

TEXTURAL PROPERTY OF SIX LEGUME CURDS
IN RELATION TO THEIR PROTEIN CONSTITUENTS

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ABSTRACT

We determined the relationship between textural property of legume curds and constituents of their proteins. The hardness, springiness and cohesiveness of curds prepared from soybeans, chickpeas and faba beans were 6.0-9.4 N, 0.93-0.95 and 0.67-0.77, respectively, higher than those of curds made from smooth peas, mung beans and lentils, which were 4.2-4.9 N, 0.92 and 0.57-0.59, respectively. Soybeans, chickpeas and faba beans had a higher proportion of 11S globulin and a lower proportion of 7S globulin than lentils, smooth peas and mung beans. Soybeans, chickpeas and faba beans produced a better texture of curd than did lentils, smooth peas and mung beans, due to a higher proportion of 11S proteins.

Key Words: gelation, curd, gel electrophoresis, legume, protein constituent

Introduction

Protein constituents are one of the most important factors affecting the protein functionality and have been the subject of many investigations (Kinsella 1979; Damodaran and Kinsella 1981). Utsumi and Kinsella (1985a) investigated the gelation of 7S and 11S soybean globulins and soybean protein isolate and found that the force involved in the gelation of soybean 7S globulin was predominantly hydrogen bonding, whereas forces involved in the gelation of 11S soybean globulin included disulfide and hydrogen bonding. It has been reported that the extent of disulfide crosslinking of 7S soybean globulin is limited because there are only 2 to 3 cystine groups per mole of protein (Kinsella 1979). On the other hand, it was reported that 11S soybean globulin contained 6 and 37 sulfhydryl and disulfide groups per mole of protein, contributing a significant amount of crosslinking during the gelation of 11S soybean globulin (Kinsella 1979). Gels prepared from 11S globulin were reported to be firmer than those from 7S proteins (Saio and Watanabe 1978; Kinsella 1979).

7S and 11S together make up 87% of the total soybean protein (Kinsella 1979) and 56% of the total chickpea protein (Chavan and others 1989). 7S globulins typically have a molecular weight of 140–210 kDa, whereas 11S globulins have a molecular weight of 300 to 400 kDa (Derbyshire and others 1976). The composition of subunits of 7S and 11S globulins varies among legume species. The major 7S globulin of soybeans, β -conglycinin, exists as 6 isomer molecular species, each of which is composed of 3 discrete protein subunits, α' , α and β -subunits (Thanh and Shibasaki, 1976), with a molecular weight of 80, 76 and 50 kDa (Qi and others 1997), respectively. 11S globulin contains both acidic and basic subunits with a molecular weight in the range of 27-37

kDa and 20-24 kDa, respectively (Derbyshire and others 1976; Schmidt and Morris 1984; Bacon and others 1990). Similarities in the properties of the subunits of 11S globulin from different sources have been demonstrated by Derbyshire and others (1976).

Our recent studies on bean curd preparation from a variety of legumes indicated that curd texture varied markedly among different legume species (Cai and others 2001). An investigation on curd texture in relation to protein constituents for various legumes is essential in understanding the variations in curd texture and in texture improvement. Our objective was to evaluate the textural property of curds from different legumes, to determine the constituents of legume proteins and to relate the texture of curds to constituents of legume proteins so as to understand the differences in texture of curds prepared from various legumes.

Materials and Methods

Materials

Chickpea cv. Dwelley was provided by the USA Dry Pea and Lentil Council (Moscow, ID), smooth pea cv. Columbian by the Genesee Union Warehouse (Genesee, WA) and lentil cv. Pardina by Moscow Idaho Seed, Inc. (Moscow, ID). Soybeans were purchased from Grain Place Foods, Inc. (Marquette, NE), faba beans from Zursun, Ltd. (Twin Falls, ID) and mung beans from Mountain People, Inc. (Ketchum, ID).

Legume seeds, except soybeans, were crushed to smaller fragments using a Quaker City mill model 4-E (Philadelphia, PA) and then milled to flours using an experimental Buhler mill (Buhler Co., Uzwil, Switzerland). Soybeans were milled to flour using a cyclone sample mill (Udy Co., Fort Collins, CO).

