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Characteristics of mung bean starch isolated by using lactic acid fermentation solution as the steeping liquor

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Abstract

Physicochemical properties of commercial mung bean starch isolated with lactic acid fermentation solution (LFS) and starches laboratory-prepared by using NaOH, Na_2SO_3 and distilled water as steeping liquors were examined with the aim of elucidating the effect of different steeping liquors on the properties of starches. Results indicated that the amylose content, granular morphology and X-ray diffraction pattern of starches isolated with different steeping liquors did not show obvious differences. However, the LFS-isolated starch had significantly ($p < 0.05$) higher weight percentage of longer B chains and B_1 chains, a lower weight percentage of A chains and a lower ratio of short-to-long chains in amylopectin than those of the other preparations. Moreover, the LFS-isolated starch showed significantly ($p < 0.05$) lower pasting viscosity, a higher onset temperature, a narrower temperature range and a lower enthalpy of gelatinization than the other preparations. No significant differences on the physicochemical properties mentioned above were found among the laboratory-prepared starches. The results suggest that mung bean starch is degraded during isolation with lactic acid fermentation solution, which leads to the loss of starch granules with less integrity.

Keywords: Mung bean starch; Lactic acid fermentation solution; Chain length distribution; Pasting properties; Gelatinization thermal properties

1. Introduction

Starch noodles, one of traditional foods in Taiwan, have low cooking loss, translucence, smoothness and flexibility (not easily broken during cooking) as its cooking properties. A general process of manufacturing starch noodles involves mixing native starch with pre-gelatinized starch as a binder to form a loaf of dough. Afterward the dough is directly extruded into boiling water into the shape of a noodle, cooled in cold water, kept overnight at refrigerated temperature, warmed in cold water and dried.

Owing to the absence of gluten as compared with wheat flour, physicochemical properties of starch affects its starch noodle quality. Meanwhile the influence of starch functionality on starch noodle quality would be noticed as a result of the retrogradation step included in the manufacturing process. Mestres, Colonna, and Buleon (1988) utilized acid hydrolysis to investigate the internal structure of mung bean starch noodle. They proposed that a junction zone, mainly composed of amylose, contributed to the completed structure of starch noodle. Additionally, the properties of starch noodles made from different botanical starches have been studied, such as using red bean starch (Lii & Chang, 1981), pigeon pea starch (Singh, Voraputhaporn, Rao, & Jambunathan, 1989), tuber starch (Chang & Lii, 1987; Collado & Corke, 1997) and blends of tuber and high-amylose starches (Kasemsuwan, Bailey, & Jane, 1998; Kim & Wiesenborn, 1996). These investigations indicated that the cooking qualities of prepared starch noodle were not only affected by the amylose content of the raw material, but also by its pasting properties. Lii and Chang (1981) proposed that starch isolated from mung bean (*Vigna radiate*) was the best raw material to produce high quality starch noodles resulting from its high amylose content, restricted

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swelling of starch during gelatinization and the high shear resistance of its paste.

In Taiwan, traditional starch noodle manufacturers use mung bean starch as a unique ingredient to produce starch noodles with good cooking quality. Moreover, the mung bean starch isolated by using sour water (lactic fermentation solution; LFS) as the steeping liquor is preferred. It is generally recognized that using LFS-isolated mung bean starch in the process contributes to higher quality of starch noodle than using starches isolated in other ways. Investigations have focused on the effect of steeping liquor containing lactic acid on the physicochemical properties of maize starch and illustrated that the pasting properties, thermal properties and molecular weight distribution of starch were affected by the concentration of lactic acid in the steeping liquor (Haros, Perez, & Rosell, 2004; Shandera & Jackson, 1996). In the case of the isolation process for LFS-isolated mung bean starch, the kernels are steeped in LFS for 11–12 h. After wet-milling, the starch is isolated by repeated settling, washed, dewatered, and dried. As the steeping process takes time, the degradation of starch may occur.

In this study, a commercial LFS-isolated mung bean starch and laboratory-prepared mung bean starches isolated by using of NaOH, Na_2SO_3 and distilled water as the steeping liquor were used as the samples. The physicochemical properties of the starches including granular morphology, size distribution, internal structure, crystalline structure, molecular structure, pasting properties and gelatinization thermal properties were determined and compared for elucidating the difference among LFS-isolated starch and starches isolated using other steeping liquors.

2. Materials and methods

2.1. Materials

2.1.1. Isolation of starch

Mung bean (*V. radiate*) kernels and its starch isolated by LFS were purchased from Jung-ho Starch Company (Nantou, Taiwan). The mung beans were stored at refrigerated temperature until being used to produce the laboratory-prepared isolated starch as described below.

