Preparation of Bean Curds from Protein Fractions of Six Legumes

R. Cai,* B. Klamczynska, and B.-K. Baik

Department of Food Science and Human Nutrition and IMPACT, Washington State University, Pullman, Washington 99164-6376

Chickpeas, lentils, smooth peas, mung beans, and faba beans were milled into flours and fractionated to protein and starch fractions. Compositions of the seeds, cotyledons, and flours were compared for each legume and the weight and protein recovery of each fraction analyzed. Bean curds were prepared from the protein fractions through heat denaturation of protein milk, followed by coagulation with calcium sulfate or magnesium sulfate. The effect of chickpea protein concentration and coagulant dosage on the texture of bean curds was evaluated using a texture analyzer. Textural analysis indicated that curd prepared at 2.3−3.0% protein concentration and 1.5% $CaSO_4$ dosage had better yield and better texture than curds prepared under other conditions. Bean curds prepared from chickpeas and faba beans exhibited the second highest springiness and cohesiveness after those from soybeans. Curds of mung beans and smooth peas, on the other hand, had the highest yields and the highest moisture contents. The protein yield of the first and second soluble extracts used for curd preparation accounted for ∼90% of the total protein of the seeds.

Keywords: *Bean curd; chickpea; faba bean; gel electrophoresis; legume protein; lentil; mung bean; smooth pea; soybean; tofu*

INTRODUCTION

Legume seeds contain 20−25% protein, 2−3 times more than cereals, and have therefore been considered as leading candidates for protein supply to malnourished areas of the world (*1*). There has been an increased interest in utilizing legume fractions, starch and protein, as food components (*2*). Pea starch, for example, has been commercially used as a substitute for traditional starches in canned meats, cooked sausages, and patés (*3*, *4*). Legume starches provide unique properties to food systems, such as high gelation temperature, resistance to shear thinning, fast retrogradation, and high elasticity of gel, owing to their higher amylose content compared to cereal starches (*5*, *6*). In contrast, legume proteins have been investigated for the preparation of bean curd using field peas (*7*) and winged beans (*8*), although no commercial products other than soybean tofu are currently available.

Soybean tofu preparation has been investigated by several researchers (*9*−*11*). Calcium sulfate is predominantly employed as a coagulant to induce curd formation in heated soybean milk (*11*−*13*), although magnesium sulfate and glucono-δ-lactone have also been used (*14*, *15*). With any coagulant, curds are induced by reducing the overall charge of the protein through the addition of cations and encouragement of the association of the denatured protein molecules in the solution (*16*). Structure in relation to the gelation property of soybean proteins has also been documented (*17*, *18*), with hydrogen bonding, hydrophobic interactions, electrostatic interactions, and disulfide bonds being forces involved in gelation.

The similarity between protein components of soybean and those of other legumes (*19*) suggests that they may have similar functions and applications. The storage proteins, 7S (conglycinin) and 11S (glycinin), are the principal components of soybean proteins (*17*), whereas 7S (vicilin) and 11S (legumin) are the principal components of other legume proteins (*19*, *20*). However, differences in gelation properties between soybean and other legume proteins have been demonstrated. In soybean protein, gelation of 7S mainly involves hydrogen bonding and hydrophobic interactions with no disulfide bonding (*21*). This differs from the gelation of soybean 11S, which involves disulfide bonding (*22*). A gel of 7S has been shown to be harder than that of the 11S from soybean proteins (*18*). On the other hand, it has been reported that purified vicilin, but not legumin, forms heat-induced gels in an investigation on pea proteins (*23*).

In comparison with the use of soybean proteins in milk and tofu preparation, similar applications for other legume proteins have not been accomplished. Nevertheless, the utilization of legume proteins for curd preparation is one of the most promising methods for increasing the value of legumes other than soybeans. However, information on curd preparation from these legumes is limited, although such information is important for product development from legumes.

The objectives of this research were to investigate legume curd preparation conditions and to compare curds from protein fractions of six legumes. Protein content and protein yield of each legume during milling and fractionation were also compared in order to determine the efficiency of the process in the use of protein fractions.

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),

* Corresponding author: Phone: 509 335-4054. Fax: 509 335-4815.

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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).

Milling of Seeds. Prior to milling, all seeds with the exception of 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.). Break and reduction flours were collected together and blended thoroughly. The blended flours of each legume were used throughout this research. Soybeans were milled to flour using a cyclone sample mill (Udy Co., Fort Collins, CO).