The legume flours were fractionated into water solubles, prime starch and tailings starch according to the method of Czuchajowska and Pomeranz (1994). Flour (200 g) was blended with 500 mL distilled water for 3 min using a blender (Osterizer; J. Oster Manufacturing, Milwaukee, WI) at the highest setting. The slurry was then centrifuged at 1500 g for 15 min. The same procedure was repeated once more. Solubles were collected after each centrifugation and termed first or second solubles during curd preparation, corresponding to the number of fractionations. For gel electrophoresis of proteins before curd making, DSC and chemical analysis, the solubles were freeze-dried, ground using a mortar and pestle and stored at room temperature (21°C) until use. The first and second solubles were combined and used for curd making.

Chemical analyses

Moisture, starch, ash and lipid contents were determined according to AACC Methods 44-15A, 76-13, 08-01 and 30-25 (AACC 1995), respectively. Moisture content of curd was determined by drying 5 g of curd in an air convection oven at 105°C to a constant weight, as described by Tsai and others (1981). Protein content was determined using a Leco instrument (Leco Corp., St. Joseph, MI) equipped with a thermoconductivity detector. Ash, protein, free lipids and starch of legume flours and solubles were expressed on dry weight basis.

Preparation of bean curd

The bean curd was prepared from 6 legumes according to the procedure of Cai and others (2001). The first (about 420 mL) and second (about 530 mL) solubles from the fractionation process were combined, and the solution was diluted with an appropriate amount of water to a protein concentration of approximately 3%. A 750-mL portion of the protein solution was boiled for 10 min and then transferred to a glass container placed in a boiling water bath. After the protein solution was cooled to 85°C, 1.5 g of CaSO₄ suspended in 50 mL water was added in 10 s while stirring. The temperature of the solution in the container was maintained at 80°C for 20 min to form the curd. The curd formed was then transferred to a wooden mold (70 mm x 70 mm x 70 mm) lined with cheesecloth and compressed with a 2-kg weight (47 g/cm²) for 10 min. The curd was then removed, and allowed to cool for 20 min at room temperature before its weight and moisture content was determined. The curd was kept for an additional 100 min in a plastic container with a lid before determination of texture. For gel electrophoresis of

proteins after curd making, curds were freeze-dried and ground using a mortar and pestle and stored at room temperature (21°C) until use.

Texture profile analysis (TPA) of curd

Texture of curd was determined by TPA using a TA-XT2 Texture Analyzer (Stable Micro System, Haslemere, England). Three curd samples of cylindrical shape were cut vertically from a curd using a cylindrical cutter (25 mm diameter). The cylindrical curds were sliced into 10-mm-thick slices using a wire cutter, and one slice from the center of each cylindrical curd was used for texture analysis. The slice was compressed twice to 30% of its original height with a metal disc (60 mm diameter). The TPA curve was recorded and used to calculate the hardness, springiness and cohesiveness using the software provided with the Texture Analyzer.

Gel electrophoresis

Legume proteins both before and after curd making corresponding to native and denatured proteins were used. All proteins were analyzed using both a nonreduced and reduced sodium dodecyl sulfate-polyacrylamide gel electrophoresis (SDS-PAGE), without and with the addition of 2-mercaptoethanol as reducing agent to protein. The purpose of conducting both nonreduced and reduced SDS-PAGE was to identify the major bands of 11S globulin by examining the conversion of sulfur-containing amino acids from non-reduced to reduced subunits. These subunits are the major subunits of 11S globulin.

Reduced and nonreduced SDS-PAGE was performed using Tris-HCl ready gels (Bio-Rad, Richmond, CA), composed of 12% separating gel and 4% stacking gel. All electrophoreses were run at a constant voltage of 200 mV in a Mini-Protein II cell unit (Bio-Rad, Richmond, CA). The running buffer (pH 8.4) was composed of 25 mM Tris, 190 mM glycine and 0.1% SDS. Gels were stained with 0.25% Coomassie brilliant blue G-250 in water/methanol/acetic acid (60%, 30% and 10%) for 2 h and destained with water/methanol/acetic acid (60%, 30% and 10%) for 10 h.