Mung beans were soaked overnight in three times their weight of steeping liquor at room temperature. The steeping liquors used were NaOH (0.1%, w/v), Na_2SO_3 (0.2%, w/v) and distilled water. After steeping, the liquor was decanted and the swollen and softened beans were washed with distilled water before being ground in a burrstone mill (Golden Pineapple Grinder Co., Tapiei, Taiwan) with fresh steeping liquor. The slurry was filtered through a steel sieve with a 63 μm pore size. The residue was re-suspended in steeping liquor, ground in a blender for 10 min, and filtered through the sieve. The procedure of filtering and grinding was repeated three times. All the filtrates were collected and allowed to settle for 2 h. The supernatant was decanted and discarded. The starch was re-suspended and re-settled in steeping liquor twice more and in distilled water five times. Afterward the starch was rinsed with 95% ethanol and dried at 40 °C for 24 h. Finally, the starch was gently ground by pestle and mortar and passed through a steel sieve (250 μm pore size).

2.1.2. Reagents and enzyme

Chemical reagents used were of analytical grade. Isoamylase (EC 3.2.1.68) of *Pseudomonas amyloderamosa* (59,000 U/ml) was purchased from Hayashibara Biochemical Laboratories, Inc. (Okayama, Japan).

2.2. Methods

2.2.1. Chemical compositions and amylose content

The moisture and crude protein contents of mung bean starch were determined by Methods 44-15 A and 46-12 of AACC (2000), respectively. A conversion factor of 6.25 was used for the calculation of crude protein content. In addition, the crude lipid content of starch was analyzed by refluxing a sample in 85% methanol at 80 °C for 48 h. The defatted starch was also used for determining the amylose content by the potentiometric titration procedure (Schoch, 1964); iodine affinity of its pure amylose was assigned as 19.2% (Chang & Lii, 1987).

2.2.2. Morphology, structure and size distribution of granule

The granular morphology of starch was observed by a scanning electron microscope (SEM ABT32-I, Topcon Co., Japan). Starch granules were mounted on circular aluminum stubs with double sided tape, coated with gold, and then examined and photographed at an accelerating potential of 15 kV. For observation of the internal structure of granules, they were stained with PATAg (periodic acid–thiosemicarbazide–silver) according to Planchot, Colonna, Gallant, and Bouchet (1995) and then observed by a transmission electron microscope (TEM 1200EXII, JOEL, Tokyo, Japan) under an accelerating potential of 100 kV. Granule size distribution of starch was determined by a dynamic laser-light scattering-based particle size analyzer (Mastersizer Micro, Malvern Instruments, Malvern, UK.) with 15–16% for obscuration and 2520 rpm for paddle speed.

2.2.3. X-ray diffraction pattern

X-ray diffraction pattern of starch, equilibrated in saturated relative humidity chamber at room temperature for 72 h, was examined on a Shimadzu XRD-6000 X-ray diffractometer (Kratos Analytical Inc., Kyoto, Japan) with copper Kα radiation. The diffractometer was operated at 30 mA and 40 kV. Signals of reflection angle of 2θ, from 4° to 40° at a scanning rate of 1.2°/min, were recorded.

2.2.4. Molecular weight distribution

Weight percentage of amylopectin and amylose and their weight-average molecular weights (M_w) were deter-

mined by a high-performance size-exclusion chromatography (HPSEC) system as previously described (Lin, Lee, & Chang, 2003), except that the mobile phase was replaced by 100 mM $NaNO_3$ containing 0.02% NaN_3. Electronic outputs of refractive index (RI) and multiple-angle laser light scattering (MALLS) detectors were collected by ASTRA software (ver. 4.50, Wyatt Tech., Santa Barbara, CA, USA). The Berry plot was used to analyze the signal of MALLS, and peaks were assigned according to the gyration radius distribution as proposed by You, Fiedorowicz, and Lim (1999).

Because of reduced sensitivity of MALLS for small molecular species (McPherson & Jane, 2000), the M_w of peak two (amylose and degraded amylopectin fragments, F2) was computed from the RI signal with a calibration curve instead of from the MALLS signal as used for amylopectin (peak one, F1). A calibration curve was constructed from a set of pullulan standards (PSS-USA Inc., Silver Spring, MD, USA) with average molecular weights ranging from 5.6 to 769.5 kDa.

2.2.5. Chain length distribution

Chain length distribution of starches isolated with different steeping liquors were observed by the method proposed by Lin et al. (2003), and the computation of MALLS signal was based on the Debye plot. In addition, the peaks of HPSEC profile were assigned according to RI responses.

Due to the same reason mentioned above, the M_w of the second to the fourth peaks (DF2 to DF4) were calculated from the RI signal with a calibration curve rather than from the MALLS signal as used for the first peak (amylose fraction, DF1). Maltohexaose (M9153, Sigma-Aldrich Co., St. Louis, MO, USA) and a series of pullulan standards with average molecular weights ranging from 5.6 to 46.0 kDa (PSS-USA Inc.) were used to compose the calibration curve.

2.2.6. Pasting properties

Pasting properties of starch were determined by a Rapid Visco-Analyzer (RVA 3 D+, Newport Scientific, Australia). Starch suspension (6%, dry weight) was equilibrated at 35 °C for 1 min, heated at a rate of 6 °C/min to 95 °C, maintained at 95 °C for 5 min, cooled at the same rate to 50 °C, and maintained at 50 °C for 2 min. Paddle speed was set at 960 rpm for the first 10 s and at 160 rpm for the rest of analysis.

