± 0.0[e]	209.2 ± 3.9[b]	91.9 ± 3.4[b]
Black bean starch	77.0 ± 0.3[bc]	148.8 ± 4.4[b]	121.0 ± 4.9[b]	27.7 ± 0.5[c]	225.2 ± 8.9[a]	104.2 ± 4.0[a]
Navy bean starch	77.8 ± 0.2[b]	124.5 ± 0.9[d]	107.3 ± 1.1[c]	17.2 ± 0.1[d]	206.1 ± 1.7[b]	97.9 ± 2.8[ab]
Corn starch	81.2 ± 0.8[a]	146.1 ± 3.6[bc]	92.4 ± 3.6[d]	53.8 ± 2.8[b]	156.7 ± 3.2[c]	64.3 ± 2.5[c]
Potato starch	62.1 ± 0.2[d]	584.2 ± 5.0[a]	146.4 ± 8.6[a]	437.8 ± 7.8[a]	205.2 ± 4.0[b]	58.8 ± 2.3[c]

Results are means ± standard deviations of duplicate analysis. Values followed by different letter in the same column are significantly different ($p < 0.05$).

gelatinization properties of starch are related to a variety of factors including the size, proportion and kind of crystalline organization, and ultra structure of the starch granule (Lindeboom et al., 2004).

3.4. Pasting properties

Rapid Visco Analyzer (RVA) is an effective instrument for measuring pasting properties of starch (Bello-Pérez & Paredes-López, 2009; Blazek & Copeland, 2008). The pasting characteristics of the common bean starches are summarized in Table 3. Significant differences ($p < 0.05$) in pasting properties among different common bean starches were observed. Black bean starch exhibited the highest peak viscosity (PV), breakdown (BD), final viscosity (FV) and setback (SB), whereas red kidney bean starch showed the lowest values for pasting temperature (PT), PV, BD and SB. The low BD of red kidney bean starch indicated that this starch was more resistant to the effect of sheer during heating. The low SB agreed with its relatively low amylose content (Table 1). Higher amylose content and proportion of long branch chains in amylopectin increase starch pasting temperature and setback, and decreased peak viscosity and shear thinning (Jane et al., 1999; Park et al., 2007). Pasting temperatures of all the common bean starches, between 76.6 and 77.8 °C, were higher than that of the potato starch, and lower than that of the corn starch. The high pasting temperature of navy bean starch indicates that this starch has a higher resistance to swelling and rupture. Peak and trough viscosity of all the bean starches were lower than potato starch. Final viscosity and setback of all the bean starches were higher than those of potato and corn starches, and breakdown were lower than those of potato starch and corn starch. Final viscosity was affected by the aggregation of the amylose molecules (Blazek & Copeland, 2008). Amylopectin contributes to swelling of starch granules and pasting, whereas amylose inhibits the swelling (Tester & Morrison, 1990). The starch pasting properties was influenced by granule swelling, friction between swollen granules, amylose leaching, starch crystallinity, amylose content and chain length of the starch components (Chung et al., 2008; Hoover & Sosulski, 1991; Jane et al., 1999; Ratnayake et al., 2001; Tester & Morrison, 1990).

3.5. Amylopectin molecular weight and gyration radius

The molecular structure of starch plays a decisive role in its nutritional and functional properties. Weight-average molecular weights (M_w) and z-average radii of gyration (R_z) of the bean amylopectins are shown in Table 4. Significant differences in M_w and R_z of amylopectin were observed among the bean starches. Amylopectin of red kidney bean starch had the largest M_w (8.31×10^8 g/mol) and R_z (306.95 nm), whereas black bean starch had the smallest values of M_w and R_z. M_w of amylopectin was positively correlated to R_z ($r = 0.998$, $p < .01$). M_w of amylopectin of bean starches showed negative correlation with amylose content ($r = -0.846$). Similar inverse relationship between M_w of amylopectin and amylose content has been reported earlier for mango and banana starches (Millan-Testa, Mendez-Montealvo, Ottenhof, Farhat, & Bello-Pérez, 2005), wheat starch (Yoo & Jane, 2002) and legume starch (Sandhu & Lim, 2008). The common bean starches had larger amylopectin M_w than potato starch but smaller than corn starch. The differences in the molecular weight, gyration radius of amylopectin can be explained by molecular structures. Molecular weight (M_w) of amylopectins varied depending on the botanical source. The branch chain-length and branching pattern of the amylopectin molecule are determined the R_z of amylopectin (Yoo & Jane, 2002).

3.6. Branch chain-length distribution of amylopectin

Branch chain-length distribution is summarized in Table 5. The proportions of DP 6–12, DP 13–24, DP 25–36, and DP ≥ 37 and average chain length of common bean starches were 23.30–35.21%, 47.79–53.53%, 8.99–12.65%, 6.39–13.49%, and 17.91–21.56, respectively. The result agreed with previous report (Hoover et al., 2010; Ratnayake et al., 2001). It has been proposed that the branch chains of DP 6–24 are located in a single cluster structure of amylopectin

Table 4
Amylopectin molecular weight and gyration radius of starch.