For reduced SDS-PAGE, freeze-dried protein samples (2 mg/mL) before and after curd making were mixed with a sample buffer (pH 6.8) in microcentrifuge tubes (Intermountain Scientific Corporation, Daysville, UT). The sample buffer was prepared by mixing a 62.5 mM Tris solution with 10% glycerol (w/v), 2% SDS (w/v), 0.01% (w/v) bromophenol blue and 5% (V/V) 2-mercaptoethanol. The protein was dispersed into the sample buffer and vortexed for 10 s twice with a 10-min interval and then heated in a 95°C water bath for 5 min. The heated mixture was vortexed again for 10 s twice at a 10 min interval and then centrifuged using a centrifuge (Jouan, Inc., Winchester, VA) at a setting of 10,000 rpm. Immediately after centrifugation, the supernatant was applied to the ready Tris-HCl gel at an injection volume of 15 μ L using a 25- μ L syringe.

For nonreduced SDS-PAGE, the same sample buffer, but without 2-mercaptoethanol, was used and the sample was not heated. The mixtures were subjected to the same vortexing and centrifugation procedures as described above. Immediately after centrifugation, the supernatant was applied to the ready Tris-HCl gel at an injection volume of 20 μ L.

Protein standards were subjected to the same treatment as for the legume proteins. Protein standards were purchased from Bio-Rad and contain phosphorylase b (97 kDa), bovine serum albumin (66 kDa), ovalbumin (45 kDa), carbonic anhydrase (31 kDa), trypsin inhibitor (22 kDa) and lysozyme (15 kDa). The identification of the missing bands due to treatment with the reducing agent was done by comparing the nonreduced and reduced electrophoreses. Molecular weight of the subunits was determined by measuring the distance of migration in comparison with standards.

Differential scanning calorimetry (DSC)

Thermal property of proteins from different legumes was determined using a differential scanning calorimeter model DSC Pyris-1 (Perkins-Elmer Corp., Norwalk, CT). Legume protein concentrates (200 mg each) from the freeze-dried solubles were dispersed in an appropriate amount of water to form a slurry with a protein content of 30% or 18%. Protein-water slurries were well mixed and left for 30 min for equilibrium before analysis. Protein slurry (60-70 mg) was weighed into a stainless steel capsule and heated from 20°C to 140°C at a rate of 10°C/min. A capsule with inert material (Al₂O₃) was used as a reference. Peak temperature and enthalpy were recorded using the data processing software provided with the instrument.

Amino acid compositional analysis

Amino acid compositional analysis was performed following the procedure of Stewart (1984). Legume proteins (about 10 mg) were hydrolyzed in 6 N HCl at 110°C in teflon capped vials for 22 h. After vacuum removal of HCl, the residue was dissolved in a

known quantity lithium buffer, pH 2.2. An aliquot was then applied to the column of a Beckman 6300 Automatic amino acid analyzer (Beckman Instrument Co., Palo Alto, CA). A high-performance column containing spherical cation exchange resin (Beckman Instrument Co.) was used. Four lithium buffers with pH values of 2.2, 2.8, 3.3 and 3.7 (Beckman Instrument Co.), respectively, were successively applied to the column at a flow rate of 20 mL/min. The ninhydrin flow rate was 10 mL/h under these conditions and a typical analysis required 160 min.

The cys (cysteine and cystine) content of legume protein was determined by analyzing the cysteic acid produced by oxidation of the cys (Stewart 1984). A sample of the solid material was first hydrolyzed using 6 N HCl to produce a soluble product. These amino acids were then reacted with acetic anhydride to protect the amine group. The product was then dried, treated with performic acid to oxidize the cys to cysteic acid, dried again, and then rehydrolyzed with 6 N HCl to remove the acetyl group. This product was then analyzed. An amino acid standard containing cys was treated parallel with the samples and used to quantify the cys content.

Statistical analysis

All tests were run at least in duplicate. Analysis of variance (ANOVA) and Duncan's multiple range test were performed using the Statistical Analysis System (Release 6.12, 1996; SAS Institute Inc., Cary, NC). Significance of difference was defined at $p \leq 0.05$.

Results and Discussion

Composition of flour and solubles for curd preparation

The composition of legume flour and solubles after fractionation is shown in Table 1. Soybean flour had a protein content of 49.9%, the highest among the tested legumes. Flours of chickpeas, lentils, smooth peas, mung beans and faba beans had a protein content of 27.1% to 35.7%, whereas the solubles of these legumes had a protein content of 54.1% to 69.7%. After fractionation, protein content of the solubles of chickpeas, lentils, smooth peas, mung beans and faba beans doubled from that of their flours, while protein content of the solubles from soybeans only increased from 49.9% to 55.7%. Soybeans contained a negligible amount of starch, while the starch content of the other legumes ranged from 49.7% for faba beans to 59.4% for lentils. The solubles of all legumes contained no starch. Ash contents of legume flours were in the range of 2.8% for lentils to 5.3% for soybeans. The ash content in the solubles of legumes was almost doubled from the content in their flours. Soybean flour had a lipids content of 23.3%, in contrast to a lipids content of 6.6% for chickpeas and around 1% for other legume flours.

