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Studies for Physicochemical and *In Vitro* Digestibility Characteristics of Flour and Starch from Chickpea (*Cicer arietinum* L.)

Hyun-Jung Chung

School of Food Science, Kyungil University, Gyeongbuk 712-701, Korea

Abstract

Flour and isolated starch from chickpea (desi type, *328S-8*) were evaluated for their *in vitro* digestibility and physicochemical properties. The protein content, total starch content and apparent amylose content of chickpea flour and isolated starch were 22.2% and 0.6%, 45.8% and 91.5%, and 11.7% and 35.4%, respectively. Chickpea starch granules had an oval to round shape with a smooth surface. The X-ray diffraction pattern of chickpea starch was of the C-type and relative crystallinity was 24.6%. Chickpea starch had only a single endothermic transition (13.3 J/g) in the DSC thermogram, whereas chickpea flour showed two separate endothermic transitions corresponding to starch gelatinization (5.1 J/g) and disruption of the amylose-lipid complex (0.7 J/g). The chickpea flour had a significantly lower pasting viscosity without breakdown due to low starch content and interference of other components. The chickpea starch exhibited significant high setback in the viscogram. The average branch chain length, proportion of short branch chain (DP 6～12), and long branch chains (DP≥37) of isolated chickpea starch were 20.1, 20.9% and 9.2%, respectively. The rapidly digestible starch (RDS), slowly digestible starch (SDS) and resistant starch (RS) contents of chickpea flour and starch were 9.9% and 21.5%, 28.7% and 57.7%, and 7.1% and 9.3%, respectively. The expected glycemic index (eGI) of chickpea flour (39.5), based on the hydrolysis index, was substantially lower than that of isolated chickpea starch (69.2).

Key words: chickpea, flour, starch, *in vitro* starch digestibility, physicochemical properties

INTRODUCTION

Pulses are an important nutritional food for humans and are defined as the edible seeds of certain leguminous plants that include lentil, bean, pea and chickpea (1). Pulses are rich in starch, protein and dietary fiber with significant amounts of vitamins and minerals, and are thus well suited to meet the demands of health conscious consumers (2). Chickpea (*Cicer arietnum*) is a crop of economic importance in India, as well as other countries, and is fifth in importance of pulse crops worldwide (3). Chickpea is rich in proteins (20～30%) and complex carbohydrates (50～60%), and is a fairly good source of minerals, vitamins, and polyunsaturated free fatty acids, as are most other pulses (4). Chickpea cultivars are broadly divided into two groups, desi and kabuli. Kabuli seeds are characterized by their larger size, ram-head shape and low fiber content, whereas the seeds of desi cultivars are small and wrinkled at beak with a brown, black or green color (5).

A particularly attractive feature of most edible pulses, including chickpea, is their slow-release nature, which is due to a large amount of starch and fibers that are resistant to digestion in the small intestine (2). Pulses could prevent blood glucose levels from rising too rapidly after a meal, resulting in reduced glycemic and insulinemic responses, and thus pulses are considered a low glycemic index (GI) food (6). The GI, which characterizes the carbohydrate in different foods, is a ranked on the basis of the postprandial increase in blood glucose (7). The GI is tested by a standardized procedure using human subjects who consume food portions containing 50 g of carbohydrate (8). Low GI foods have been associated with reduced incidence and prevalence of heart disease, diabetes, and also some forms of cancer (8,9). The low starch digestibility of pulse has been attributed to the presence of intact tissue/cell structure, high content of viscous soluble dietary fibers, the presence of various antinutrients, and relatively high amylose content in starch (2).

There have been several reports on the *in vitro* starch digestibility and physicochemical properties of pulses or pulse starches (10-13). However, relatively few studies on the physicochemical properties of chickpea or chickpea starch have been reported (4,14-16). There is also a dearth of information on *in vitro* starch digestibility, including rapidly and slowly digestible starches, and the glycemic index of chickpea cultivar. Furthermore, no

E-mail: hjchung@kiu.ac.kr
Phone: +82-53-850-7172

study has yet been conducted that compares the physicochemical properties of chickpea flour and its isolated starch. Therefore, we investigated the *in vitro* starch digestibility of both chickpea flour and isolated starch, including expected glycemic index and various physicochemical properties.