Sample	$M_w \times 10^8$ (g/mol)	R_z (nm)
Pinto bean starch	5.28 ± 0.26[b]	261.85 ± 9.26[b]
Red kidney bean starch	8.31 ± 1.01[a]	306.95 ± 11.53[a]
Black bean starch	3.06 ± 0.29[bc]	220.05 ± 8.0[c]
Navy bean starch	3.27 ± 0.98[bc]	226.80 ± 26.0[bc]
Corn starch	10.27 ± 2.50[a]	324.25 ± 16.48[a]
Potato starch	1.93 ± 0.40[c]	244.05 ± 2.76[bc]

Results are means ± standard deviations of duplicate analysis. Values followed by different letter in the same column are significantly different ($p < 0.05$). M_w, weight average molecular weight; R_z, z-average radius of gyration.

Table 5
Branch chain length distribution and average chain length (CL) of starch.

Sample	Distribution (%)				CL
	DP 6–12	DP 13–24	DP 25–36	DP ≥ 37	
Pinto bean starch	35.21 ± 0.84[a]	47.79 ± 0.29[d]	9.63 ± 0.90[b]	7.37 ± 0.35[c]	18.04 ± 0.02[c]
Red kidney bean starch	23.65 ± 0.12[c]	51.21 ± 0.02[c]	12.65 ± 0.31[a]	12.49 ± 0.45[a]	21.20 ± 0.06[a]
Black bean starch	23.30 ± 0.79[c]	51.02 ± 0.25[c]	12.19 ± 0.28[a]	13.49 ± 0.76[a]	21.56 ± 0.34[a]
Navy bean starch	31.09 ± 0.85[b]	53.53 ± 0.97[b]	8.99 ± 0.46[b]	6.39 ± 0.57[c]	17.91 ± 0.22[c]
Corn starch	30.39 ± 0.14[b]	54.55 ± 0.30[b]	8.67 ± 0.39[b]	6.40 ± 0.06[c]	18.03 ± 0.08[c]
Potato starch	24.29 ± 0.86[c]	57.10 ± 0.84[a]	9.73 ± 0.54[b]	8.88 ± 0.32[b]	19.39 ± 0.16[b]

Results are means ± standard deviations of duplicate analysis. Values followed by different letter in the same column are significantly different ($p < 0.05$). DP is the degree of polymerization.

molecules, forming semicrystalline structures of the starch granules (Hanashiro, Abe & Hizukuri, 1996; Srichuwong & Jane, 2007). The branch chains of DP 13–24 would form double helices, which span the entire length of crystalline regions. On the other hand, the existence of the short chains of DP 6–12 would result in inferior crystalline structures (Jane et al., 1999; Srichuwong et al., 2005). Larger proportion of these short chains was in relation to decreased gelatinization temperatures and swelling power, and increased *in vitro* enzyme digestibility of starch granules (Jane et al., 1999; Srichuwong et al., 2005). Significant differences in average chain length and chain length distribution were observed among the common bean starches (Table 5). The differences in amylopectin structure have great influence on the physicochemical and digestibility properties of starch from different botanical source (Srichuwong et al., 2005). Black bean starch had a smaller proportion of DP 6–12 and a larger proportion of DP ≥ 37 and average chain length. Navy bean starch had a larger proportions of DP 6–12, DP 13–24 and smaller proportions of DP25-36, DP ≥ 37, and average chain length, which molecular structure could have contributed to its relatively lower T_o, T_p and T_c (Table 2). The differences in the chain length distribution could be due to differences in genetic background or genetic variation of starch biosynthetic enzymes (Matsuki, Yasui, Kohyama, & Sasaki, 2003).

3.7. *In vitro starch digestibility*

RDS, SDS, and RS contents of raw and cooked common bean starches are shown in Table 6. The RDS, SDS, RS contents of raw common bean starch were 8.6–10.3%, 13.1–18.1%, and 72.1–78.3%, respectively. SDS contents of raw bean starches were lower than corn starch (44.8%) but higher than potato starch (5.9%). However, RS contents of all the native bean starches were larger than corn starch (24.5%), but smaller than potato starch (84.3%). The results are consistent with previous reported (Chung et al., 2008; Zhang, Ao, & Hamaker, 2006). The SDS content, which is more slowly digested in the small intestine and is considered generally the most desirable form of dietary starch, is the highest in red kidney bean starch (18.1%) and the lowest in pinto bean starch (13.1%). These values were lower than previous reported, which were determined using the Englyst method, by Zhang et al. (2006) and Chung et al. (2008).