Chemical Analyses. Cotyledons of smooth peas, lentils, faba beans, and soybeans were obtained by dehulling, using a tangential abrasive dehulling device (Venables Machine Works, Ltd., Saskatoon, SK, Canada). Cotyledons of chickpeas and mung beans were obtained by soaking the seeds overnight in distilled water and then dehulling by hand. Cotyledons were then freeze-dried. To determine chemical composition, seeds and cotyledons were ground on a cyclone sample mill (Udy Co.) fitted with a screen having 0.5 mm round openings. Ash and free lipid contents were determined according to AACC Methods 44-15A, 08-01, and 30-25 (*24*), 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 et al. (*10*). Protein content was determined using a Leco instrument (Leco Corp., St. Joseph, MI) equipped with a thermoconductivity detector. Starch content was determined using a megazyme kit according to AACC Method 76-13 (*24*).

The proportion of hulls and cotyledons of all legume seeds was determined by soaking seeds overnight in distilled water, removing the seed coat by hand, and then measuring the weight of the lyophilized hulls and cotyledons.

Gas Chromatography (GC). Fatty acid composition of lipids from legume flours was analyzed using GC. Lipids were extracted from flours using hexane in a Soxhlet apparatus (*24*). Lipid extracts (~15 mg) were methylated by heating in 2 mL of 25% (w/v) sodium methoxide in methanol at 60 °C for 3 h. After the mixture had cooled to room temperature (22 °C), fatty acid methyl esters were extracted from the mixture using hexane.

The fatty acid methyl esters were analyzed with a Hewlett-Packard gas chromatograph, model HP 6890 GC (Agilent, Willmington, DE), using a fused silica capillary column (Stabilwax, 60 m × 0.25 mm i.d.) (Restek, Bellefonte, PA). Helium was used as carrier gas at a flow rate of 1.1 mL/min. The temperature of the injector and detector was 260 °C. The column temperature was increased from its initial temperature of 50 to 200 °C at a rate of 10 °C/min, then increased from 200 to 240 °C at a rate of 2 °C/min, and maintained at 240 °C for 26 min. Individual fatty acid esters were identified on the basis of the retention time of standards of fatty acid methyl esters (Sigma Chemical Co., St. Louis, MO). The percentage of fatty acids was estimated according to peak areas of known concentrations of standards using the ChemStation software provided with the GC instrument.

Fractionation of Flour. The flours were fractionated into water solubles, prime starch, and tailing starch according to the method of Czuchajowska and Pomeranz (*25*). Two hundred grams of flour was blended with 500 mL of 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 solubles were collected, and the remaining solid layers were blended with another 500 mL of water for 3 min and centrifuged as above. The same procedure was repeated once more. The tailing starch was then separated from the bottom prime starch. Solubles were collected after each centrifugation and termed first or second solubles during curd preparation, corresponding to the number of fractionations. For chemical analysis, solubles were freeze-dried and ground using a mortar and pestle. Prime starch was air-dried and ground using a mortar and pestle. Tailing starch was freeze-dried and ground using a cyclone sample mill (Udy Co.).

Gel Electrophoresis. Protein constituents of various legumes were analyzed by sodium dodecyl sulfate−polyacrylamide gel electrophoresis (SDS-PAGE) using Tris-HCl ready gels composed of 12% separating gel and 4% stacking gel (Bio-Rad, Richmond, CA). Freeze-dried proteins (2 mg/mL) were dissolved in a sample buffer (pH 6.8) in microcentrifuge tubes (Intermountain Scientific Corp., Daysville, UT). The sample buffer was composed of 62.5 mM Tris, 10% (v/v) glycerol, 2% (w/v) SDS, and 0.01% (w/v) bromophenol blue. Twenty microliters of the protein solution was applied to the Tris-HCl ready gel using a 25-μL syringe. The electrophoresis was run at a constant voltage of 200 mV in a Mini-Protean II cell unit (Bio-Rad). The running buffer (pH 8.4) was composed of 25 mM Tris, 190 mM glycine, and 0.1% (w/v) SDS. Gels were stained with 0.25% (w/v) Coomassie Brilliant Blue G-250 in water/methanol/acetic acid (60, 30, and 10%, respectively) for 2 h and destained with water/methanol/acetic acid (60, 30, and 10%, respectively) for 10 h.