2.2.7. Gelatinization thermal properties

Thermal properties of starch during gelatinization were analyzed by differential scanning calorimetry (Micro DSC VII, Setaram Co., Caluire, France). About 150 mg starch suspension (25%, db) sealed in a stainless steel crucible was heated from 25 to 115 °C at a rate of 1.2 °C/min. Enthalpy (ΔH), onset (T_O), peak (T_P), and completion temperature (T_C) of gelatinization were then quantified.

2.2.8. Statistical analysis

The General Linear Model (GLM) procedure of Statistical Analysis System (SAS Institute Inc., Cary, NC, USA) was used for performing statistical analysis. The significant difference of means was analyzed by Duncan's multiple range test at $p < 0.05$.

3. Results and discussion

3.1. Chemical compositions

Crude protein and crude lipid contents of starches isolated by different steeping liquors as shown in Table 1 were less than 0.1% and 0.2%, respectively. In addition, amylose contents of the mung bean starches, which were similar to the result reported by Chang and Lii (1987), ranged from 30.9% to 31.1%. The result indicated that steeping liquor used in starch isolation did not significantly influence the amylose content of starch.

3.2. Morphology and granule size characteristics

The appearance of starch granules isolated using different steeping liquors (left side of Fig. 1) was irregular and varied from oval to round to kidney shape. The internal structure of starch granules is shown on the right side of Fig. 1. An obvious cavity was found inside the mung bean starch granules in spite of the steeping liquor used, which was true even for the starch granules isolated using distilled water (Fig. 1h). The presence of a cavity inside starch granules has been observed by using confocal scanning laser microscopy which has the characteristic of sectioning, the granule optically rather than mechanically (Velde, Riel, & Tromp, 2002). Therefore, the presence of cavity inside the mung bean starch granules observed in this study was caused neither by the isolation procedure nor by the treatment for observation.

The granule size distribution profile of starches (Fig. 2) was bimodal. The distribution curves could be divided into two fractions: one for small granules (FS, 0.4–4.2 μm) and one for large granules (FL, 7.7–48.3 μm). The volume percentage of FS fraction among starches isolated using different steeping liquors ranged from 6.7% to 6.8% and did not show a significant difference (Table 2). The same is true for

Table 1
Chemical compositions of mung bean starches isolated using different steeping liquors

Steeping liquor	Crude protein (%, db)	Crude lipid (%, db)	Amylose (%, db)
LFS	0.08 ± 0.02a[A]	0.20 ± 0.03a	30.9 ± 0.1a
NaOH	0.08 ± 0.01a	0.16 ± 0.03a	30.9 ± 0.1a
Na_2SO_3	0.09 ± 0.00a	0.19 ± 0.02a	31.0 ± 0.2a
Distilled water	0.07 ± 0.02a	0.19 ± 0.01a	31.1 ± 0.2a

[A] Means within a column followed by different letters are significantly different ($p < 0.05$).