Texture of curds from 6 legume proteins

Characteristics of curds prepared from 6 legumes are shown in Table 2. Legume types had a significant effect on the yield of curds. Mung beans had the highest yield with 193.2 g per 100 g flour, whereas chickpeas had the lowest yield with only 125.8 g. Soybeans had a curd yield of 172.6 g per 100 g flour. In general, lower curd yields correspond to lower moisture content of the curds. The moisture content of curds from mung beans and lentils was 83.6% and 84.3%, respectively, and was significantly higher than the moisture content of the chickpeas, which was 77.7%. Since the protein

constituents determined the gelation process when other conditions such as protein concentrations and coagulant dosages were constant, protein constituents would also determine the water retention of curds. The degree of crosslinking of curds through disulfide bonding and the number and intensity of hydrogen bonding and hydrophobic interactions, determined by protein constituents, would affect the water holding capacity of the curds. Soybeans, chickpeas and faba beans had lower moisture content, probably due to a more orderly curd structure through covalent disulfide bonding between protein constituents. On the other hand, lentils, smooth peas and mung beans had a higher moisture content, which may be resulted from a higher number of protein-water interactions through hydrogen bonding

Soybeans produced the hardest curds (9.4 N), followed by chickpeas (7.7 N) and faba beans (6.0 N). On the other hand, the hardness of curds from lentils, smooth peas and mung beans ranged from 4.2 N to 4.9 N. Soybean curd had the highest springiness and cohesiveness, 0.95 and 0.77, respectively, followed by chickpea and faba bean curds. Springiness and cohesiveness were 0.93 and 0.68 in chickpea curd, and 0.93 and 0.67 in faba bean curd, respectively. Curds from mung beans, lentils and smooth peas exhibited the lowest springiness (0.92) and cohesiveness (0.57-0.59). Our determination on the texture of commercial tofu (SEASIA, Seattle, WA) exhibited that while hardness of tofu ranged from 5 N in soft tofu to 9 N in firm tofu, springiness and cohesiveness stayed in the narrow range from 0.95 to 0.98 and from 0.75 to 0.80, respectively, regardless of its firmness. Accordingly, low hardness is not necessarily an indication of poor quality, whereas low springiness and cohesiveness is. In comparison, the texture of curds from soybeans, chickpeas and faba beans was superior to that of curds from lentils, smooth

peas and mung beans because of the higher scores for springiness and cohesiveness, with hardness in the appropriate range.

Gel electrophoresis of legume proteins

SDS-PAGE of legume proteins before curd making is shown in Fig. 1A-B. Nonreduced protein exhibited bands of both 7S and 11S protein subunits, with major bands at around 60 to 70 kDa. The bands at around 63 kDa of the nonreduced gel electrophoreses were believed to be the 11S globulin subunits composed of several acidic and basic subunits linked through disulfide bonds. The 11S soybean globulin subunit before reducing agent treatment at around 63 kDa was decomposed to form smaller protein subunits of 40 kDa and 23 kDa, after reducing agent treatment. In chickpeas, two 11S globulin subunits before reducing agent treatment at around 66 and 63 kDa were decomposed to form subunits at 23 and 43, and 25 and 38 kDa after reducing agent treatment. In lentils, two 11S globulin subunits at around 71 and 63 kDa before reducing agent treatment were decomposed to form subunits at 40, 16 and 15 kDa, and 39 and 24 kDa after reducing agent treatment. In smooth peas, one 11S globulin subunit at 70 kDa before reducing agent treatment was decomposed to form subunits at 25 and 45 kDa after treatment. Bacon and others (1987) observed bands from the reducing gel at between 21 and 24 kDa as basic subunits and a band at 40 kDa as acidic subunit, which resulted from a band at around 60 kDa from the nonreducing gel. In mung beans, an 11S globulin subunit at 85 kDa was decomposed to form 61 and 24 kDa subunits. In faba beans, a major 11S globulin subunit at 63 kDa was decomposed to form subunits at 41 and 22 kDa after treatment. Three other bands at 82, 80 and 50 kDa were also decomposed to form smaller

subunits. Other bands for acidic and basic subunits were also seen in the reduced SDS-PAGE. In soybeans, for example, 2 minor bands at above and below the acidic bands at 41 kDa were seen, corresponding to bands reported previously (Utsumi and Kinsella 1985b).