MATERIALS AND METHODS

Materials

Chickpea cultivar (*328S-8*) from the 2009 growing season was provided by Crop Development Centre, University of Saskatchewan (Saskatchewan, Canada). Chickpea cultivar tested in this study was desi market class. Chickpea seed was milled to flour without dehulling using a cyclone mill (A10 analytical mill, Tekmar Co., Cincinnati, OH, USA), and passed through a screen with 125 μm openings for analysis. Chickpea starch was isolated from milled chickpea flour according to the method described by Otto et al. (17). The milled chickpea flour (100 g) was blended with 200 mL of water for 2 min using a blender at 3,500 rpm (model 34BL97, Waring Commercial, Torrington, CT, USA) and the slurry was then filtered through 75 μm polypropylene mesh screen. The residue was washed thoroughly with 200 mL of distilled water. The filtrate slurry was centrifuged at 1,500×*g* for 15 min. The supernatant was discarded and the upper non-white layer was carefully separated from the bottom prime starch. The prime starch was further purified by mixing, blending, and centrifuging. This purification step was repeated three times. The starch pellet was air dried at 40°C in convection oven. The dried starch cake was ground and passed through a screen with 125 μm openings.

Chemical composition

Protein content of chickpea flour and isolated starch was determined by using a protein analyzer (ThermoQuest CE Instrument, NA 2100, ThermoQuest Italia S.P.A., Ann Arbor, MI, USA) with four standards (atropine, DL-methionine, acetanilide and nicotinamide). Total starch content was determined by the standard AACC method 76.13B (18). Apparent amylose content was determined using the method of Williams et al. (19).

Granular morphology

The starch granule surface and shape of chickpea starch was studied by a Hitachi S-4500 field emission scanning electron microscope (Hitachi Ltd., Tokyo, Japan) equipped with Quartz PCI digital image acquisition software (Quartz Imaging Corp., Vancouver, BC, Canada). Starch sample was mounted on a metal plate with double-sided adhesive tape and then coated with gold: palladium (60:40) using a Polaron SC500 sputter coater (Quorum Technologies, East Sussex, UK), and examined at 5.0 kV accelerating voltage and 1000× magnification. Polarized light micrographs of chickpea starch were taken by a binocular microscope (DME, Leica Canada, Mississauga, ON, Canada) equipped with a digital camera with real time viewing (Micropublisher 5.0, Q-Imaging, Burnaby, Canada). Granule size of chickpea starch was determined using software (QCapture Pro 5.1, Q-Imaging) at 400× magnification from the taken polarized light micrographs.

X-ray diffraction pattern and relative crystallinity

X-ray diffractogram of chickpea starch was obtained with a Rigaku RPT 300 PC X-ray diffractometer (Rigaku-Denki Co., Tokyo, Japan). The chickpea starch sample (~10% moisture content) was packed tightly into an elliptical aluminum holder. The operating conditions were: target voltage 40 kV, target current 100 mA, scanning range 3~35° (2θ), and scanning speed 2.0°/min. Relative crystallinity of chickpea starch was calculated using the method of Nara and Komiya (20) using software (Origin 6.0, Microcal Inc., Northampton, MA, USA). A line connecting peak baselines was computer-plotted on the diffractogram. The area above the smooth curve was considered the crystalline portion and the lower area between the smooth curve and a linear baseline was taken as the amorphous portion. The ratio of the upper area to the total diffraction area was calculated as the relative crystallinity.

Swelling factor (SF) and amylose leaching (AML)

The swelling factor (SF) of the chickpea flour and starch in the range of 60~90°C was measured according to the method of Tester and Morrison (21). The extent of amylose leaching with chickpea flour and starch at the temperature of 60~90°C was determined using a method described by Chung et al. (12).

Thermal properties

Thermal characteristics were measured using a differential scanning calorimeter (2920 Modulated DSC, TA Instruments, New Castle, DE, USA) equipped with a refrigerated cooling system. Chickpea starch and flour (12 mg db) were weighed into high-volume pans and distilled water (28 μL) was added with a microsyringe (70% moisture content). The pans were hermetically sealed and allowed to stand for 12 hr at room temperature to attain an even distribution of water. The sealed sample pans were then heated from 5 to 180°C at a heating rate of 10°C/min. The DSC analyzer was calibrated using indium and an empty pan was used as reference. Thermal transitions were characterized by T_o (onset temperature), T_p

(peak temperature), T_c (conclusion temperature), and ΔH (melting enthalpy).

Pasting properties

Pasting properties of the chickpea flour (11.9% w/w, 28 g total weight) and isolated starch (9.2% w/w, 28 g total weight) were evaluated using a Rapid Visco-Analyzer (RVA-4, Newport Scientific, Warriewood, Australia) following AACC method 76-21 (18), in which the sample was 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. Since the pasting viscosity of chickpea flour was too low, the different moisture level in chickpea flour compared to chickpea starch was used in this study.