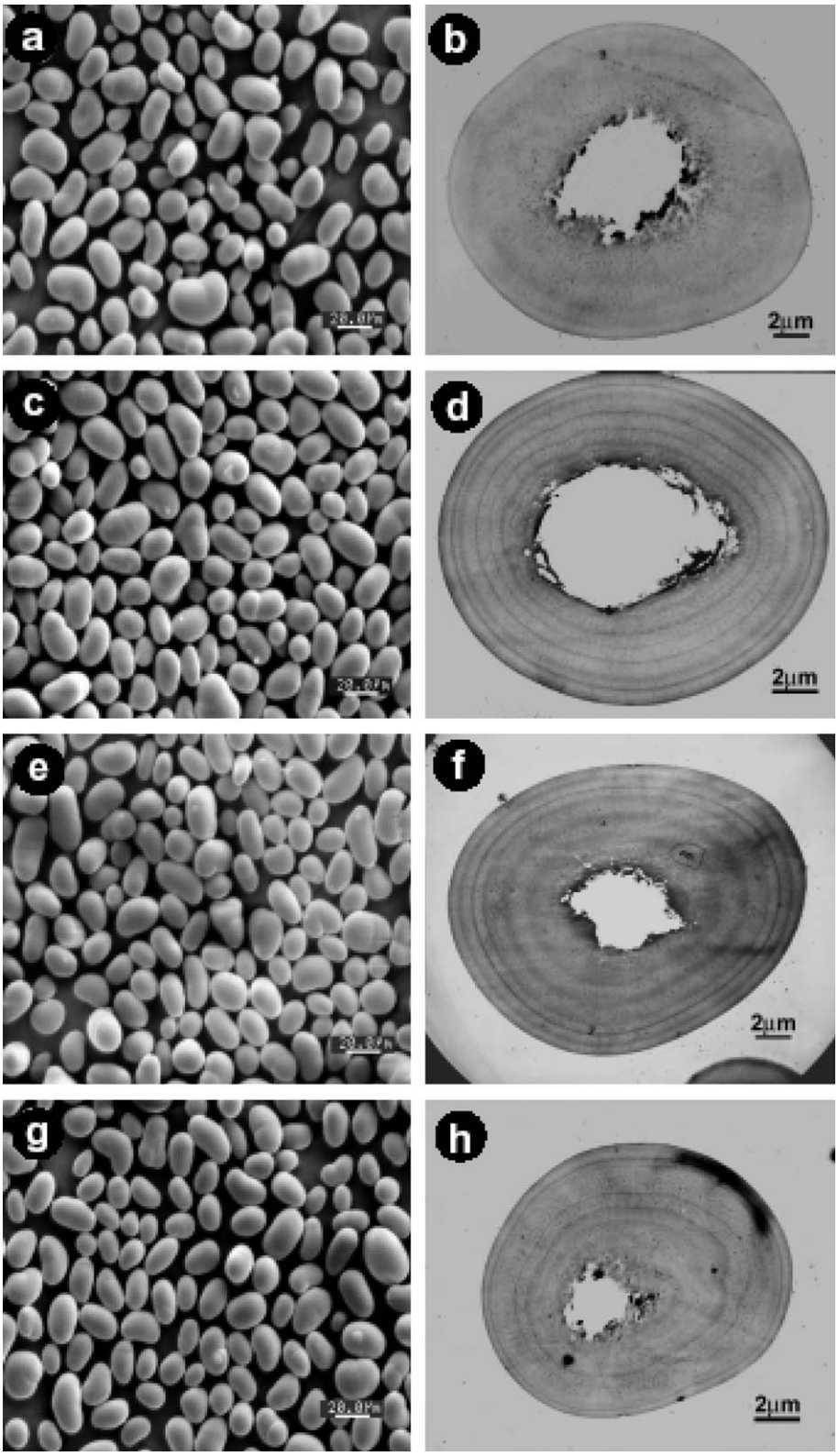

Fig. 1. Scanning (a, c, e, g) and transmission (b, d, f, h) electron micrographs of mung bean starches isolated by LFS (a, b), NaOH (c, d), Na_2SO_3 (e, f), and distilled water (g, h), respectively.

the volume percentage of FL fraction, which ranged from 93.2% to 93.3%. However, a noticeable difference was observed in the FL fraction when it was further fractionated at the point of 16.6 μm as indicated by Fig. 2. The volume percentage of the fraction of granular size within 7.7–16.6 μm was 28.0% for LFS-isolated starch, which was significantly ($p < 0.05$) higher than those of other starches (19.0–20.6%) (Table 2). As a result, the average granule size

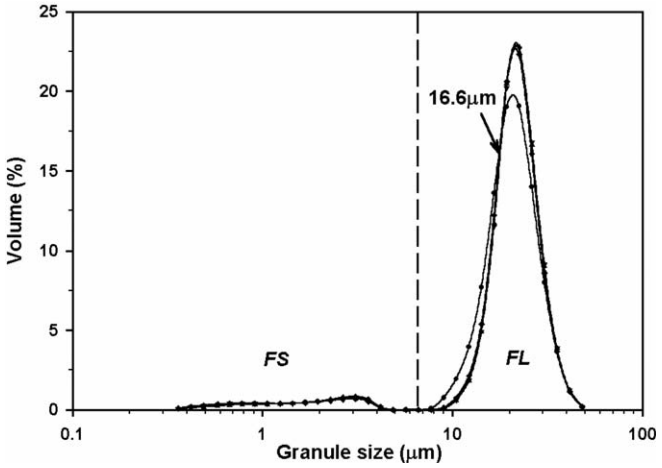

Fig. 2. Granule size distributions of mung bean starches isolated by LFS (●), NaOH (◆), Na_2SO_3 (▲), and distilled water (▼), respectively.

Table 2
Average granule sizes and volume percentages of fractions of mung bean starches isolated using different steeping liquors

Steeping liquor	Average granule size (μm)	Volume (%)		
		FS[A]	FL[A]	
		0.4–4.2 μm	7.7–16.6 μm	16.6–48.3 μm
LFS	18.7 ± 0.2c[B]	6.8 ± 0.1a	28.0 ± 0.4a	65.2 ± 0.5c
NaOH	19.4 ± 0.2b	6.8 ± 0.0a	20.6 ± 1.1b	72.6 ± 1.1b
Na_2SO_3	19.7 ± 0.1a	6.8 ± 0.1a	19.0 ± 0.5c	74.2 ± 0.4a
Distilled water	19.7 ± 0.0a	6.7 ± 0.1a	19.1 ± 0.3c	74.2 ± 0.4a

[A] FS and FL stand for small-sized granule fraction and large-sized granule fraction as shown in Fig. 2, respectively.
[B] Means within a column followed by different letters are significantly different ($p < 0.05$).

of LFS-isolated starch (18.7 μm) was significantly ($p < 0.05$) smaller than the starches isolated by NaOH, Na_2SO_3 and distilled water (19.4–19.7 μm).

3.3. X-ray diffraction pattern

According to the classification proposed by Hizukuri, Fujii, and Nikuni (1960), all four mung bean starch preparations had typical C-type X-ray diffraction patterns (Fig. 3). The diffraction intensity of peak 1 and the intensity difference between peak 4a and 4b for LFS-isolated starch were the lowest among the four starches isolated, whereas no obvious difference was found among starches isolated by NaOH, Na_2SO_3 and distilled water. This implies that the crystalline structure within LFS-isolated starch is different from those of starches isolated with other steeping liquors, and further reveals that the lactic fermentation solution may alter the crystalline structure of starch during isolation.

