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In vitro starch digestibility, expected glycemic index, and thermal and pasting properties of flours from pea, lentil and chickpea cultivars

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ABSTRACT

In vitro starch digestibility, expected glycemic index (eGI), and thermal and pasting properties of flours from pea, lentil and chickpea grown in Canada under identical environmental conditions were investigated. The protein content and gelatinization transition temperatures of lentil flour were higher than those of pea and chickpea flours. Chickpea flour showed a lower amylose content (10.8–13.5%) but higher free lipid content (6.5–7.1%) and amylose–lipid complex melting enthalpy (0.7–0.8 J/g). Significant differences among cultivars within the same species were observed with respect to swelling power, gelatinization properties, pasting properties and *in vitro* starch digestibility, especially chickpea flour from desi (*Myles*) and kabuli type (*FLIP 97-101C* and *97-Indian2-11*). Lentil flour was hydrolyzed more slowly and to a lesser extent than pea and chickpea flours. The amount of slowly digestible starch (SDS) in chickpea flour was the highest among the pulse flours, but the resistant starch (RS) content was the lowest. The eGI of lentil flour was the lowest among the pulse flours.

1. Introduction

Pulses are the edible seeds of certain leguminous plants that include lentil (*Lens culinaris* L.), bean (*Phaseolus vulgaris* L.), pea (*Pisum sativum* L.) and chickpea (*Cicer arietinum* L.). Pulse production has been rising steadily in Canada. In 2005, pulse production was 4.9 million tonnes (MT), of which peas represented 3.1 MT, lentils 1.3 MT, beans 0.4 MT and chickpeas 0.1 MT (FAO, 2005). Pulses are rich in starch, protein and dietary fibre with significant amounts of vitamins and minerals, and thus are well suited to meet the demands of health conscious consumers (Almeida Costa, Queiroz-Monici, Machado Reis, & Oliveira, 2006; Tharanathan & Mahadevamma, 2003).

Several researchers have reported that inclusion of pulses in the daily diet has many beneficial effects in controlling and preventing various metabolic diseases, such as diabetes mellitus and coronary heart disease (Englyst, Vinoy, Englyst, & Lang, 2003; Jenkins et al., 1982a; Tharanathan & Mahadevamma, 2003). In addition, pulses have been considered to be appropriate for weight management, because pulses have a low fat content and are rich in protein, fibre and resistant starch, which lead to delayed gastric emptying, resulting in an earlier sense of fullness during a meal, reduced hunger, and increased satiety after a meal (Schneeman, 2002). Pulses have a low glycemic index (GI), meaning they release glucose slowly into the blood stream, which leads to minimal fluctuations in blood glucose levels and a more stable insulin response, which is particularly beneficial for people with diabetes (Rizkalla, Bellisle, & Slama, 2002; Sparti et al., 2000). The glycemic index (GI) is a scale that ranks carbohydrate-rich foods by how much they raise blood glucose levels (Jenkins, 2007; Jenkins et al., 1982b). The GI is measured by the postprandial incremental glycemic area after a test meal, expressed as the percentage of the corresponding area after an equi-carbohydrate portion of the reference food (glucose or white bread) (Brand-Miller, 2007; Roberts, 2000). Foods with a low GI value (<55) have been recommended, because increases in blood glucose and insulin levels are risk factors for cardiovascular disease, obesity, and type 2 diabetes (Brand-Miller, 2007; Rizkalla et al., 2002). The reduced rate and overall reduced starch digestibility of pulses is affected by various factors: cell-wall structure (Hoover & Zhou, 2003), antinutrients such as amylase inhibitors, phytates and polyphenolics (Bravo, Siddhuraju, & Saura-Calixto, 1998; Siddhuraju & Becker, 2005; Yadav & Khetarpaul, 1994), high amylose content (Hoover & Zhou, 2003; Tharanathan & Mahadevamma, 2003), and high content of viscous soluble dietary fibre components (Tharanathan & Mahadevamma, 2003).

The chemical composition and physicochemical properties of pulse flours have been reported by several researchers (Almeida Costa et al., 2006; Kaur, Sandhu, & Singh, 2007; Kaur & Singh, 2005; Liu, Donner, Yin, Huang, & Fan, 2006; Siddhuraju & Becker, 2005; Osorio-Diaz et al., 2002). However, most of the studies on pulse flour have been on a single cultivar or different cultivars in

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single species and it is difficult to ascertain whether the used pulse flours were grown under identical environmental conditions, since environmental conditions have been known to influence physicochemical properties (Tester & Karkalas, 2001). Furthermore, there is a dearth of information on *in vitro* starch digestibility in pulse flours including nutritionally important starch fractions (rapidly digestible, slowly digestible, and resistant starches) and glycemic index of difference cultivars. Starch nutritional fractions as well as thermal and pasting properties of pulse flour are essential for food and industrial application. Thus, the objective of the present study was to evaluate the *in vitro* starch digestibility, expected glycemic index, and thermal and pasting properties in pulse flours from some newly introduced cultivars of pea, lentil and chickpea grown in Canada under identical environmental conditions.

2. Materials and methods

2.1. Materials

Three different cultivars of pea (*1674-13*, *1215-33*, and *1329-12*), two cultivars of lentil (*CDC Meteor* and *CDC Robin*), and three cultivars of chickpea (*Myles*, *FLIP 97-101C* and *97-Indian2-11*) from the 2005 growing season were provided by Crop Development Centre, University of Saskatchewan. The three pea cultivars are all yellow cotyledon market class. *CDC Meteor* is a medium size green seed coat, yellow cotyledon lentil cultivar, while *CDC Robin* is a small seed size red cotyledon cultivar. *Myles* is desi market class, while *FLIP 97-101C* and *97-Indian2-11* are kabuli. All pulses were grown in the same location in Saskatchewan, Canada.