Amylopectin chain length distribution

The amylopectin branch chain length distribution of chickpea starch was determined by high-performance anion exchange chromatography with pulsed amperometric detection (HPAEC-PAD, Dionex, Sunnyvale, CA, USA) following the procedure of Liu et al. (22).

***In vitro* starch digestibility and expected glycemic index**

In vitro starch digestibility of both chickpea flour and starch was determined using approved AACC methods 32-40 (18). The chickpea flour or starch (100 mg) was incubated with 10 mg pancreatin from porcine pancreas (cat. no. P-1625, activity 3×USP/g, Sigma Chemical Company, St. Louis, MO, USA), and 12 U amyloglucosidase (EC 3.2.1.3., 3,300 U/mL, Megazyme International Ireland Ltd., Bray, Ireland) in 4 mL of 0.1 M sodium maleate buffer (pH 6.0) at 37°C with continuous shaking (200 strokes/min) for 0～16 hr. After incubation, ethanol (95%) was added to inactivate the enzyme and the sample was centrifuged at 2,000 rpm for 10 min. The glucose content of the supernatant was measured using a glucose oxidase-peroxidase assay kit (Megazyme International Ireland Ltd.). The classification of starch based on its digestibility was as follows: rapidly digestible starch (RDS) as the starch that was hydrolyzed within 0.5 hr, resistant starch (RS) as the starch not hydrolyzed even after 16 hr and slowly digestible starch (SDS) as the starch digested during the period between 0.5 and 16 hr (12). The hydrolysis index (HI) was obtained by dividing the area under the hydrolysis curve (0～16 hr) of the sample by the corresponding area obtained for reference sample (white bread). The expected glycemic index (eGI) was calculated using the equation described by Granfeldt et al. (23): eGI = 8.198 + 0.862 HI.

Statistical analyses

All analyses were performed at least in duplicate. Statistical analyses were carried out with Duncan's multiple range test ($p<0.05$) using the SPSS statistical software (SPSS Institute Inc., Cary, NC, USA).

Table 1. Chemical composition of chickpea flour and starch

Sample	Protein content (%)	Total starch content (%)	Amylose content (%)
Chickpea flour	22.2±0.7[a]	45.8±0.3[b]	11.7±0.1[b]
Chickpea starch	0.6±0.1[b]	91.5±1.5[a]	35.4±0.4[a]

Values followed by a different superscript in each column are significantly different ($p<0.05$).

RESULTS AND DISCUSSION

Chemical composition

The protein, total starch and amylose contents of chickpea flour and starch are presented in Table 1. The protein content of chickpea flour was 22.7%. This value was comparable to those reported in other studies (12,15). Total starch content of chickpea flour was 45.8% (Table 1). This value was higher than those reported by Singh et al. (14) for Indian chickpea cultivars (29.0～35.2%), but was comparable to those reported by Chung et al. (12) for Canadian chickpea cultivars (42.9～46.3%). The apparent amylose content was 11.7%, which was in the range (10.8～13.5%) reported by Chung et al. (12).

The protein content of isolated chickpea starch was characterized by low protein of 0.6% (Table 1). The low protein content of the extracted indicates purity of isolated starches. The total starch content of isolated chickpea was 91.5%. The isolation of starches from pulse, including chickpea, is reported to be a difficult process due to the presence of a fine fiber fraction that exists in the cell wall along with the starch granules (24). The apparent amylose content of isolated chickpea starch was 35.4% (Table 1). Comparable amylose contents were reported by Chung et al. (13) for Canadian chickpea starches (36.5～37.5%) and Singh et al. (14) for Indian chickpea starches (28.6～34.3%).

Morphological characteristics of isolated starch granules

SEM images and polarized light micrographs of isolated chickpea starch are presented in Fig. 1. Granules

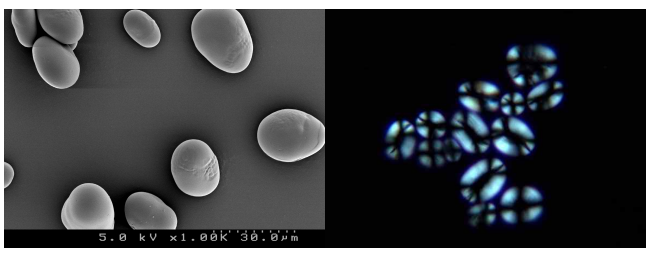

Fig. 1. Scanning electron micrograph (A, ×1000) and polarized light micrograph (B, ×400) of chickpea starch.