As can be seen from the intensity of the bands, in comparison with soybean, faba bean and chickpea proteins, where a large proportion of 11S was observed, proteins from lentils, smooth peas and especially mung beans appeared to contain only a small amount of 11S globulin. This could account for the lower textural scores for lentil, smooth pea and mung bean curds in comparison with soybean, faba bean and chickpea curds. This result was confirmed by the nonreduced and reduced SDS-PAGE of legume proteins after curd making (Fig.2A-B). Nonreduced SDS-PAGE (Fig.2A) of proteins after curd making indicated that all 11S protein subunits at 63-85 kDa were missing from the gel electrophoresis, suggesting that 11S globulins were polymerized to form components insoluble in the sample buffer after curd making. Therefore, nonreduced SDS-PAGE showed only the major bands of 7S globulins, which were rarely responsible for the construction of network structure of protein in curds. When the proteins after curd making were treated with a reducing agent, 2-mercaptoethanol, all bands that previously appeared in the reduced SDS-PAGE before curd making were observed (Fig.2B). This suggests that the insoluble components formed during curd making were polymerized through disulfide bonds. Once cleaved by 2-mercaptoethanol, the polymerized components were converted to the same subunits as found in the proteins before curd making.

DSC Analysis

DSC thermograms of 6 legume proteins are given in Fig.3A-B. When determined at a protein content of 30% (Fig.3A), all legume proteins except mung beans exhibited 2 major peaks corresponding to 7S and 11S components. Soybean, faba bean and chickpea proteins had a relatively higher 11S component compared to lentils and smooth peas, which had a higher 7S component. Mung beans, on the other hand, showed only 7S with no peaks for 11S globulin. This result confirmed the results of SDS-PAGE electrophoresis. When determined at a protein content of 18% (Fig.3B), the 11S globulins in smooth peas and the 7S globulins in chickpeas were less pronounced. Denaturation enthalpies of all legumes appeared to remain unchanged regardless of the protein content of slurries. The denaturation temperatures were different for different legume proteins, indicating that legume proteins from various legume sources may require different extents of heat treatment for curd preparation. The denaturation temperature, denaturation enthalpy and the enthalpy ratio between 7S and 11S determined at 30% protein content are given in Table 3. The low enthalpy ratio between 7S to 11S globulins for soybeans, chickpeas and faba beans indicates a low amount of 7S and high amount of 11S in these proteins. On the other hand, the ratio suggests that mung beans, lentils and smooth peas had a high amount of 7S component.

Amino acid compositional analysis

Results from amino acid compositional analysis of proteins from 6 legumes are shown in Table 4. All legume proteins showed a similar amino acid compositional profile with asparagine and glutamine being the highest and sulfur-containing amino acids (cysteine,

cystine and methionine) being the lowest in their mole percentages. The higher percentage of cys (cysteine and cystine) in soybean proteins than in mung bean proteins is consistent with previous results from SDS-PAGE and DSC, in which soybeans had a higher 11S, while mung beans had a lower 11S globulin. The 11S globulin had higher sulfur containing amino acids.

This can also be seen from the absolute value of cys (cysteine and cystine) contents, as shown in Table 5. The higher cys content in soybeans than in mung beans again confirmed the results of SDS-PAGE and DSC, indicating a high 11S content for soybeans and a low 11S content for mung beans. However, cys content of all other legumes was lower than that of soybean protein and there was not a large difference as expected because of a higher amount of 11S component for chickpeas and faba beans and a lower amount for lentils and smooth peas.

In conclusion, curds produced from soybeans, chickpeas and faba beans showed a better texture, with higher texture scores for hardness, springiness and cohesiveness, than curds produced from lentils, smooth peas and mung beans. Soybeans, chickpeas and faba beans had higher 11S and produced a curd with higher hardness, springiness and cohesiveness. Ji and others (1999) also reported that higher 11S/7S globulin ratio resulted in higher firmness of tofu in two out of three soybean cultivars. On the other hand, curds of smooth peas, lentils and mung beans had lower hardness, springiness and cohesiveness due to the lower amount of 11S globulin and higher amount of 7S globulin present.