The whole pea, lentil and chickpea seeds were milled to flour without their dehulling using a cyclone mill (A10 analytical mill, Tekmar Co., Cincinnati, OH) and passed through a screen with 125 μm opening for analysis.

Pancreatin from porcine pancreas (Cat. No. P-1625, activity 3× USP/g) was purchased from Sigma Chemical Company (St. Louis, MO, USA). Amyloglucosidase (EC 3.2.1.3., 3300 U/mL) and glucose oxidase–peroxidase assay kit (Cat. No. K-GLUC) were purchased from Megazyme (Megazyme International Ireland Ltd., Bray, Ireland).

2.2. Chemical composition

Moisture content of pulse flour was determined by oven drying for 2 h at 120 °C. Protein content was determined using a protein analyzer (ThermoQuest CE Instrument, NA 2100, ThermoQuest Italia S.P.A., Ann Arbor, MI). The four standards (atropine, DL-methionine, acetanilide and nicotinamide) were used and the nitrogen conversion factor used was 6.25. Apparent amylose content of pulse flours was measured by the method of Williams, Kuzina, and Hlynka (1970). Total starch content of pulse flour was determined by AACC (2000) method 76.13 B. Lipid contents (free, bound) were determined according to the method of Vasanthan and Hoover (1992).

2.3. Swelling power

Swelling power (SP) of pulse flours (ratio of the weight of swollen flour to the initial weight of the dry flour) when heated to 60–90 °C in excess water was measured according to the method of Subramanian, Hoseney, and Bramel-Cox (1994).

2.4. Amylose leaching

Pulse flours (20 mg db) in water (10 mL) were heated at 60–90 °C in sealed tubes for 30 min. The tubes were then cooled to room temperature and centrifuged at 2000 rpm for 10 min. Supernatant was withdrawn and its amylose content was determined according to the method of Williams et al. (1970).

2.5. Differential scanning calorimetry (DSC)

Gelatinization properties of pulse flours were measured using a differential scanning calorimeter (2920 Modulated DSC, TA Instruments, New Castle, DE) equipped with a refrigerated cooling system. The pulse flour (12 mg) was weighed into high-volume pans and distilled water was added (28 μL, 70% moisture content). The sealed pans were equilibrated overnight at room temperature. The sample pans were then heated from 5 to 180 °C at a heating rate of 10 °C/min. The onset (T_o), peak (T_p) and conclusion (T_c) temperatures, and enthalpy (ΔH) were determined from the thermogram. The reported values are the means of duplicate measurements.

2.6. Pasting properties

The pasting properties of the pulse flours were measured using a Rapid Visco-Analyser (RVA-4, Newport Scientific Pty. Ltd., Warriewood, NSW, Australia). Pulse flour (11.9% dsb, 29 g total weight) and distilled water were used to make a slurry. The STD 2 profile (AACC method 76-21; AACC, 2000) was used in which the sample is equilibrated at 50 °C for 1 min, heated at 6 °C/min to 95 °C, held at 95 °C for 5 min, cooled at 6 °C/min to 50 °C, and held at 50 °C for 2 min. Peak viscosity, final viscosity, breakdown, setback, and pasting temperature were determined from the viscogram. The reported values are means of duplicate measurements.

2.7. In vitro starch digestibility and expected glycemic index

Starch digestibility in pulse flour was determined using AACC (2000) method 32-40 with minor modification. Pulse flour (100 mg) was incubated with porcine pancreatic α-amylase (10 mg) and amyloglucosidase (12 U) in 4 mL of 0.1 M sodium maleate buffer (pH 6.0) in a shaking water bath (200 strokes/min) at 37 °C (0.5–16 h). After incubation, ethanol (95%) was added and the sample was centrifuged at 2000 rpm for 10 min. The glucose content of supernatant was measured using a glucose oxidase–peroxidase (GOPOD) kit.

Rapidly digestible starch (RDS) and slowly digestible starch (SDS) were measured after incubation for 0.5 h and a further 15.5 h, respectively, and resistant starch (RS) was the starch remaining after 16 h incubation.

The digestion kinetics and expected glycemic index (eGI) of the pulse flour were calculated in accordance with the procedure established by Goni, Garcia-Alonso, and Saura-Calixto (1997). A non-linear model following an equation [$C = C_\infty(1 - e^{-kt})$] was applied to describe the kinetics of starch hydrolysis, where C, C_∞ and k were the hydrolysis degree at each time, the maximum hydrolysis extent and the kinetic constant, respectively. The hydrolysis index (HI) was calculated as the relation between the area under the hydrolysis curve (0–16 h) of pulse flour sample and the area of standard material from white bread. The expected glycemic index (eGI) was calculated using the equation proposed by Granfeldt, Björck, Drews, and Tovar (1992): eGI = 8.198 + 0.862HI.

2.8. Statistical analysis

The data reported are the mean of duplicate measurements. Statistical analyses were carried out with Duncan's multiple test ($P < 0.05$) using software SPSS V. 8.2 (SPSS Institute Inc., Cary, NC) to determine statistical significance of the data.