3.4. Molecular weight and chain length distribution

The HPSEC profiles of starches from different steeping liquors are shown in Fig. 4, and its calculated result is

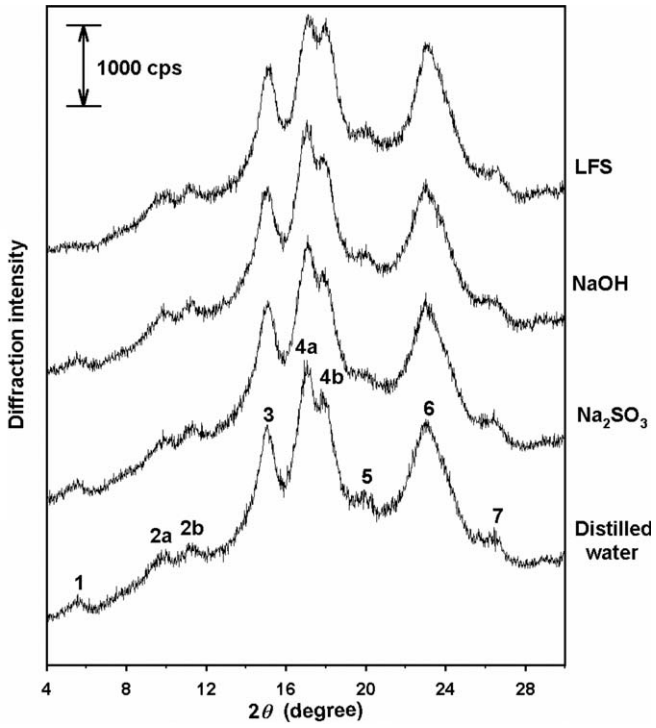

Fig. 3. X-ray diffraction patterns of mung bean starches isolated using different steeping liquors.

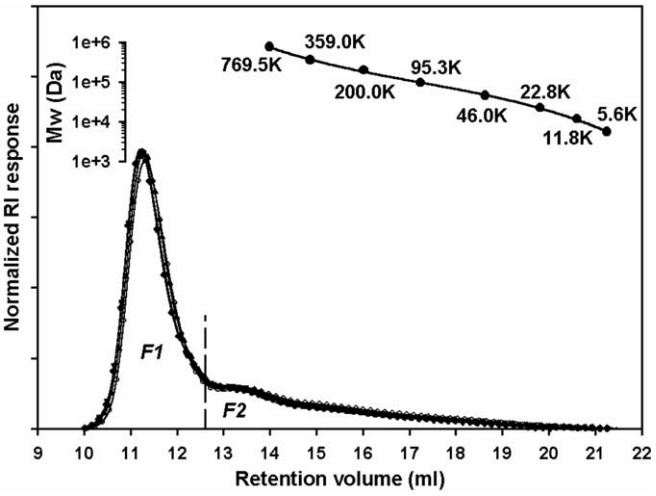

Fig. 4. High-performance size-exclusion chromatograms of mung bean starches isolated using different steeping liquors: LFS (○), NaOH (◆), Na_2SO_3 (▲), distilled water (▼), and molecular weight of pullulan standard (●).

summarized as Table 3. The first fraction (F1) with a shorter retention volume corresponds to amylopectin, and the second fraction (F2) to the low molecular weight molecules consisting of amylose and low molecular weight amylopectin. The weight–average molecular weight (M_w) of F1 and F2 fractions among starches isolated by different steeping liquors were similar and ranged from 7.25 to 8.06×10^7 and 9.09 to 10.17×10^5 Da, respectively. However, the LFS-isolated starch had a significantly ($p < 0.05$)

Table 3
Weight percentages and average molecular weights (M_w) of HPSEC fractions of mung bean starches isolated using different steeping liquors

Steeping liquor	Distribution (%, w/w)		M_w (Da)	
	F1	F2	F1($\times 10^7$)[A]	F2($\times 10^5$)[B]
LFS	66.3 ± 0.7b[C]	33.7 ± 0.7a	8.06 ± 0.31a	9.09 ± 0.53c
NaOH	70.0 ± 0.1a	30.0 ± 0.1b	7.25 ± 0.27b	10.17 ± 0.31a
Na_2SO_3	69.7 ± 0.5a	30.3 ± 0.5b	7.97 ± 0.10a	9.85 ± 0.14ab
Distilled water	69.1 ± 1.1a	30.9 ± 1.1b	7.71 ± 0.02a	9.48 ± 0.29bc

[A] Molecular weight was determined by light scattering and refractive index detectors.
[B] Molecular weight was determined by refractive index detector based on pullulan standard curve.
[C] Means within a column followed by different letters are significantly different ($p < 0.05$).

lower amount of F1 fraction than starches isolated by NaOH, Na_2SO_3 and distilled water. As a result, the proportion of F2 fraction for LFS-isolated starch was higher than those of starches isolated using other steeping liquors. Shandera and Jackson (1996) indicated an increase on the proportion of low M_w fraction of corn starch when the concentration of lactic acid used in the steeping process increased from 0.2% to 1.5%, and concluded that depolymerization of starch during steeping was enhanced by higher concentration of lactic acid used. Therefore, the significant reduction in the amount of F1 fraction for the LFS-isolated starch should be attributed to the partial degradation of amylopectin during isolation.