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CAPTIONS FOR FIGURES:

Fig. 1A-B. Electrophoresis patterns of nonreduced (A) and reduced (B) proteins of 6 legumes before curd making.

Fig. 2A-B. Nonreduced (A) and reduced (B) SDS-PAGE electrophoresis of 6 legume proteins after curd making. Std: standard; Soy: soybean; Chick: chickpea; Mung: mung bean; Faba: faba bean.

Fig. 3. DSC thermograms of protein fractions from legumes at a protein concentration of 30% (A) and 18% (B). 7S: 7S globulin; 11S: 11S globulin.

Table 1. Composition of flours and water-solubles from soybeans, chickpeas, lentils, smooth peas, mung beans and faba beans ^a.

		Protein (%)	Starch (%)	Ash (%)	Lipids (%)
Soybean	flour	49.9	0.9	5.3	23.3
	solubles	55.7	-	5.4	0.6
Chickpea	flour	27.1	51.5	3.4	6.6
	solubles	54.1	-	6.6	7.5
Lentil	flour	30.7	59.4	2.8	1.0
	solubles	67.8	-	6.4	0.3
Smooth pea	flour	30.4	55.8	3.6	1.2
	solubles	67.4	-	6.4	0.2
Mung bean	flour	32.6	57.9	3.5	1.0
	solubles	67.0	-	6.6	0.2
Faba bean	flour	35.7	49.7	4.1	1.4
	solubles	69.7	-	8.0	0.2

^a All values are dry basis.

Table 2. Yield, moisture and texture of curds prepared from different legumes ^a.

	Yield (g/100 g flour)	Moisture (%)	Hardness (N)	Springiness (Ratio)	Cohesiveness (Ratio)
Soybean	172.6 ^{AB}	79.1 ^{AB}	9.4 ^A	0.95 ^A	0.77 ^A
Chickpea	132.4 ^B	77.7 ^B	7.7 ^{AB}	0.93 ^{BC}	0.67 ^B
Lentil	155.7 ^{AB}	84.3 ^A	4.2 ^B	0.92 ^{CD}	0.57 ^C
Smooth pea	140.7 ^{AB}	82.8 ^{AB}	4.7 ^B	0.92 ^{CD}	0.59 ^C
Mung bean	193.2 ^A	83.6 ^A	4.9 ^B	0.92 ^D	0.58 ^C
Faba bean	152.6 ^{AB}	81.4 ^{AB}	6.0 ^{AB}	0.93 ^B	0.67 ^B

^a Column values with the same letters are not significantly different ($p \leq 0.05$).

Table 3. Denaturation temperature (Td), enthalpy (ΔH) and enthalpy ratio of 7S and 11S protein globulins from solubles of different legumes.

	T_{d1} (7S) (°C)	ΔH_1 (7S) (J/g)	T_{d2} (11S) (°C)	ΔH_2 (11S) (J/g)	$\Delta H_1/\Delta H_2$ Ratio
Soybean	86.6	1.74	109.2	6.57	21 / 79
Chickpea	96.8	1.58	115.3	5.19	23 / 77
Lentil	97.8	5.76	110.5	0.55	91 / 9
Smooth pea	95.8	4.28	111.5	1.63	72 / 28
Mung bean	103.6	13.96	-	-	100 / 0
Faba bean	99.8	1.99	113.5	4.73	30 / 70

Table 4. Amino acid composition (mole %) of various legume proteins

	Soybean	Chickpea	Lentil	Smooth pea	Mung bean	Faba bean
CYS	0.36	0.19	0.24	0.19	0.04	0.22
ASP	15.64	15.68	15.86	15.40	13.00	15.16
THR	5.19	4.87	4.66	4.75	4.09	4.63
SER	6.64	6.60	6.75	6.23	6.48	6.39
GLU	17.67	16.22	16.17	16.71	18.87	16.71
ALA	6.02	6.26	6.21	6.38	6.66	6.31
GLY	7.51	7.42	7.56	8.03	6.68	7.84
VAL	5.65	5.16	5.74	5.41	4.38	5.60
MET	0.23	0.00	0.23	0.12	0.27	0.00
ILE	4.86	4.56	4.73	4.46	4.72	4.52
LEU	8.26	7.95	8.35	8.04	8.53	8.32
TYR	2.90	2.42	2.74	2.83	2.48	2.90
PHE	4.34	5.11	4.72	4.37	5.10	3.90
LYS	5.69	6.19	6.67	7.04	7.23	6.39
HIS	2.16	2.13	1.95	1.98	3.66	2.43
ARG	6.90	9.25	7.43	8.06	7.85	8.69