3. Results and discussion

3.1. Chemical composition

The data on chemical composition is presented in Table 1. The protein content of pulse flour ranged from 20.7% (*97-Indian2-11*-chickpea) to 31.5% (*CDC Meteor*-lentil). This was in the range reported by Kaur et al. (2007), Almeida Costa et al. (2006), and Kaur and Singh (2005) for pulse flours. Lentil flours had higher protein contents (28.7–31.5%) than pea (25.6–26.8%) and chickpea flours (20.7–25.0%). Almeida Costa et al. (2006) also reported that chickpea had the lowest protein content among legume flours (pea, common bean, chickpea and lentil). The free and bound lipid contents ranged from 1.8 (*1674-13*-pea) to 7.1% (*97-Indian2-11*-chickpea) and 0.3 (*CDC Robin*-lentil) to 0.9% (*97-Indian2-11*-chickpea), respectively. Chickpea flours (6.7–7.1%) had higher free lipid contents than pea (1.8–2.0%) and lentil flours (2.0%). The bound lipid content of lentil flours (0.3–0.4%) was lower than that of pea (0.8%) and chickpea flours (0.6–0.9%). The amylose content varied significantly among species and cultivars (Table 1). The amylose content of chickpea flour [10.8% (*Myles*) to 13.5% (*97-Indian2-11*)] was lower than that of pea and lentil flours. Total starch content of pulse flours followed the order: pea (46.6–49.4%) > lentil (46.0–47.1%) > chickpea (42.9–46.3%). The pea samples used in this experiment were yellow pea, whereas lentil and chickpea were different seed types. *CDC Meteor* is from the medium seed size green lentil market class, while *CDC Robin* is from the small seed size red lentil market class. This different seed type between *CDC Meteor* and *CDC Robin* could partially explain the significant differences in amylose content, total starch content and protein content (Table 1). Of the chickpea cultivars, *Myles* was desi type whereas the other two were kabuli type. *Myles* showed significantly lower amylose content, total starch content and protein content. The variation in chemical composition between flours from desi and kabuli chickpea cultivars could be due to inherent genetic differences (Table 1).

3.2. Swelling power and amylose leaching

The swelling power (SP) of pulse flours was investigated over the temperature range 60–90 °C (Table 2). SP increased with increasing temperature, as expected. Beyond 60 °C, chickpea flour exhibited lower SP value than did the other pulse flours. At 90 °C, the SP of pea, lentil and chickpea flours ranged between 10.9–11.8%, 10.9–11.9%, and 9.2–10.4%, respectively. SP of flour is influenced by hydrophilic carbohydrates and water binding/soluble proteins such as polysaccharides and albumins, respectively (Kaur & Singh, 2005). Therefore, a lower SP in chickpea flour could be attributed to its small amount of hydrophilic carbohydrates and water binding/soluble proteins. Significant differences in SP were observed among cultivars within the same species. In all flours, differences in SP among cultivars were most pronounced at temperatures exceeding 80 °C. Among the pea cultivars, the SP followed the order: *1674-13* > *1215-33* > *1329-12*. Whereas, in lentil and chickpea flours, the corresponding order was *CDC Meteor* > *CDC Robin*, and *97 Indian2-11* > *FLIP 97-101C* > *Myles*, respectively.

Table 1
Chemical composition of pea, lentil, and chickpea flours[A]

Sample	Moisture content (%)	Apparent amylose content (%)	Total starch content (%)	Protein content (%)[B]	Free lipid content (%)[C]	Bound lipid content (%)[D]
Pea						
1674-13	8.2 ± 0.0^{c}	13.7 ± 0.2^{cd}	46.6 ± 1.1^{b}	26.0 ± 1.6^{c}	1.8 ± 0.0^{d}	0.8 ± 0.0^{a}
1215-33	7.9 ± 0.1^{d}	14.0 ± 0.7^{bc}	49.4 ± 0.3^{a}	25.6 ± 0.8^{c}	2.0 ± 0.0^{c}	0.8 ± 0.1^{a}
1329-12	7.7 ± 0.0^{e}	15.9 ± 0.3^{a}	47.3 ± 1.6^{b}	26.8 ± 0.8^{c}	2.0 ± 0.0^{c}	0.8 ± 0.1^{a}
Lentil						
CDC Meteor	8.6 ± 0.2^{b}	13.3 ± 0.7^{cd}	47.1 ± 0.7^{b}	31.5 ± 1.1^{a}	2.0 ± 0.1^{c}	0.4 ± 0.1^{bc}
CDC Robin	8.8 ± 0.1^{a}	14.5 ± 0.2^{b}	46.0 ± 0.7^{b}	28.7 ± 0.5^{b}	2.0 ± 0.1^{c}	0.3 ± 0.1^{c}
Chickpea						
Myles	7.5 ± 0.0^{fg}	10.8 ± 0.1^{e}	42.9 ± 0.7^{c}	25.0 ± 0.8^{c}	6.5 ± 0.0^{b}	0.6 ± 0.1^{b}
FLIP 97-101C	7.4 ± 0.0^{g}	12.8 ± 0.5^{d}	46.2 ± 1.0^{b}	22.8 ± 0.4^{d}	7.0 ± 0.1^{a}	0.8 ± 0.2^{a}
97-Indian2-11	7.6 ± 0.0^{ef}	13.5 ± 0.0^{cd}	46.3 ± 0.9^{b}	20.7 ± 0.3^{e}	7.1 ± 0.0^{a}	0.9 ± 0.0^{a}

[A] Mean (±standard deviation) of duplicate analysis. Values followed by a different superscript in each column are significantly different ($P < 0.05$).
[B] Total nitrogen × 6.25.
[C] Lipids extracted by chloroform–methanol 2:1 (*v*/*v*) at 25 °C (mainly unbound lipids).
[D] Lipids extracted by hot *n*-propanol–water 3:1 (*v*/*v*) from the residue left after chloroform–methanol extraction (mainly bound lipids).