To further investigate the effect of lactic acid fermentation solution on the structure of mung bean starch, the chain-length distribution of starch (Fig. 5) isolated using different steeping liquors was observed after debranching by isoamylase. The HPSEC profile was divided into four

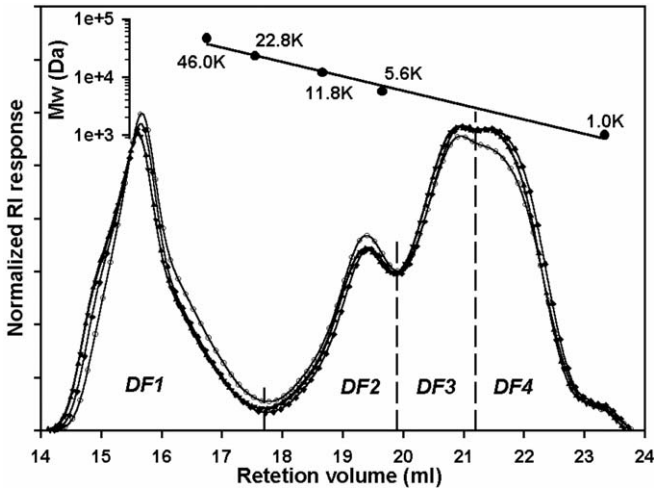

Fig. 5. High-performance size-exclusion chromatograms of isoamylase-debranched mung bean starches isolated using different steeping liquors: LFS (○), NaOH (◆), Na_2SO_3 (▲), distilled water (▼), and molecular weight of pullulan standard (●).

fractions. These fractions correspond to amylose (DF1), and longer B chains (DF2, B_2 chains or longer), B_1 chains (DF3) and A chains (DF4) of amylopectin (Hizukuri, 1986).

Table 4 summarizes the weight percentage and weight–average degree of polymerization (DP_w) for each fraction of starch after debranching. The DP_w of DF1, DF2, DF3 and DF4 for the isolated starches had ranges of 4516–5665, 61.1–63.8, 25.9–27.3 and 12.6–13.5, respectively. In addition, weight percentages of DF1 (amylose) for different preparations, ranged from 31.8% to 32.8%, and showed no significant differences. These results agreed with results obtained by potentiometric titration (Table 2). However, LFS-isolated starch had significantly ($p < 0.05$) higher percentage of fractions DF2 (longer B chains) and DF3 (B_1 chains) than other starches. Consequently, the percentage of DF4 (A chains) for LFS-isolated starch was the lowest. Furthermore, the ratio of short–to–long chains (S/L ratio = [DF3 + DF4]/DF2) of amylopectin for LFS-isolated starch was 2.61, and was significantly ($p < 0.05$) lower than those (3.09–3.20) of starches isolated using different steeping liquors. The relatively lower values of the weight-percentage of DF4 fraction and S/L ratio for the LFS-isolated starch could be attributed to the degradation of amylopectin and amylose during steeping in lactic acid fermentation solution.

The importance of molecular characteristics of starch on noodle quality had been reported by Mestres et al. (1988). They illustrated that the amylose and amylopectin macromolecules would reorganize within a new crystalline structure during processing. Furthermore, the extent of retrogradation would depend on the amylopectin structure as the starches shared similar amylose content. Starch with a higher proportion of long chains in its amylopectin fraction tends to have a higher extent of retrogradation (Wang, Wang, & Porter, 2002). Therefore, this may be one of the reasons that the manufacturers of mung bean starch noodle tend to use LFS-isolated mung bean starch, which has a lower S/L ratio, as the raw material for producing starch noodles with good cooking qualities.

3.5. Pasting properties

Pasting viscosity profiles of mung bean starches isolated using different steeping liquors are shown in Fig. 6. The profile of starch measured by the RVA was similar to that of type C starches, i.e., without an apparent pasting peak during cooking and an obvious breakdown of hot paste, obtained by a Brabender Viscoamylograph (Schoch & Maywald, 1968). Pasting properties of the isolated starches are summarized in Table 5. The results indicate that the LFS-isolated starch had significantly ($p < 0.05$) lower values of peak, hot paste and final viscosity than those of other starches. In addition, it also exhibited the lowest values of breakdown and setback. The pasting properties of maize starch isolated using a steeping liquor containing lactic acid were similar (Haros et al., 2004). However, no sig-

Table 4
Weight percentages and average polymerization degrees (DP_w) of HPSEC fractions of isoamylase-debranched mung bean starches isolated using different steeping liquors