of chickpea starch ranged in shape from oval to spherical (Fig. 1A). The SEM image revealed the surface of starches to be smooth, with no evidence of any fissures. Similar observation for chickpea starches has been reported earlier by others (14,25). The size of chickpea starch granules ranged from 11 to 28 μm in length and from 10 to 18 μm in width. Singh et al. (14) reported that the mean granule length and width of starch granules ranged between 17～20 μm and 11～14 μm, respectively. Hoover and Ratnayake (10) reported mean granule length and width of starch granules from two chickpea cultivars to be in the range of 22.0～22.4 and 18.5～18.8 μm, respectively. The birefringence of chickpea starch under polarized light showed different populations of granules (Fig. 1B). The spherical or round granules exhibited the 'Maltese cross', showing a dark cross in the center, whereas the oval granules had a different image with two cross lines at the two ends of the ellipse and a dark line in the center. Similar observation on multiple Maltese crosses of bean starch had been earlier reported by Chung et al. (26). In our previous study (27), most of corn starch granules, which are of the A type of starch, exhibited a visible dark cross in the center. On the other hand, the potato starch (a B type starch) showed wide variations of birefringence pattern between individual granules, as found in chickpea (28).

X-ray diffraction

The X-ray pattern of isolated chickpea starch is shown in Fig. 2. Starch granules from various botanical sources have one of three X-ray diffraction patterns, called A, B, and C types. Most cereal starches exhibit the A type, whereas tuber starches show B type. The C type has been suggested to be a mixture of A and B types. The chickpea starch showed diffraction peaks at 15, 18, 20 and 23° (2θ) (29). Starch from chickpea cultivar showed the characteristic C type pattern of legume starches, which is a mixture of A and B type starches. Intensity of the peak at 5.6° (2θ), characteristic of the B polymorphic form, was smaller in the chickpea starch than the other legume starches as reported by others (10,12,14). The relative crystallinity calculated by the diffraction pattern was 24.6%. Similar values for relative crystallinity of C-type legume starch, including chickpea starch, have been reported (13,30).

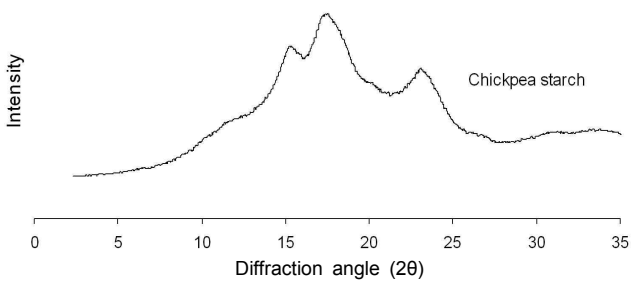

Fig. 2. X-ray diffraction pattern of chickpea starch.

Swelling factor (SF) and amylose leaching (AML)

The extent of SF and AML of chickpea flour and starch in the temperature range 60～90°C is shown in Fig. 3. The SF ranges were 4.6～10.7 and 5.2～23.4, and the AML ranges were 1.4～6.4% and 4.1～16.0% for chickpea flour and isolated chickpea starches, respectively. The isolated starch from chickpea showed significantly higher SF and AML than did chickpea flour (Fig. 3). A similar trend has been observed for other legumes (12, 13,26). This result could be attributed to the presence of protein, fiber, and lipid in chickpea flour, which may have influenced their SF and AML. In all chickpea flours and starches, SF and AML increased dramatically between 60 and 70°C and, thereafter, increases were gradual (Fig. 3). Hoover and Sosulski (24) claimed that the rapid increase in SF and AML was attributed to the melting of the starch crystallite. Tester and Morrison (21) suggested that swelling was characterized by three steps, which was an initial phase of slight swelling, a second phase of rapid swelling and a final stage in which maximum swelling was reached. The second phase of rapid