Protein standards (Bio-Rad) 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).

Preparation of Bean Curd. *Preparation of Curds from Chickpea Solubles with 3% Protein Concentration, Using Different Concentrations of $CaSO_4$ or $MgSO_4$ as Coagulants.* The first solubles from chickpea flour were used in this experiment. Three hundred milliliters of first solubles was diluted with 600 mL of water. The solubles were boiled for 10 min and then transferred to a glass container placed in a boiling water bath. After the solubles had cooled to 85 °C, 50 mL of either $CaSO_4$ or $MgSO_4$ solution was added in 10 s with stirring. The temperature of the solubles in the container was maintained at 80 °C for 20 min to form the curd. The amount of $CaSO_4$ added was 0.5, 1.0, 1.5, or 2.0% and the amount of $MgSO_4$ was 0.5, 1.0, 2.0, or 3.0% of the weight of chickpea flour used for fractionation. The curd formed was then transferred to a wooden mold (70 mm × 70 mm × 70 mm) lined with cheesecloth and compressed with a 2 kg weight (47 g/cm^2) for 10 min. The curd was then removed and allowed to cool for 20 min at room temperature before its weight and moisture content were determined. Curd weight was reported as grams per 100 g of legume flour (dry basis). The curd was then covered and kept for an additional 100 min before determination of texture.

Preparation of Curds from Chickpea Solubles with Different Protein Concentrations Using $CaSO_4$ as a Coagulant. The first solubles from chickpea flour were used in this experiment. Three hundred milliliters of the first solubles was diluted with an appropriate amount of water to obtain a protein concentration of 1, 2, 2.3, 2.5, 2.6, 3, or 4%. The solubles were boiled for 10 min and then transferred to a glass container placed in a boiling water bath. After the boiled solubles had cooled to 85 °C, 1.5 g of $CaSO_4$ (1.5% of the initial weight of chickpea flour used for fractionation) suspended in 50 mL of water was added in 10 s with stirring. The temperature of the solubles in the container was maintained at 80 °C for 20 min to form the curd. The curd was then molded and analyzed as above.

Preparation of Curd from Different Legumes Using $CaSO_4$ as a Coagulant. The first and second solubles from the fractionation process were combined, and the volume was adjusted to 1500 mL with distilled water (protein content of ~3%). A 750-mL portion of the solubles was boiled for 10 min and then transferred to a glass container placed in a boiling water bath. After the solubles had cooled to 85 °C, 1.5 g of $CaSO_4$ (1.5% of the initial weight of legume flour used for fractionation) suspended in 50 mL of water was added in 10 s with stirring. The temperature of the solubles in the container was maintained at 80 °C for 20 min to form the curd. The curd was then molded and analyzed as above.

Texture Profile Analysis (TPA) of Curd. The texture of curd was determined by TPA using a TA-XT2 texture analyzer (Stable Micro System, Haslemeres, U.K.). 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

Table 1. Some Physical Properties of Seeds[a]

seed	1000 seed weight (g)	hull (%)
soybean	100.7[C]	7.1[C]
chickpea	259.6[B]	5.0[D]
lentil	17.0[F]	8.2[B]
smooth pea	91.9[D]	8.6[B]
mung bean	30.5[E]	8.2[B]
faba bean	759.1[A]	14.4[A]

[a] Values within a column with the same letter were not significantly different ($p \leq 0.05$).

Table 2. Composition of Chickpeas, Lentils, Smooth Peas, Mung Beans, and Faba Beans[a]

		%			
		protein	starch	ash	lipid
soybean	seeds	49.9[B]	0.2[B]	5.3[A]	23.3[B]
	cotyledons	52.5[A]	0.9[A]	5.3[A]	26.5[A]
	flour	49.9[B]	0.2[B]	5.3[A]	23.3[B]
chickpea	seeds	25.7[C]	47.2[C]	3.4[A]	6.0[A]
	cotyledons	26.8[B]	48.2[B]	3.3[A]	6.2[A]
	flour	27.1[A]	51.5[A]	3.4[A]	6.6[A]
lentil	seeds	28.4[C]	53.2[C]	2.8[A]	0.9[A]
	cotyledons	30.0[B]	57.7[B]	3.0[A]	0.9[A]
	flour	30.7[A]	59.4[A]	2.8[A]	1.0[A]
smooth pea	seeds	27.8[C]	50.8[C]	3.1[B]	1.1[A]
	cotyledons	29.6[B]	54.2[B]	3.0[B]	1.0[A]
	flour	30.4[A]	55.8[A]	3.6[A]	1.2[A]
mung bean	seeds	30.5[B]	51.3[B]	3.5[A]	0.9[A]
	cotyledons	30.3[B]	52.0[B]	3.3[A]	1.1[A]
	flour	32.6[A]	57.9[A]	3.5[A]	1.0[A]
faba bean	seeds	31.1[B]	43.0[C]	4.2[A]	1.2[A]
	cotyledons	36.0[A]	48.0[B]	4.3[A]	1.4[A]
	flour	35.7[A]	49.7[A]	4.1[A]	1.4[A]