Table 5. Cysteine and cystine (cys) content of various legume proteins

	cys (nmole/mg protein)
Soybean	25.5
Chickpea	11.7
Lentil	13.6
Smooth pea	11.1
Mung bean	4.0
Faba bean	13.5

Figure 1.

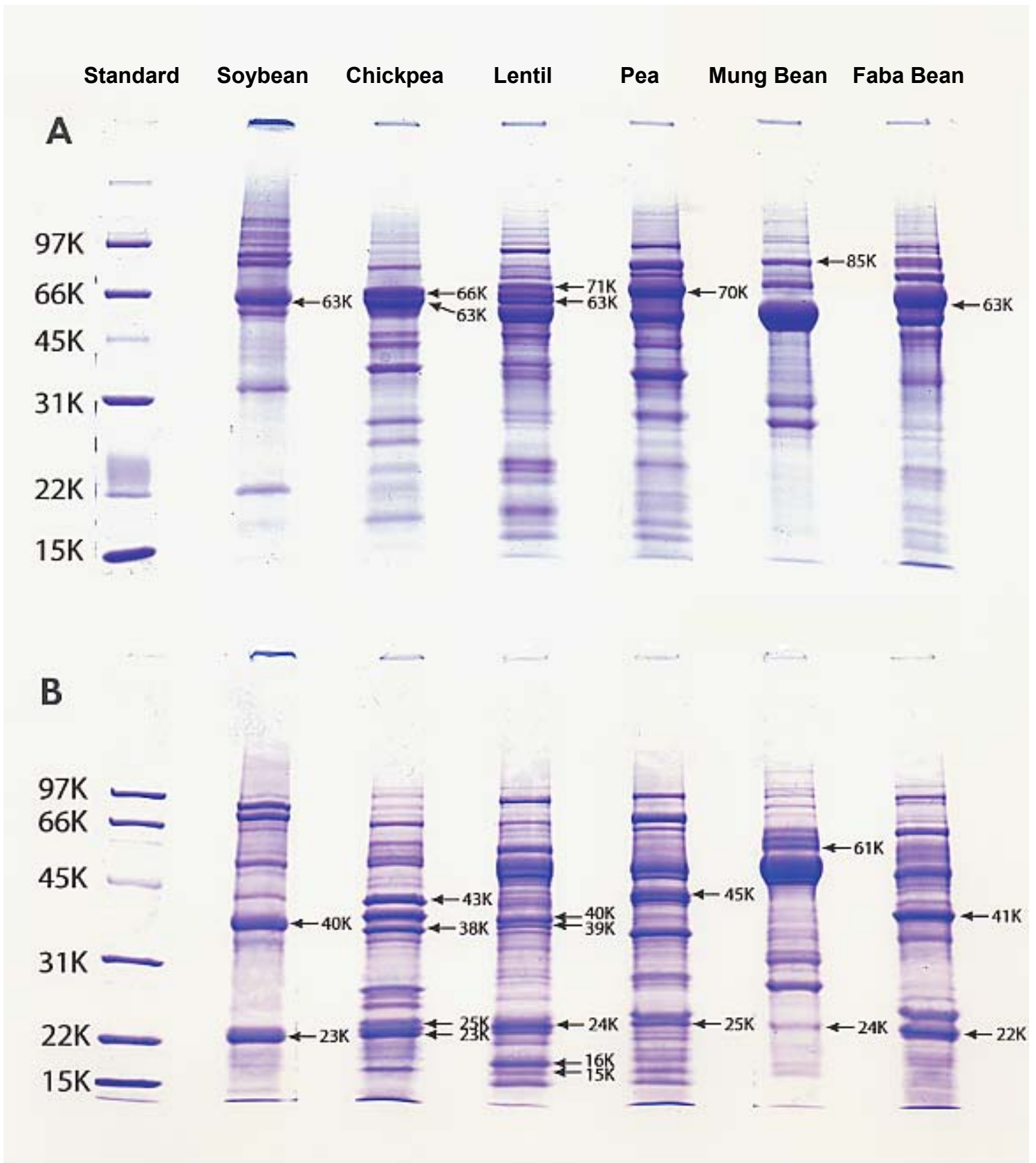


Figure 2.