Table 2
Swelling power and amylose leaching of pea, lentil, and chickpea flours in the temperature range 60–90 °C[A]

Sample	Swelling power				Amylose leaching (%)			
	60 °C	70 °C	80 °C	90 °C	60 °C	70 °C	80 °C	90 °C
Pea								
1674-13	4.6 ± 0.3^{bc}	7.7 ± 0.1^{a}	10.9 ± 0.2^{a}	11.8 ± 0.3^{a}	1.3 ± 0.2^{bc}	4.3 ± 0.1^{bc}	7.0 ± 0.4^{a}	8.2 ± 0.5^{a}
1215-33	4.9 ± 0.3^{ab}	7.7 ± 0.3^{a}	9.9 ± 0.3^{c}	11.6 ± 0.2^{a}	1.3 ± 0.2^{bc}	4.7 ± 0.2^{b}	7.5 ± 0.5^{a}	8.6 ± 0.3^{a}
1329-12	4.9 ± 0.3^{ab}	7.6 ± 0.3^{a}	9.9 ± 0.0^{c}	10.9 ± 0.0^{b}	1.5 ± 0.1^{b}	4.5 ± 0.2^{b}	7.0 ± 0.5^{a}	8.5 ± 0.4^{a}
Lentil								
CDC Meteor	4.4 ± 0.1^{c}	7.8 ± 0.3^{a}	10.5 ± 0.1^{b}	11.9 ± 0.0^{a}	1.0 ± 0.4^{bc}	5.2 ± 0.0^{a}	7.6 ± 0.1^{a}	8.8 ± 0.0^{a}
CDC Robin	4.3 ± 0.1^{c}	7.4 ± 0.0^{ab}	9.7 ± 0.1^{cd}	10.9 ± 0.1^{b}	0.9 ± 0.2^{c}	5.1 ± 0.2^{a}	7.4 ± 0.0^{a}	8.5 ± 0.6^{a}
Chickpea								
Myles	4.6 ± 0.1^{bc}	6.9 ± 0.4^{c}	8.4 ± 0.1^{f}	9.2 ± 0.5^{d}	1.2 ± 0.1^{bc}	3.3 ± 0.1^{d}	4.5 ± 0.1^{b}	5.6 ± 0.1^{b}
FLIP 97-101C	5.0 ± 0.1^{ab}	7.0 ± 0.1^{c}	9.3 ± 0.0^{e}	10.0 ± 0.1^{c}	1.3 ± 0.2^{bc}	4.0 ± 0.3^{c}	5.0 ± 0.5^{b}	5.9 ± 0.5^{b}
97-Indian2-11	5.3 ± 0.1^{a}	7.3 ± 0.0^{bc}	9.4 ± 0.2^{de}	10.4 ± 0.0^{bc}	2.1 ± 0.1^{a}	4.1 ± 0.1^{c}	4.7 ± 0.1^{b}	5.5 ± 0.0^{b}

[A] Mean (±standard deviation) of duplicate analysis. Values followed by a different superscript in each column are significantly different ($P < 0.05$).

Amylose leaching (AML) also increased with temperature (Table 2). Among the pulse flours, chickpea flour showed the lowest AML beyond 70 °C. The AML has been reported to be influenced by lipid complexed amylose, total amylose content and interaction between starch chains (Hoover & Vasanthan, 1994; Jayakody, Hoover, Liu, & Weber, 2005). The lower AML in chickpea flour could be attributed to its lower amylose content (Table 1).

3.3. Thermal characteristics

The gelatinization temperatures (T_o, T_p, and T_c) and enthalpy (ΔH) of the pulse flours are shown in Table 3. The DSC thermogram of the pulse flours exhibited two endothermic peaks (Fig. 1a). The first peak at a lower temperature is due to starch gelatinization, and the second peak at a higher temperature represents melting of the amylose–lipid complex. There were significant differences in gelatinization behavior among the species. Lentil flours had the highest gelatinization temperature (67.3–68.4 °C for T_o and 75.6–76.1 °C for T_p) among the pulse flours. The pea and chickpea flours exhibited similar gelatinization temperature (71.6–72.4 °C and 70.3–72.5 °C for T_p, respectively). The difference in gelatinization temperature among the pulse flours could be attributed to differences in protein content and starch structure (Kaur & Singh, 2005). The gelatinization temperature ranges (T_c–T_o) of pea and chickpea flours were around 20 °C, whereas that of lentil flour was 15 °C. In addition, the melting enthalpies of gelatinization for pea and chickpea flours ranged from 4.3 to 5.1 J/g, whereas that of lentil from 3.0 to 3.2 J/g. The pea and chickpea flours had relatively separate starch gelatinization and amylose–lipid complex melting peaks, while the two peaks in lentil flour were partially overlapped (Fig. 1a). Therefore, we assume that the conclusion temperature (T_c) of gelatinization in lentil flour was not determined accurately by the DSC software, which resulted in reduced gelatinization enthalpy and gelatinization temperature range.

The gelatinization parameters of pea and lentil flours did not show significant differences among the cultivars. However, a significant difference was observed among the chickpea cultivars. The T_p and T_c of chickpea flours were higher in *Myles* (72.5 °C and 81.5 °C, respectively) than *FLIP 97-101C* (71.1 °C and 80.2 °C, respectively) and *97-Indian2-11* (70.3 °C and 80.1 °C, respectively). *Myles*, however, had the lowest melting enthalpy (4.3 J/g) possibly due to difference in starch structure by inherited difference in type (desi vs. kabuli seed). However, Kaur and Singh (2005) reported that kabuli chickpea flour exhibited lower T_o, T_p, T_c and ΔH than the desi type. This could be attributed to difference in cultivars.