[a] All values were dry basis. For each legume type, values within a column with the same letter were not significantly different ($p \leq 0.05$).

from the center of each cylindrical curd was used for textural analysis. The slice was compressed twice to 30% of its original height with a metal disk (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.

Statistical Analysis. All values were reported as means of at least two determinations. Analysis of variance (ANOVA) and Duncan's multiple-range test were performed using the Statistical Analysis System (SAS Institute, Cary, NC, 1986). Significance of difference was defined at $p \leq 0.05$.

RESULTS AND DISCUSSION

Characteristics of Legume Seeds, Cotyledons, and Flours. There were significant differences among the 1000 seed weights of the six legumes (Table 1). The 1000 seed weight ranged from 759.1 g in faba beans to 17.0 g in lentils. The proportion of hull was the highest in faba beans (14.4%) and the lowest in chickpeas (5.0%). The proportion of hulls was not significantly different among lentils, smooth peas, and mung beans, all being ~8.0%. The hull constituted 7.1% of soybeans.

The composition of seeds, cotyledons, and flours of chickpeas, smooth peas, lentils, mung beans, faba beans, and soybeans is summarized in Table 2.

Protein contents ranged from 25.7% in chickpeas to 49.9% in soybeans. However, protein content of all legumes other than soybeans was not higher than 31.1%. Starch content of legumes ranged from 43.0% for faba beans to 53.2% for lentils. Soybeans contained <1% starch. The removal of seed coats increased both protein and starch contents of legume seeds. Cotyledons and flours exhibited much higher protein and starch contents than whole seeds. Ash content ranged from 2.8% for lentils to 5.3% for soybeans. There were no significant differences in ash content in seeds, cotyledons, and flours for all legumes except smooth peas, which had a significantly higher ash content in flour than in seeds. Lipid content of soybeans was 23.3%, whereas lipid content of smooth peas, lentils, mung beans, or faba bean was only ~1%. Chickpeas contained ~6% of lipids. There were also no significant differences in lipid content in seeds, cotyledons, and flours for all legumes except soybeans, which had a significantly higher lipid content in the cotyledon than in seeds.

Table 3. Fatty Acid Composition of Lipids from Various Legumes

	fatty acid composition (%)				
	C16:0	C18:0	C18:1	C18:2	C18:3
soybean	11.2	4.7	29.7	49.3	4.5
chickpea	9.4	1.5	42.0	43.6	1.8
lentil	14.3	1.8	22.9	44.8	13.4
smooth pea	12.6	3.8	29.0	44.8	8.4
mung bean	29.8	5.3	4.7	42.9	15.3
faba bean	13.9	2.0	22.7	54.0	4.6

Fatty Acid Composition of Lipids from Various Legume Flours. The fatty acid composition of various legume flours is given in Table 3. Linoleic acid was the predominant fatty acid in all legumes, ranging from 42.9 to 54.0%. With a content of 22.7−42.0%, oleic acid was the second highest fatty acid in all legumes except mung beans, which had an oleic acid content of 4.7%. On the other hand, lipids of mung beans had high levels of stearic acid and linolenic acid.

Yield and Composition of Legume Fractions. The yields of first solubles, second solubles, prime starches, and tailing starches by weight and by protein content are given in Figure 1. Overall, prime starch yielded the highest amount by weight, ~27−40%, followed by the first solubles and tailing starches. The second solubles yielded the lowest amount by weight, only ~10% (Figure 1A). On the other hand, the first solubles had the highest protein yield, ~70%, followed by the second solubles, ~20%. Prime and tailing starches had only a negligible protein yield (Figure 1B). The use of legume proteins with the first and second solubles for curd preparation, therefore, utilized ~90% of the total protein of the seeds.