The largest RS content was found in pinto bean starch (78.3%) and the smallest for red kidney bean starch (72.1%). High RS content of legume starches offers its potential as a food ingredient as RS possesses physiological benefits similar to dietary fiber. Low RS content of red kidney bean starch may be attributed to its lower amylose content (Table 1), higher peak viscosity and lower setback (Table 3). Size of starch granules may also affect digestibility, as the relationship between surface area and starch volume, and thus contact between substrate and enzyme decreases as the size of granule increases (Svihus, Uhlen, & Harstad, 2005). Both RDS and SDS showed a negative correlation with relative crystallinity and a positive with amylose content (Kaur et al., 2010). In the present study, all the raw bean starches showed high SDS and RS, which is beneficial in management of diseases such as diabetes, as a high level of SDS and RS does not produce hyperglycemia. So we speculate that starch from native common bean could be considered as an ideal RS material. Differences in the digestibility of native starches among species have been attributed to the interplay of many factors such as starch source (Hoover & Sosulski, 1991), granule surface organization (*e.g.* pores), granule size and architecture (Lindeboom et al., 2004), amylose/amylopectin ratio, retrogradation of amylose (Hoover & Sosulski, 1991), degree of crystallinity (Sandhu & Lim, 2008), type of crystalline polymorphic forms (Jane et al., 1999), and the presence of compound granules. The exact underlying mechanism of relative resistance of starch granules is complicated because those factors are often interconnected.

The digestibility also can be affected by the physicochemical properties of the starch, which are influenced by processing or storage conditions. Compared with raw common bean starch, RDS contents of cooked starches significantly were increased, while SDS and RS contents were significantly reduced after cooking. RS and SDS contents of cooked bean starches were higher than that of corn starch and potato starch. There was no significant difference in RS and SDS contents among the common bean starches. The uncooked starches were less susceptible to enzymatic hydrolysis. However, gelatinized starch undergoes changes in structure due to disorganization, increasing the accessibility to the digestive enzymes and consequently its hydrolysis (Chung et al., 2008). In general,

Table 6
Rapidly digestible starch (RDS), slowly digestible starch (SDS) and resistant starch (RS) contents of raw and cooked starches.

Sample	Raw starch			Cooked starch		
	RDS (%)	SDS (%)	RS (%)	RDS%	SDS%	RS%
Pinto bean starch	10.3 ± 0.5[b]	14.7 ± 0.8[c]	75.0 ± 1.2[bc]	87.0 ± 0.7[d]	3.1 ± 0.6[a]	10.0 ± 1.5[ab]
Red kidney bean starch	9.8 ± 1.0[b]	18.1 ± 0.4[b]	72.1 ± 1.6[c]	87.0 ± 0.2[d]	2.0 ± 1.1[ab]	11.0 ± 1.2[a]
Black bean starch	8.6 ± 0.7[b]	13.1 ± 0.3[c]	78.3 ± 1.2[b]	89.1 ± 1.1[bc]	1.1 ± 0.3[b]	9.8 ± 1.4[ab]
Navy bean starch	9.3 ± 0.1b[b]	13.3 ± 0.2[c]	77.4 ± 0.2[b]	87.9 ± 0.3[cd]	2.0 ± 0.7[b]	10.2 ± 1.0[ab]
Corn starch	30.6 ± 0.9[a]	44.8 ± 1.6[a]	24.5 ± 1.7[d]	89.9 ± 0.1[b]	1.7 ± 0.1[ab]	8.4 ± 0.2[ab]
Potato starch	9.9 ± 0.6[b]	5.9 ± 0.7[d]	84.3 ± 1.4[a]	91.4 ± 0.5[a]	0.6 ± 0.4[b]	8.0 ± 0.8[b]

Results are means ± standard deviations of duplicate analysis. Values followed by different letter in the same column are significantly different ($p < 0.05$).

RS content of granular starches is positively correlated with the amylose content (Sang, Bean, Seib, Pedersen & Shi, 2008; Zhu, Liu, Wilson, Gu & Shi, 2011). But, in this study no significant correlations were found between enzymatic digestibility and amylose content of common bean starches, the results are agreement with previous reported on field pea starches (Wang, Sharp, & Copeland, 2011).

4. Conclusions

Black bean starch exhibited the highest peak viscosity, breakdown, final viscosity and setback, whereas red kidney bean starch showed the lowest values for pasting temperature, peak viscosity, breakdown, and setback. Pinto bean showed the highest T_o, T_p and the lowest R, but navy bean starch exhibited in contrast. Amylopectin of red kidney bean starch had the highest M_w and R_z, whereas, black bean starch had the lowest values for M_w and R_z of amylopectin. The proportions of DP 6–12, DP 13–24, DP 25–36, and DP ≥ 37 and average chain length of common bean starches ranged from 23.30% to 35.21%, 47.79% to 53.53%, 8.99% to12.65%, 6.39% to 13.49%, and 17.91 to 21.56, respectively. RDS contents of uncooked common bean starches were lower than corn starch. The largest RS content was found in pinto bean starch and the smallest in red kidney bean starch. RDS contents within cooked starch were significantly increased, while SDS and RS contents were significantly reduced after cooking. No significant difference ($p > 0.05$) in SDS and RS contents were noted amongst bean starches after cooking. The low RDS and the high RS and SDS contents of common bean starches offer their potential as a good source of RS.

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