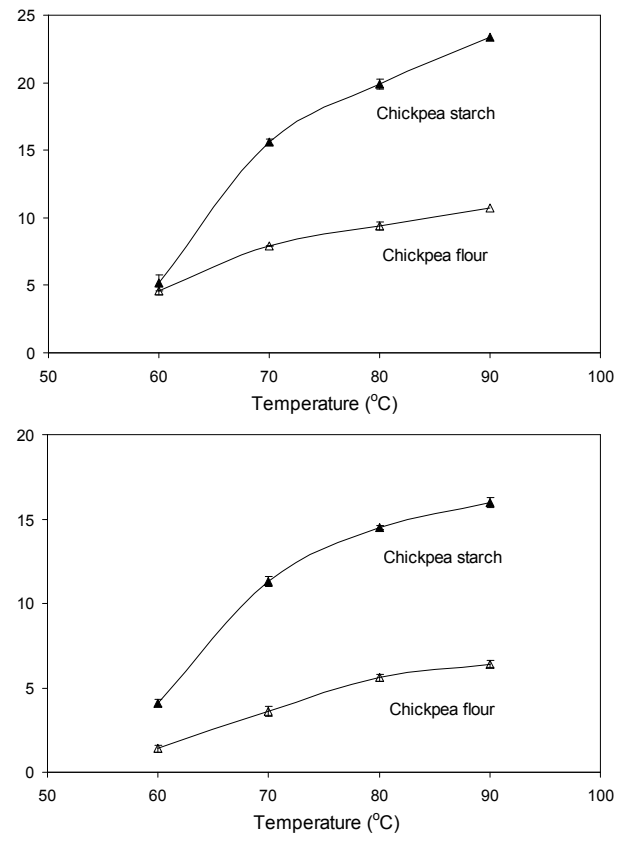

Fig. 3. Swelling factor (SF) and amylose leaching (AML) of chickpea flour and isolated starch.

swelling was suggested to be resulted from the loss of birefringence and a large decrease in gelatinization enthalpy, which was due to dissociation of crystalline structures. Chung et al. (13,26) observed that rapid increases in SF and AML for pea, lentil and bean starches occurred between 70 and 80°C, which were higher than that observed in chickpea starch. This could be due to difference in melting temperature of crystalline structure. Chung et al (13) reported that the chickpea starch had a lower gelatinization temperature compared to other pulse starches (pea or lentil). Therefore, since the rapid increases in SF and AML are due to melting of crystalline structure, the rapid increase at lower temperature of chickpea compared to other pulses could be attributed to its low gelatinization temperature. The AML of chickpea starch was 16.0% at 90°C, which was similar to that reported by Chung et al. (13) for desi type of chickpea starch. However, the kabuli type of chickpea starch exhibited higher AML (18.5～19.1% at 90°C). This result could be due to the difference in chemical composition between desi type and kabuli type chickpea cultivars, which is based on the inherent genetic differences.

Thermal characteristics

The DSC thermograms from chickpea flour and isolated starch are shown in Fig. 4. Chickpea starch showed only a single endothermic transition which was due to gelatinization. However, chickpea flour showed two separate endothermic transitions which were attributed to starch gelatinization for the first peak at a lower temperature and disruption of amylose-lipid complex for the second peak at a higher temperature. The transition temperatures (T_o, T_p and T_c) and melting enthalpy (ΔH) of flour and starch from chickpea are presented in Table 2.

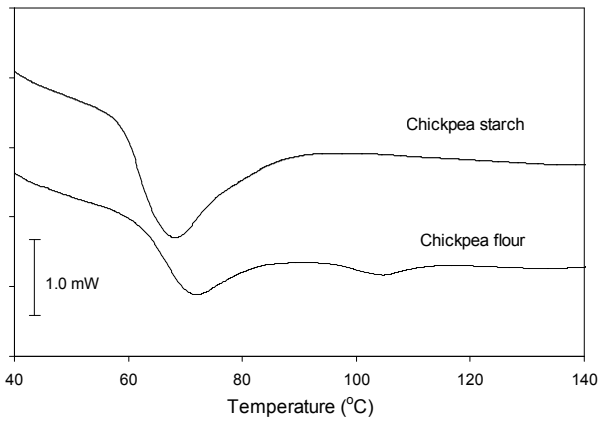

Fig. 4. DSC thermograms of chickpea flour and isolated starch.

The isolated starch from chickpea flour showed significantly lower transition temperatures and higher transition enthalpy than did chickpea flour. Similar results have been reported earlier by Chung et al. (26) for beans. This result may be attributed to the presence of non-starch components in flour, such as protein, fiber, and lipid. The protein in chickpea flour could interact with the starch, which leads to disruption and melting of crystalline structure at a much higher temperature and the lipid could complex with amylose chains, which results in decreasing the extent of hydration in the amorphous regions, thereby increasing temperature for crystallite melting (31). Tester and Morrison (21) claimed that gelatinization enthalpy reflects the overall crystallinity of amylopectin. The amount of crystalline structure in chickpea flour could be low compared to chickpea starch due to presence of non-starch components, which directly caused low gelatinization enthalpy.