Protein, ash, and lipid contents of the water solubles, as well as protein and ash contents of prime and tailing starches, are shown in Table 4. Protein content of solubles of all legumes other than soybeans ranged from 50.5 to 69.7%, about twice as high as that of the legume flours (Tables 2 and 4). Protein content of the first solubles was significantly higher than that of the second solubles for all legumes, whereas ash content was significantly lower in the first solubles than in the second solubles. Lipid content of the first solubles was significantly higher than that of the second solubles for all legumes except mung beans. Protein and ash contents of prime starches ranged from 0.7 to 1.4% and from 0.13 to 0.4%, respectively, indicating high purity of the prime starch after fractionation. The protein content of tailing starches ranged from 5.4% for mung beans to 7.2% for faba beans, whereas the ash content of tailing starches ranged from 0.7% for lentils to 2.1% for faba beans.

Gel Electrophoresis of Legume Proteins. The SDS-PAGE patterns of legume proteins are shown in Figure 2. Each legume protein showed its own electro-

Table 4. Protein, Ash, and Lipid Contents of Solubles and Protein and Ash Contents of Prime and Tailing Starches[a]

	solubles				prime starch		tailing starch	
	fraction	protein (%)	ash (%)	lipid (%)	protein (%)	ash (%)	protein (%)	ash (%)
chickpea	first	54.1^{A}	6.6^{B}	7.5^{A}	1.4	0.1	6.1	1.4
	second	50.5^{B}	7.1^{A}	4.2^{B}				
lentil	first	67.8^{A}	6.4^{B}	0.3^{A}	0.7	0.2	5.6	0.7
	second	61.2^{B}	7.1^{A}	0.1^{B}				
smooth pea	first	67.4^{A}	6.4^{B}	0.2^{B}	0.9	0.2	5.6	1.0
	second	62.7^{B}	7.1^{A}	0.3^{A}				
mung bean	first	67.0^{A}	6.6^{B}	0.2^{A}	0.8	0.2	5.4	0.7
	second	55.8^{B}	7.3^{A}	0.1^{A}				
faba bean	first	69.7^{A}	8.0^{B}	0.2^{B}	1.4	0.4	7.2	2.1
	second	65.6^{B}	8.6^{A}	0.3^{A}				

[a] All values were dry basis. For solubles of each legume type, values within a column with the same letter were not significantly different ($p \leq 0.05$).

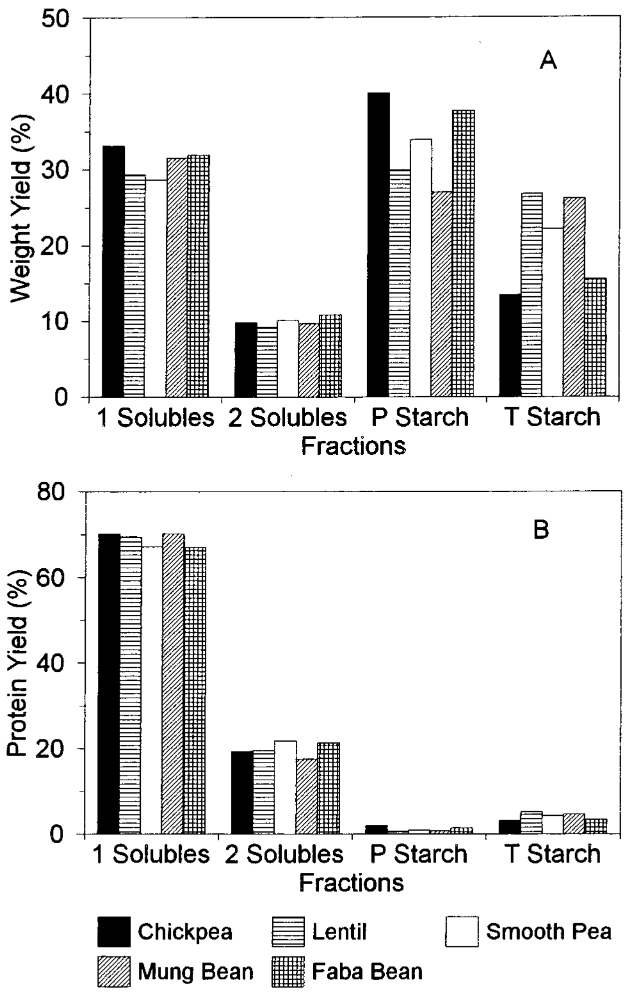

Figure 1. Weight yield (A) and protein yield (B) of the first solubles, second solubles, prime starch (P starch), and tailing starch (T starch) for different legumes.