The amylose–lipid complex of pea and lentil flours was disrupted around 80–100 °C (Fig. 1a). However, chickpea flour showed a much higher melting temperature for the amylose–lipid complex melting endotherm (around 90–110 °C). The enthalpy of the amylose–lipid complex of chickpea flours (0.7–0.8 J/g) was also much higher than that of pea (0.2–0.6 J/g) and lentil flours (0.5 J/g). This could be attributed to the higher free lipid content of the chickpea flours (Table 1).

Table 3
Gelatinization characteristics of pea, lentil, and chickpea flours[A]

Sample	Gelatinization				Amylose–lipid complex			
	T_o (°C)	T_p (°C)	T_c (°C)	ΔH (J/g)	T_o (°C)	T_p (°C)	T_c (°C)	ΔH (J/g×10^{-1})
Pea								
1674-13	61.6 ± 0.2^{c}	71.7 ± 0.0^{cd}	80.8 ± 0.1^{bc}	4.5 ± 0.0^{d}	85.7 ± 0.2^{d}	94.4 ± 0.7^{c}	103.5 ± 0.0^{b}	4.8 ± 0.1^{d}
1215-33	61.9 ± 0.0^{c}	72.4 ± 0.2^{bc}	81.3 ± 0.2^{ab}	4.6 ± 0.0^{cd}	89.7 ± 0.4^{c}	95.9 ± 0.3^{b}	103.6 ± 0.2^{b}	2.2 ± 0.1^{e}
1329-12	61.9 ± 0.1^{c}	71.6 ± 0.1^{cd}	80.6 ± 0.1^{bc}	4.8 ± 0.1^{bc}	85.2 ± 0.2^{de}	93.2 ± 0.5^{d}	102.1 ± 0.2^{c}	6.4 ± 0. 1^{c}
Lentil								
CDC Meteor	68.4 ± 0.2^{a}	75.6 ± 0.4^{a}	82.0 ± 0.4^{a}	3.2 ± 0.1^{f}	85.0 ± 0.3^{e}	92.2 ± 0.6^{d}	102.4 ± 0.3^{c}	5.1 ± 0.1^{d}
CDC Robin	67.3 ± 0.1^{b}	76.1 ± 0.1^{a}	82.0 ± 0.1^{a}	3.0 ± 0.0^{g}	84.9 ± 0.1^{e}	94.8 ± 0.4^{c}	102.6 ± 0.8^{c}	5.0 ± 0.1^{d}
Chickpea								
Myles	60.3 ± 0.2^{e}	72.5 ± 0.0^{b}	81.5 ± 1.1^{ab}	4.3 ± 0.1^{e}	94.8 ± 0.2^{b}	104.6 ± 0.1^{a}	111.0 ± 0.1^{a}	7.9 ± 0.6^{a}
FLIP 97-101C	60.8 ± 0.1^{d}	71.1 ± 0.4^{d}	80.2 ± 0.2^{c}	5.0 ± 0.2^{b}	96.3 ± 0.1^{a}	105.2 ± 0.2^{a}	111.4 ± 0.4^{a}	7.9 ± 0.3^{a}
97-Indian2-11	60.1 ± 0.2^{e}	70.3 ± 0.7^{e}	80.1 ± 0.0^{c}	5.1 ± 0.1^{a}	96.4 ± 0.5^{a}	105.1 ± 0.2^{a}	111.0 ± 0.2^{a}	7.4 ± 0.9^{ab}

[A] Mean (±standard deviation) of duplicate analysis. Values followed by a different superscript in each column are significantly different ($P < 0.05$).

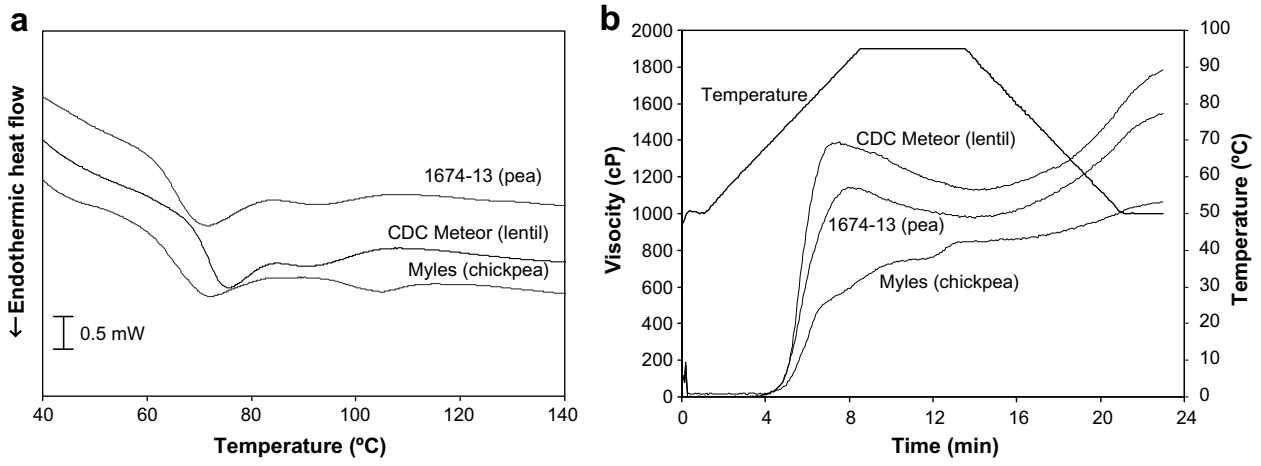

Fig. 1. DSC thermogram (a) and RVA viscogram (b) of pea, lentil, and chickpea flours in the presence of excess water upon heating.