The T_o, T_p, T_c and ΔH of chickpea flour were 62.4 °C, 72.5°C, 81.5°C, and 5.1 J/g, respectively. These values were comparable to those reported in other studies (4,12). Kaur and Singh (4) reported that the T_o, T_p, T_c and ΔH of desi chickpea flour ranged between 65.5～67.9 °C, 71.3～73.3°C, 77.7～79.4°C, and 3.9～4.5 J/g, respectively. Chung et al. (12) observed T_o, T_p, T_c and ΔH of 60.3°C, 72.5°C, 81.5°C, and 4.3 J/g, respectively for desi chickpea flour. The gelatinization temperatures observed in this study with desi chickpea flour was relatively lower that those with kabuli chickpea flour in our previous study (12). This result could be attributed to the difference in starch structure by inherited difference in the type of pulse.

In chickpea starch, T_o, T_p, T_c and ΔH for gelatinization were observed to be 58.9°C, 67.6°C, 80.2°C, and 13.3 J/g, respectively. Singh et al. (14) reported that T_o, T_p, and T_c for chickpea starch ranged between 61.5～64.8°C, 66.4～69.0°C, and 71.3～73.8°C, respectively. Chung et al. (13) reported that the range of T_o, T_p, and T_c of chickpea starches were 57.7～58.0°C, 64.4～66.8°C, and 77.7～79.9°C, respectively. The difference in gelatinization

Table 2. Thermal properties of chickpea flour and starch

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)
Chickpea flour	62.4±0.4[a]	72.5±0.2[a]	81.5±0.2[a]	5.1±0.0[b]	96.7±1.2	104.8±0.4	111.0±0.1	0.7±0.0
Chickpea starch	58.9±0.1[b]	67.6±0.3[b]	80.2±0.2[b]	13.3±0.1[a]	ND	ND	ND	ND

Values followed by a different superscript in each column are significantly different ($p<0.05$)
ND = not detected.

temperature with other studies could be due to the difference in amylose content, granule size, and internal arrangement of starch fractions, which is based on the inherited difference in cultivar. The gelatinization enthalpy of chickpea starch was much higher than those reported by Singh et al. (14) for Indian chickpea starch (7.2～8.7 J/g) and by Hoover and Ratnayake (10) for Canadian chickpea starch (9.7～12.4 J/g). This explains that higher energy is required to break the intermolecular bonds in chickpea starch tested in our study compared to that in other studies. The gelatinization temperature range (T_c－T_o) was 21.3°C, which was relatively high compared to those reported by Singh et al. (14) for Indian chickpea starch (9.1～10.2°C). This wide gelatinization temperature range indicates the greater degree of heterogeneity in starch crystallites within granules (14).

The endothermic peak for the amylose-lipid complex was observed between 96.7～110.0°C for chickpea flour. The melting enthalpy of amylose-lipid complex was 0.7 J/g. This result was comparable to those reported by our previous study (12) for Canadian chickpea flour (0.74～0.79 J/g), but higher than those for other legume flour (0.22～0.64 J/g for pea flour, 0.50～0.51 J/g for lentil flour). The difference in enthalpy for the amylose-lipid complex among legume flours may be due to difference in lipid bound with amylose and apparent amylose content.

Pasting characteristics

The significant difference in the pasting curves between isolated starch and chickpea flour is shown in Fig. 5. The chickpea starch showed the typical pasting visocgram of legume starch in which it exhibits a rapid increase in pasting viscosity during heating by swelling of starch granule, a decrease in viscosity during the holding period at 95°C by breakdown, and another significant increase in viscosity during cooling by high setback. However, compared to chickpea starch, the chickpea flour showed a pasting profile characterized by restricted swelling (lower pasting viscosity) and a slight continuous increase in viscosity with no breakdown during the holding period at 95°C and the cooling period. This difference in pasting curves might be due to lower starch content and the presence of lipid, protein, and fiber in the chickpea flour. Compared with cereal and tuber, pasting viscogram of chickpea starch exhibited a restricted swelling and higher setback indicative of its higher amylose content (Table 1) and long amylopectin chain length (Fig. 6).