Steeping liquor	Distribution (%, w/w)				*S*/*L* ratio[A]	DP_w			
	DF1	DF2	DF3	DF4		DF1[B]	DF2[C]	DF3[C]	DF4[C]
LFS	32.5 ± 0.1a[D]	18.7 ± 0.7a	24.7 ± 0.7a	24.1 ± 1.4b	2.61 ± 0.14b	4516 ± 105b	63.1 ± 0.6a	25.9 ± 0.2c	12.6 ± 0.1c
NaOH	32.3 ± 1.2a	16.2 ± 0.6b	23.2 ± 0.6b	28.4 ± 1.3a	3.20 ± 0.10a	5444 ± 115a	61.1 ± 0.9b	26.3 ± 0.4b	12.9 ± 0.2b
Na_2SO_3	32.8 ± 1.6a	15.9 ± 0.8b	23.0 ± 0.9b	28.4 ± 0.5a	3.23 ± 0.13a	5665 ± 257a	63.2 ± 0.6a	27.3 ± 0.2a	13.4 ± 0.1a
Distilled water	31.8 ± 0.4a	16.7 ± 0.3b	23.0 ± 0.4b	28.5 ± 0.3a	3.09 ± 0.10a	5472 ± 110a	63.8 ± 0.2a	27.3 ± 0.1a	13.5 ± 0.0a

[A] *S*/*L* ratio = [(DF3% + DF4%)/(DF2%)].
[B] Molecular weight determined by light scattering and refractive index detectors.
[C] Molecular weight determined by refractive index detector based on pullulan standard curve.
[D] Means within a column followed by different letters are significantly different ($p < 0.05$).

nificant difference in pasting properties was found among starches isolated by NaOH, Na_2SO_3 and distilled water.

The pasting properties of starch were considered to be affected by its amylose content and chain-length distribution of amylopectin, with a larger proportion of long chains resulting in a lower peak viscosity if the starches had similar amylose contents (Jane et al., 1999). Therefore, the lower peak viscosity of LFS-isolated starch could be attributed to a lower *S*/*L* ratio of amylopectin resulting from the degradation of starch during isolation. Moreover, the LFS-isolated starch had lower setback than the other starches, which might relate to the lower degree of polymerization of amylose fraction (Jane & Chen, 1992).

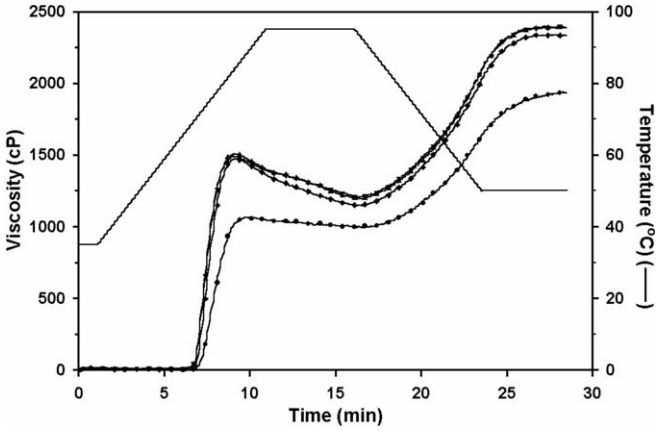

Fig. 6. Pasting profiles of mung bean starches isolated by LFS (●), NaOH (◆), Na_2SO_3 (▲), and distilled water (▼), respectively.

3.6. Gelatinization thermal properties

The thermal transition profiles of starches isolated using different steeping liquors are shown in Fig. 7. The profile of LFS-isolated starch exhibited a narrow, mono-modal distribution as compared with the broad, bimodal distributions of other preparations (isolated by NaOH, Na_2SO_3 and distilled water). Table 6 indicates that the onset (T_O) and peak (T_P) temperatures of pasting of LFS-isolated starch were significantly ($p < 0.05$) higher than those of the other starches. Moreover, there was no significant dif-

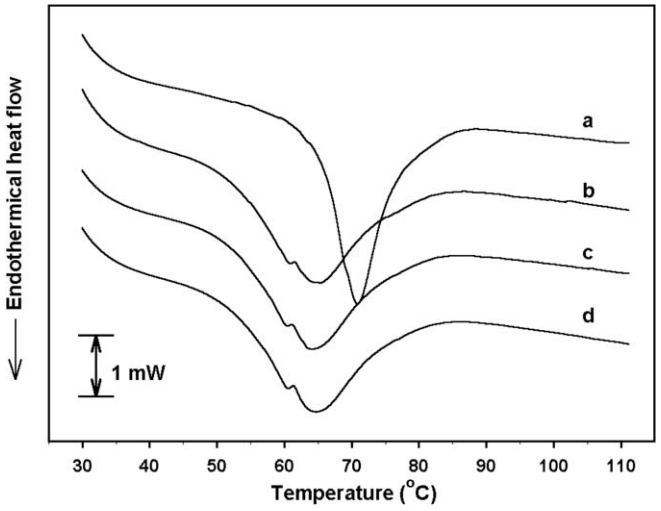

Fig. 7. Differential scanning calorimeter thermograms at scanning rate of 1.2 °C/min of mung bean starches isolated by LFS (a), NaOH (b), Na_2SO_3 (c), and distilled water (d), respectively.