3.4. Pasting characteristics

The pasting properties of pulse flours are presented in Table 4. Pasting temperature, peak viscosity, breakdown, setback and final viscosity of pulse flours ranged from 69.1 to 71.8 °C, 755 to 1371 cP, 93 to 239 cP, 320 to 670 cP and 1068 to 1938 cP, respectively (Table 4). The pasting temperatures of pea, lentil, and chickpea flours were nearly similar (Fig. 1b). The chickpea flour exhibited an increase in viscosity during the holding period at 95 °C, whereas the viscosity of pea and lentil flours differed significantly (Fig. 1b).

Among the pea cultivars, peak viscosity (1371 cP), breakdown (172 cP), setback (670 cP) and final viscosity (1870 cP) was higher in *1329-12*. *CDC Robin* (lentil) exhibited a higher pasting temperature than *CDC Meteor*, but a lower peak viscosity, breakdown, setback and final viscosity. The desi cultivar (*Myles)* of chickpea flour significantly differed from the kabuli cultivars with respect to higher pasting temperature and lower peak viscosity, setback and final viscosity. This could be attributed to its lower swelling power (Table 2) and higher protein content (Table 1). A greater amount of protein in desi cultivar (*Myles*) could induce increased protein–starch interactions, which could decrease starch swelling, thereby increasing the pasting temperature (Liu, Gu, Donner, Tetlow, & Emes, 2007). The setback represents amylose–amylose aggregation and the presence of fragmented granules embedded in the leached amylose network. Since the extent of amylose leaching was comparable in *Myles* and desi cultivars (Table 2), the lower setback exhibited by *Myles* suggests the absence or lower amount of granule fragments (due to its lower extent of granule swelling) in the leached amylose network. Kaur and Singh (2005) also reported that flour from desi chickpea cultivars showed higher pasting temperatures and lower peak viscosities, setback, and final viscosities than kabuli chickpea cultivars. This suggests that chickpea flour can be incorporated into foods that are subjected to high temperature processing.

3.5. In vitro starch digestibility

The enzyme digestibility of starch in pulse flour by porcine pancreatic α-amylase is presented in Table 5. The amount of rapidly digestible starch (RDS), slowly digestible starch (SDS) and resistant starch (RS) of pulse flours differed significantly among species and cultivars. RDS content was the lowest in lentil flour (7.6–7.8%). The SDS content followed the order: chickpea (27.1–30.7%) > pea (23.3–26.5%) ⩾ lentil (23.7–24.7%). The RS content in chickpea flour (3.1–6.4%) was much lower than that of pea (10.1–14.7%) and lentil (14.4–14.9%) flours.

Maximum hydrolysis extent (C_∞) of pulse flours followed the order: chickpea (37.3–41.7%) > pea (33.4–37.7%) ⩾ lentil (33.1–34.0%). The kinetic constant (k), which reflects the rate of hydrolysis in the early stage, followed the order: chickpea (0.62–0.67) > pea (0.54–0.58) > lentil (0.40–0.43). The lower rate and extent of hydrolysis in lentil flour could be attributed to its higher protein content (Table 1), which could increase starch–protein interactions, thereby restricting enzyme attack. The higher rate and extent hydrolysis of chickpea flour could be attributed to its lower amylose and protein contents (Table 1).

Pea and chickpea flours showed significant difference among the cultivars with respect to starch nutritional fractions (RDS, SDS and RS) and hydrolysis kinetics. Among the pea flours, *1215-33* had the lowest RDS content and kinetic constant (k), but a

Table 4
Pasting characteristics of pea, lentil, and chickpea flours[A]

Sample	Pasting temperature (°C)	Peak viscosity (cP)	Breakdown (cP)	Setback (cP)	Final viscosity (cP)
Pea					
1674-13	69.7 ± 0.3^{cd}	1143 ± 1^{d}	165 ± 6^{bc}	576 ± 5^{b}	1554 ± 10^{e}
1215-33	69.7 ± 0.3^{cd}	1129 ± 12^{d}	93 ± 4^{d}	706 ± 35^{a}	1742 ± 43^{c}
1329-12	69.5 ± 0.0^{de}	1371 ± 1^{a}	172 ± 11^{b}	670 ± 21^{a}	1870 ± 12^{b}
Lentil					
CDC Meteor	70.0 ± 0.0^{c}	1359 ± 43^{a}	239 ± 34^{a}	662 ± 6^{a}	1781 ± 3^{c}
CDC Robin	71.1 ± 0.1^{b}	1185 ± 16^{c}	140 ± 5^{c}	605 ± 6^{b}	1651 ± 5^{d}
Chickpea					
Myles	71.8 ± 0.3^{a}	755 ± 4^{e}	ND[B]	320 ± 1^{d}	1068 ± 6^{f}
FLIP 97-101C	69.9 ± 0.0^{d}	1259 ± 4^{b}	ND	510 ± 15^{c}	1769 ± 10^{c}
97-Indian2-11	69.1 ± 0.0^{e}	1347 ± 11^{a}	ND	610 ± 31^{b}	1938 ± 44^{a}

[A] Mean (±standard deviation) of duplicate analysis. Values followed by a different superscript in each column are significantly different ($P < 0.05$).
[B] Not determined.