The pasting temperature between chick pea flour (70.0 °C) and isolated starch (69.9°C) was nearly similar. Similarly, the pasting temperature of chickpea cultivar has been reported to be 69.1～71.8°C for chickpea flour (12) and 69.1～71.1°C for chickpea starch (13). Pasting temperature means an indication of the minimum temperature required to induce swelling. Similar pasting temperatures between chickpea flour and isolated starch indicated their similar resistance toward swelling, since the starch in flour plays a major role in pasting temperature. The peak viscosity of chickpea flour and starch was 1333 cP and 2440 cP, respectively. Similar results have been reported in our previous studies for chickpea flour (755～1347 cP) and chickpea starch (2392～2501 cP), and by Singh and colleagues (4,14) for chickpea flour (1300～2100 cP) and chickpea starch (1107～2173 cP). The peak viscosity could be attributed to the swelling of starch during heating. A greater amount of protein and lipid in flour could induce increased protein-starch or lipid-starch interactions, which could decrease starch swelling, thereby decreasing peak viscosity in chickpea flour as compared to isolated starch. The setback and final viscosity of chickpea starch were 3474 cP and 5272 cP, respectively, whereas the final viscosity of chickpea flour was 1849 cP. The setback and final viscosity represents amylose-amylose aggregation and the presence of

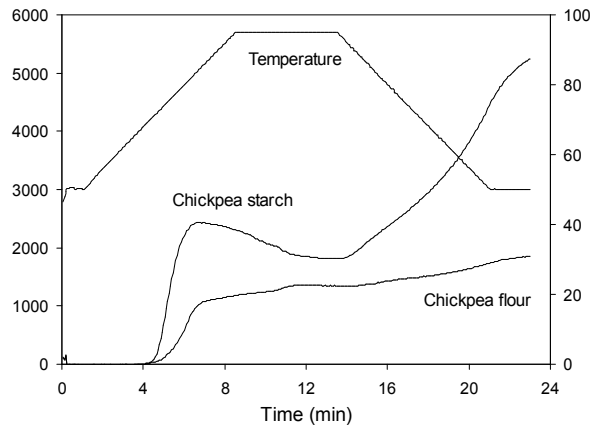

Fig. 5. Viscograms of chickpea flour and isolated starch.

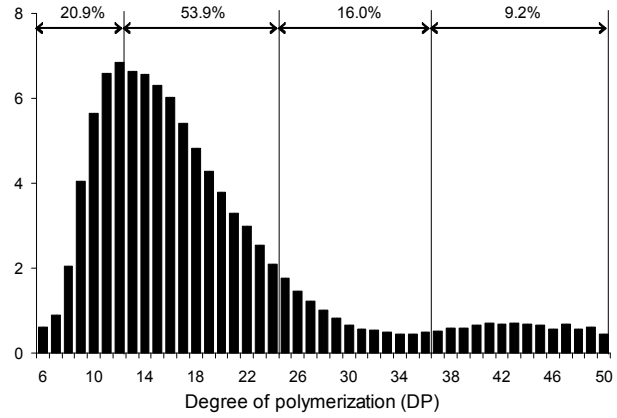

Fig. 6. Amylopectin chain length distribution profile of chickpea starch.

fragmented granules embedded in the leached amylose network (10). The amount of amylose was much higher in isolated starch compared to chickpea flour and the leached amylose during heating could be much higher in isolated starch due to absence of amylose-lipid complex as found in thermogram (Fig. 4), resulting in greater amylose-amylose association in the isolated starch.

Chain length distribution

Normalized chromatograms of branch chain length distribution of amylopectin for chickpea starch are shown in Fig. 6. Amylopectin branch chains are classified into chain types as follows: A chains (DP 6～12), B1 chains (DP 13～24), B2 chains (DP 25～36), and B3+ chains (DP≥37) (32). The proportion of DP 6～12, DP 13～24, DP 25～36, DP≥37 and average chain length of chickpea starch were 20.9%, 53.9%, 16.0%, 9.2% and 20.1, respectively (Fig. 6). The average chain length of chickpea starch was relatively higher than that of other legume starches (33). The different amylopectin chain length distribution among legume starches could be associated with different size and amount of double helix as well as crystalline structure of starch (22).