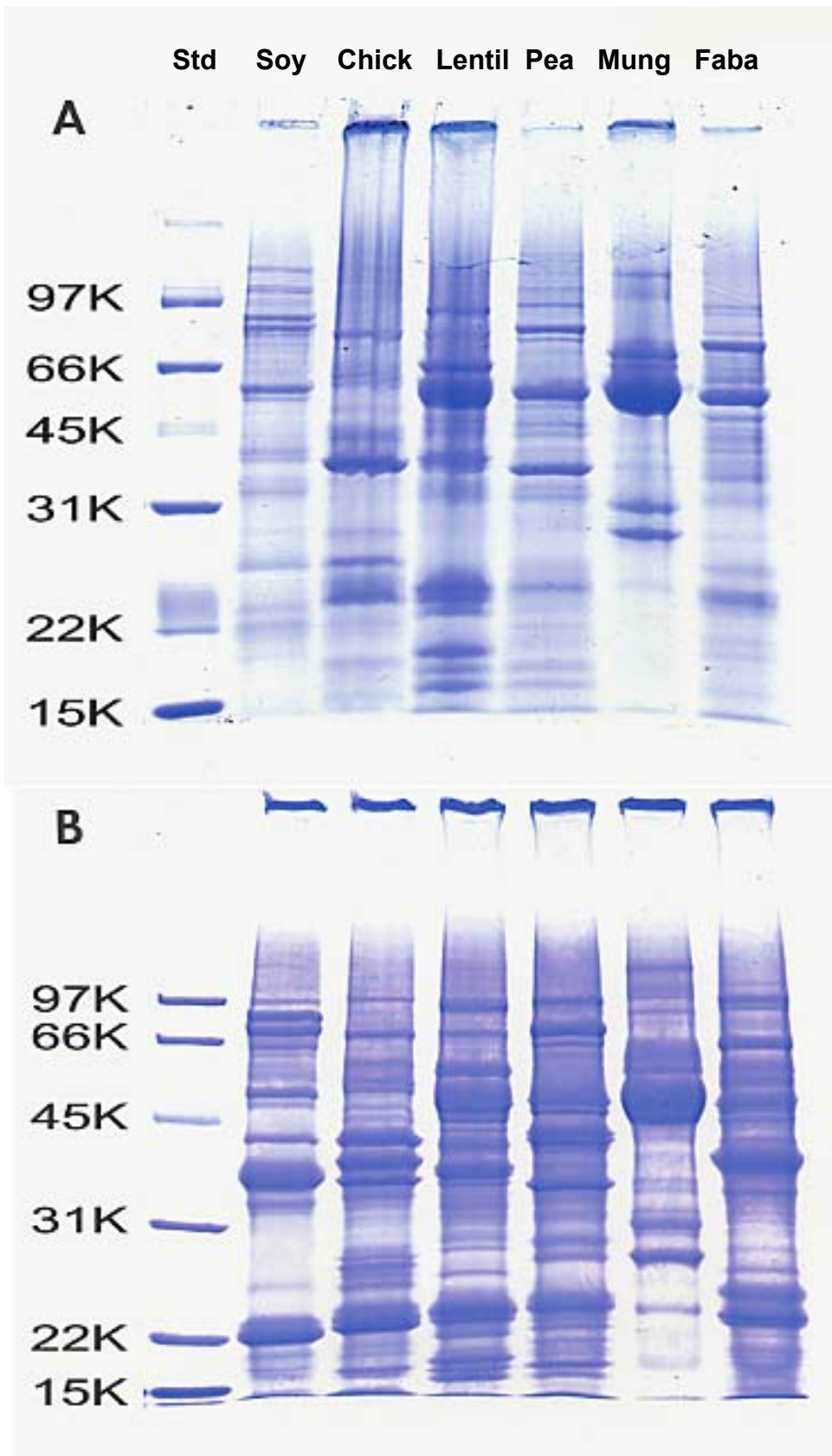


Figure 3.