Table 5
Starch nutritional fraction, hydrolysis kinetics and expected glycemic index of pea, lentil, and chickpea flours by *in vitro* starch digestion[A]

Sample	RDS[B] (%)	SDS (%)	RS (%)	C_∞ (%)	k ($\times 10^{-1}$)	HI	eGI
Pea							
1674-13	10.0 ± 0.6^{bc}	23.3 ± 0.7^{e}	13.3 ± 0.2^{b}	33.4 ± 0.4^{ef}	5.8 ± 0.3^{cd}	42.0 ± 0.2^{e}	44.4 ± 0.2^{e}
1215-33	9.2 ± 0.7^{c}	25.5 ± 0.4^{cd}	14.7 ± 0.5^{a}	35.3 ± 0.2^{d}	5.4 ± 0.1^{d}	43.7 ± 0.3^{d}	45.9 ± 0.3^{d}
1329-12	10.7 ± 0.5^{b}	26.5 ± 0.4^{bc}	10.1 ± 0.2^{c}	37.7 ± 0.4^{c}	5.8 ± 0.3^{cd}	47.3 ± 0.0^{c}	48.9 ± 0.0^{c}
Lentil							
CDC Meteor	7.6 ± 0.7^{d}	24.7 ± 1.1^{de}	14.9 ± 1.1^{a}	34.0 ± 0.9^{e}	4.0 ± 0.3^{e}	38.5 ± 0.2^{f}	41.4 ± 0.1^{f}
CDC Robin	7.8 ± 0.8^{d}	23.7 ± 1.3^{e}	14.4 ± 0.6^{a}	33.1 ± 0.9^{f}	4.3 ± 0.2^{e}	38.6 ± 0.6^{f}	41.5 ± 0.5^{f}
Chickpea							
Myles	9.4 ± 1.4^{c}	27.1 ± 1.3^{b}	6.4 ± 0.3^{d}	37.3 ± 0.2^{c}	6.2 ± 0.1^{bc}	47.2 ± 0.2^{c}	48.9 ± 0.2^{c}
FLIP 97-101C	11.1 ± 0.5^{b}	30.3 ± 0.5^{a}	4.7 ± 0.4^{e}	41.7 ± 0.4^{b}	6.3 ± 0.3^{ab}	53.1 ± 0.2^{b}	54.0 ± 0.2^{b}
97-Indian2-11	12.4 ± 0.9^{a}	30.7 ± 1.0^{a}	3.1 ± 0.3^{f}	43.1 ± 0.6^{a}	6.7 ± 0.5^{a}	55.6 ± 0.3^{a}	56.1 ± 0.3^{a}

[A] Mean (±standard deviation) of duplicate analysis. Values followed by a different superscript in each column are significantly different ($P < 0.05$).
[B] RDS: rapidly digestible starch, SDS: slowly digestible starch, RS: resistant starch, C_∞: equilibrium hydrolysis extent, k: kinetic constant, HI: hydrolysis index, eGI: expected glycemic index.

higher RS content (meaning slow hydrolysis rate and low hydrolysis extent), whereas *1329-12* had the highest extent of hydrolysis (C_∞) and SDS content, but the lowest RS content. Among the chickpea flours, *Myles* had lower RDS, SDS, and kinetic constant (k) as well as lower extent of hydrolysis (C_∞), whereas *97-Indian2-11* cultivar had higher RDS, maximum hydrolysis extent (C_∞) and kinetic constant (k), but lower RS.

The calculated hydrolysis index (HI) and expected glycemic index (eGI) of pulse flours are presented in Table 5. The HI of pulse flours ranged between 38.5 (*CDC Meteor*-lentil) and 55.6 (*97-Indian2-11*-chickpea), and the eGI were between 41.4 and 56.1. The eGI of pulse flours followed the order: chickpea (48.9–56.1) > pea (44.4–48.9) > lentil (41.5–41.6). A significant difference ($P < 0.05$) in eGI was observed among pea and chickpea cultivars. The eGI of *1674-132* (pea) was 44.4, and *1329-12* (pea) was 48.9. *Myles* had the lowest eGI value (48.9) among the chickpea cultivars, due to higher protein content and lower swelling factor. Comparable values of glycemic index of pulses have been reported *in vitro* and *in vivo* (Bravo et al., 1998; Foster-Powell & Brand Miller, 1995). Pulses are low glycemic index foods, which generate slow and moderate postprandial glucose and insulin response. This property of pulses has a beneficial effect in the management of diabetes and hyperlipidemia (Jenkins, 2007; Rizkalla et al., 2002). Therefore, the difference in eGI among the species and cultivars within the same species could be expected to produce different beneficial physiological effects.

4. Conclusions

Differences in *in vitro* starch digestibility and physicochemical properties were observed among pulse species and cultivars within the same species, even when grown under identical environmental conditions. Lentil flour showed the lowest extent and slowest rate of hydrolysis, as well as the lowest expected glycemic index (eGI), due to higher protein content and higher melting temperature, which is associated with strong molecular interactions. The higher eGI and starch digestibility in chickpea flour could be explained by its lower amylose content and lower protein content. The difference in starch digestibility of pulse flours among cultivars of the same species could be associated with differences in chemical compositions and physicochemical properties, due to inherent genetic differences.

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References

AACC (2000). Approved methods of the AACC (10th ed.), St. Paul, MN.

Almeida Costa, G. M., Queiroz-Monici, K. S., Machado Reis, S. M. P., & Oliveira, A. C. (2006). Chemical composition, dietary fibre and resistant starch contents of raw and cooked pea, common bean, chickpea and lentil legumes. *Food Chemistry, 94*, 327–330.

Brand-Miller, J. (2007). The glycemic index as a measure of health and nutritional quality: An Australian perspective. *Cereal Foods World, 52*, 41–44.

Bravo, L., Siddhuraju, P., & Saura-Calixto, F. (1998). Effect of various processing methods on the in vitro starch digestibility and resistant starch content of Indian pulses. *Journal of Agricultural and Food Chemistry, 46*, 4667–4674.