***In vitro* starch digestibility**

The hydrolysis curves for the chickpea starch and flour at different time intervals are shown in Fig. 7. Both chickpea flour and starch were hydrolyzed more rapidly at the early stage of hydrolysis, reaching a plateau after 8 hr. As expected, the maximum level of hydrolysis in chickpea starch was substantially higher than that in chickpea flour due to its higher starch content and small amount of non-starch components. A similar result already has been reported by Chung et al. (12). Rapidly digestible starch (RDS), slowly digestible starch (SDS), and resistant starch (RS) contents of chickpea flour and isolated starch, based on the hydrolysis curve, are presented in Table 3. RDS, rapidly digested in the small intestine, was 9.9% in chickpea flour. This result was comparable to that for pea (9.2～10.7%), but much higher than that for lentil (7.6～7.8%) and bean (0.2～1.2%) (12,26). SDS and RS contents of chickpea flour were 28.7% and 7.1%, respectively. The RS content of chickpea flour was much lower than that reported by Chung et al. (12,26) for pea (10.1～14.7%), lentil (14.4～14.9 %), and bean (32.4～36.0%). The authors suggested that the lower RS content of chickpea flour among pulse flours could be due to its lower amylose and protein contents. The hydrolysis index (HI) and expected glycemic index (eGI) of chickpea flour were 36.4 and 39.5, respectively (Table 3). Those results were comparable to those reported for other legume flour: 46.3 for bean (34), 41.5 for lentil (12), and 42.0 for pea (12).

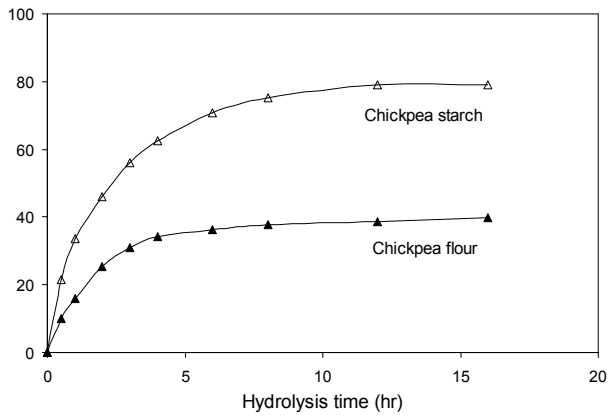

Fig. 7. Total starch hydrolysis of chickpea flour and isolated starch.

RDS, SDS, and RS contents of chickpea starch were 21.5%, 57.7% and 9.3%, respectively (Table 3). RDS content of chickpea starch was lower than corn (24.4%), wheat (40.1%) and rice (32.4%) starches (35). SDS content, which is considered a desirable form of dietary starch, was higher than those reported by Zhang et al. (35) for maize (53.0%), waxy maize (47.6%), wheat (50.0%), rice (43.8%) and potato (15.2%). Digestibility of native starch was influenced by starch source, granule size, amylose/amylopectin ratio, crystallinity, and amylopectin molecular structure (24,26,36). The low digestibility of chickpea starch as compared to other cereal and tuber starches may reflect its higher amylose content. It is generally recognized that the greater amount of amylose content in starch reduces the starch digestibility (36). The HI and eGI of chickpea starch were 70.8 and 69.2, respectively. Those results were comparable to those reported by Chung et al. (13,26) for pea (68.9～71.6 and 67.6～69.9), lentil (67.3～67.4 and 66.2～66.3), and bean (66.9～69.8 and 65.8～68.4). In our present

Table 3. Starch nutritional fraction (RDS, SDS and RS), hydrolysis index and expected glycemic index of chickpea flour and starch by *in vitro* digestion

Sample	RDS (%)	SDS (%)	RS (%)	HI	eGI
Chickpea flour	9.9±0.4[b]	28.7±0.9[b]	7.1±0.6[b]	36.4±0.4[b]	39.5±0.3[b]
Chickpea starch	21.5±0.5[a]	57.7±1.1[a]	9.3±0.7[a]	70.8±0.4[a]	69.2±0.3[a]

Values followed by a different superscript in each column are significantly different ($p<0.05$).
RDS: rapidly digestible starch, SDS: slowly digestible starch, RS: resistant starch, HI: hydrolysis index, eGI: expected glycemic index.

study, as found in legume, chickpea had low digestibility with higher amount of SDS and RS and low eGI, which could be useful for its application in the management of diabetes and hyperlidpidemia.

CONCLUSIONS

The differences in *in vitro* digestibility and physiochemical properties between chickpea flour and isolated starches were observed. The chickpea flour was substantially different from its counterpart isolated starch with respect to higher protein content and total starch content, higher gelatinization temperature, presence of amylose-lipid complex, restricted swelling and no breakdown in pasting viscogram. In addition, the flour has lower digestible starch and expected glycemic index. The difference in properties between chickpea flour and isolated starches could result from the difference in the amount of non-starch components. The chickpea starch was characterized by typical C-type X-ray diffraction pattern, granule shape having oval to round with a smooth surface, high setback in pasting curve, and high amount of slowly digestible starch. Our experimental results provide useful information for the consumers and food industries who wish to use chickpea.

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