Table 5
Pasting properties of mung bean starches isolated using different steeping liquors

Steeping liquor	Viscosity (cP)				
	Peak	Hot paste	Final	Breakdown	Setback
LFS	1003 ± 34b[A]	932 ± 30b	1875 ± 51b	71 ± 10b	943 ± 26b
NaOH	1411 ± 18a	1082 ± 38a	2273 ± 36a	330 ± 43a	1191 ± 08a
Na_2SO_3	1446 ± 37a	1129 ± 36a	2327 ± 46a	317 ± 10a	1198 ± 14a
Distilled water	1424 ± 45a	1136 ± 68a	2326 ± 66a	288 ± 31a	1190 ± 19a

[A] Means within a column followed by different letters are significantly different ($p < 0.05$).

Table 6
Gelatinization thermal properties of mung bean starches isolated using different steeping liquors

Steeping liquor	Gelatinization temperature (°C)[A]			$T_C - T_O$ (°C)	ΔH (J g^{-1}, db)
	T_O	T_P	T_C		
LFS	65.3 ± 0.1a[B]	70.9 ± 0.1a	77.4 ± 0.1a	12.0 ± 0.2b	12.3 ± 0.2b
NaOH	52.6 ± 0.4b	64.7 ± 0.4b	76.5 ± 0.5b	23.9 ± 0.6a	13.4 ± 0.2a
Na_2SO_3	52.4 ± 0.1b	64.0 ± 0.2c	77.1 ± 0.5ab	24.7 ± 0.5a	13.4 ± 0.1a
Distilled water	52.3 ± 0.3b	64.5 ± 0.1b	76.7 ± 0.4ab	24.3 ± 0.3a	13.3 ± 0.2a

[A] T_O, T_P, T_C and $T_C - T_O$ are the onset, peak, completion and temperature range of starch gelatinization, respectively. ΔH is the enthalpy change of starch gelatinization.
[B] Means within a column followed by different letters are significantly different ($p < 0.05$).

ference in T_O and T_P, ranging from 52.6 to 52.8 °C and 64.2 to 64.9 °C respectively, among the other three starches.

Jane et al. (1999) investigated the relationship between branch chain length of amylopectin and gelatinization properties of starches with different X-ray patterns. They indicated that a high average chain length of amylopectin or a lower proportion of short chains might contribute to the higher gelatinization temperature of starch. The same is true of starches from different rice cultivars even with the same X-ray pattern (Wang et al., 2002). Accordingly, the higher melting temperature of LFS-isolated starch could be attributed to its lower S/L ratio. The more narrow range of melting temperature and the lower enthalpy of gelatinization of LFS-isolated starch implies that the crystalline nature of the starch was changed as a result of the LFS treatment. The literature suggests that the change may be due to a loss of A chains of amylopectin (Genkina, Wasserman, Noda, Tester, & Yuryev, 2004).

Results of molecular weight distribution of starch (Fig. 4 and Table 3) indicated that mung bean starch was degraded during isolation with lactic acid fermentation solution. On the other hand, the LFS-isolated starch was found to have relative higher weight percentage of long chains (B2 or longer), lower weight percentage of A chains and lower S/L ratio than those of starches isolated using other liquors (Fig. 5 and Table 4). Furthermore, a narrow and mono-modal gelatinization peak (Fig. 7) with higher gelatinization temperature was also observed on the LFS-isolated starch. This discrepancy could be explained by the different integrity among individual starch granules. Ji, Ao, Han, Jane, and BeMiller (2004) indicated that the individual starch granules from a single source exhibited different behaviors. The authors separated waxy maize starch into different subpopulations according to their gelatinization temperatures, and suggested that the granules of waxy maize starch with higher gelatinization temperature had lower normalized concentration of A chains compared to granules with lower gelatinization temperature or unfractionated waxy maize starch. Ji et al. (2004) also indicated that the granules differed in the degree of structural integrity after gelatinization, and assumed that the difference in gelatinization temperature and structural integrity were due to the difference in granule organization. It could be logically inferred that a part of mung bean starch granules with less integrity and lower gelatinization temperature were lost during isolation with lactic fermentation solution.

4. Conclusion

Results of this study showed that the weight percentages of long B chains (DF2) and B_1 chains (DF3) of commercial mung bean starch, isolated by using of lactic acid fermentation solution as the steeping liquor, were significantly ($p < 0.05$) higher than those of starches laboratory-prepared with other steeping liquors. Furthermore, the LFS-isolated starch also showed a lower S/L ratio. Although all the starches studied had similar amylose contents, the LFS-isolated starch exhibited lower values of peak viscosity and breakdown, higher onset temperature, and narrower melting temperature range. These results suggest that the changes in chain length distribution of the LFS-isolated starch resulted from the degradation of starch that occurred during the isolation process and that the structural changes resulted in changes in pasting and gelatinization thermal properties. Moreover, starch granules with less integrity, which had lower gelatinization temperature and higher content of A chain of amylopectin, might be lost during isolation with lactic fermentation solution.

Mixing pre-gelatinized starch with native starch and afterwards extruding the dough in boiling water are performed in manufacturing of starch noodle. The contribution of specific physicochemical properties of LFS-isolated starch to its suitability on starch noodle manufacturing needs to be further investigated. Additionally, retrogradation of starch is involved in the process, thus the relationship between the molecular structure of amylopectin and the starch noodle quality is also worth studying.

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