Englyst, K. N., Vinoy, S., Englyst, H. N., & Lang, V. (2003). Glycemic index of cereal products explained by their content of rapidly and slowly available glucose. *British Journal of Nutrition, 89*, 329–339.

FAO – Food and Agriculture Organization of the United Nations (2005). FAOSTAT database-agriculture, Rome, Italy.

Foster-Powell, K., & Brand Miller, J. (1995). International tables of glycemic index. *American Journal of Clinical Nutrition, 62*, 871S–893S.

Goni, I., Garcia-Alonso, A., & Saura-Calixto, F. (1997). A starch hydrolysis procedure to estimate glycemic index. *Nutrition Research, 17*, 427–437.

Granfeldt, Y., Björck, I., Drews, A., & Tovar, J. (1992). An in vitro procedure based on chewing to predict metabolic responses to starch in cereal and legume products. *European Journal of Clinical Nutrition, 46*, 649–660.

Hoover, R., & Vasanthan, T. (1994). The effect of annealing on the physicochemical properties of wheat, oat, potato and lentil starches. *Journal of Food Biochemistry, 17*, 303–325.

Hoover, R., & Zhou, Y. (2003). In vitro and in vivo hydrolysis of legume starches by α-amylase and resistant starch formation in legumes – A review. *Carbohydrate Polymers, 54*, 401–417.

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

Jenkins, A. L. (2007). The glycemic index: Looking back 25 years. *Cereal Foods World, 52*, 50–53.

Jenkins, D. J. A., Thome, M. J., Camelon, K., Jenkins, A. L., Rao, A. V., Taylor, R. H., et al. (1982a). Effect of processing on digestibility and the blood glucose responses: A study of lentils. *American Journal of Clinical Nutrition, 36*, 1093–1101.

Jenkins, D. J. A., Wolever, T. M. S., Taylor, R. H., Griffiths, C., Kizeminska, K., Lawrie, J. A., et al. (1982b). Slow release dietary carbohydrate improves second meal tolerance. *American Journal of Clinical Nutrition, 35*, 1339–1346.

Kaur, M., Sandhu, K. S., & Singh, N. (2007). Comparative study of the functional, thermal and pasting properties of flours from different field pea (*Pisum sativum* L.) and pigeon pea (*Cajanus cajan* L.) cultivars. *Food Chemistry, 104*, 259–267.

Kaur, M., & Singh, N. (2005). Studies on functional, thermal and pasting properties of flours from different chickpea (*Cicer arietinum* L.) cultivars. *Food Chemistry, 91*, 403–411.

Liu, Q., Donner, E., Yin, Y., Huang, R. L., & Fan, M. Z. (2006). The physicochemical properties and in vitro digestibility of selected cereals, tubers and legumes grown in China. *Food Chemistry, 99*, 470–477.

Liu, Q., Gu, Z., Donner, E., Tetlow, I., & Emes, M. (2007). Investigation of digestibility In vitro and physicochemical properties of A- and B-type starch from soft and hard wheat flour. *Cereal Chemistry, 84*, 15–21.

Osorio-Diaz, P., Bello-Perez, L. A., Agama-Acevedo, E., Vargas-Torres, A., Tovar, J., & Paredes-Lopez, O. (2002). In vitro digestibility and resistant starch content of some industrialized commercial beans (*Phaseolus vulgaris* L.). *Food Chemistry, 78*, 333–337.

Rizkalla, S. W., Bellisle, F., & Slama, G. (2002). Health benefits of low glycemic index foods, such as pulses, in diabetic patients and health individuals. *British Journal of Nutrition, 88*, S255–S262.

Roberts, S. B. (2000). High-glycemic index foods, hunger, and obesity: Is there a connection? *Nutrition Reviews, 58*, 163–169.

Schneeman, B. O. (2002). Gastrointestinal physiology and functions. *British Journal of Nutrition, 88*, S159–S163.

Siddhuraju, P., & Becker, K. (2005). Nutritional and antinutritional composition, in vitro amino acid availability, starch digestibility and predicted glycemic index of differentially processed mucuna beans (*Mucuna pruriens* var. *utilis*): An under-utilised legume. *Food Chemistry, 91*, 275–286.

Sparti, A., Milon, H., Vetta, V. D., Schneiter, P., Tappy, L., Jequier, E., et al. (2000). Effect of diets high or low in unavailable and slowly digestible carbohydrates on the pattern of 24-h substrate oxidation and feelings of hunger in humans. *American Journal of Clinical Nutrition, 72*, 1461–1468.

Subramanian, V., Hoseney, R. C., & Bramel-Cox, P. (1994). Shear thinning properties of sorghum and corn starches. *Cereal Chemistry, 71*, 272–275.

Tester, R. F., & Karkalas, J. (2001). The effect of environmental conditions on the structural features and physico-chemical of starches. *Starch, 53*, 513–519.

Tharanathan, R. N., & Mahadevamma, S. (2003). Grain legumes – A boon to human nutrition. *Trends in Food Science and Technology, 14*, 507–518.

Vasanthan, T., & Hoover, R. (1992). A comparative study of the composition of lipids associated with starch granules from various botanical sources. *Food Chemistry, 43*, 19–27.

Williams, P. C., Kuzina, F. D., & Hlynka, I. (1970). A rapid colorimetric procedure for estimating the amylose content of starches and flours. *Cereal Chemistry, 47*, 411–420.

Yadav, S., & Khetarpaul, N. (1994). Indigenous legume fermentations: Effect on some antinutrients and in vitro digestibility of starch and protein. *Food Chemistry, 50*, 403–406.