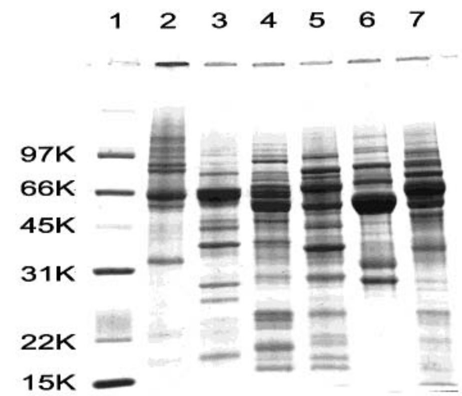

Figure 2. SDS-PAGE patterns of six legume proteins: (lane 1) standards; (lane 2) soybean; (lane 3) chickpea; (lane 4) lentil; (lane 5) smooth pea; (lane 6) mung bean; (lane 7) faba bean.

phoresis pattern with subunits of varied molecular weights. Whereas soybean, chickpea, and faba bean proteins showed major bands at ~66 kDa, mung bean showed a major band at ~58 kDa. On the other hand, lentils showed a wider distribution of the major bands, ranging from 50 to 70 kDa, and smooth pea showed a distribution from 40 to 80 kDa. The differences in protein constituents for various legumes may have caused the differences in gelation property during curd preparation.

Curd Preparation. The effect of coagulant dosage on the yield, moisture, and texture of chickpea curds is shown in Table 5. The dosage of $MgSO_4$ had no significant effect on the yield of curd, even though the curd yield showed a decreasing trend as the amount of $MgSO_4$ increased. On the other hand, the dosage of $CaSO_4$ negatively affected the yield of chickpea curds. Moisture content of curds was highest at a dosage of 0.5% for both $MgSO_4$ and $CaSO_4$. Moisture content of curds decreased significantly as the coagulant dosage increased from 0.5 to 1.0%. However, no significant changes in the moisture content of curds were observed as the dosage increased from 1.0 to 3.0% for $MgSO_4$ or from 1.0 to 2.0% for $CaSO_4$. Curds prepared with 0.5% of $MgSO_4$ were lower in hardness and cohesiveness but higher in springiness than those prepared with $MgSO_4$ concentration >1.0%. Further increase in $MgSO_4$ dosage did not significantly affect the hardness, springiness, and cohesiveness of the curd. On the other hand, there were significant increases in hardness and cohesiveness of the curd as $CaSO_4$ dosage increased from 0.5 to 1.5%. Further increase in $CaSO_4$ dosage to 2.0% did not affect textural properties of the curd. Curds made with $CaSO_4$ or $MgSO_4$ had different textural properties. At a similar coagulant dosage of 1−2%, curd prepared with $CaSO_4$ had a higher yield and a higher moisture content, but slightly lower springiness and cohesiveness, than those prepared with $MgSO_4$. In addition, chickpea curd prepared using 1.5 and 2.0% $CaSO_4$ exhibited higher hardness and cohesiveness than curds prepared using <1% $CaSO_4$.

The effect of protein concentration on the yield, moisture, and texture of chickpea curds is shown in Table 6. Curd yields were not significantly affected by protein concentration in a concentration range of 2−4%. However, curd yield at 1% protein concentration was significantly lower than at other concentrations. The moisture content of chickpea curds prepared from

Table 5. Effect of Coagulant Dosage on the Yield, Moisture, and Texture of Chickpea Curds[a]

coagulant	dose (%)	yield (g/100 g of flour)	moisture (%)	hardness (N)	springiness (ratio)	cohesiveness (ratio)
$MgSO_4$	0.5	116.4^{A}	83.5^{A}	2.2^{B}	0.97^{A}	0.57^{B}
	1	102.0^{A}	77.6^{B}	6.8^{A}	0.94^{B}	0.70^{A}
	2	99.1^{A}	77.2^{B}	7.4^{A}	0.93^{B}	0.68^{A}
	3	99.7^{A}	77.1^{B}	7.3^{A}	0.94^{B}	0.70^{A}
$CaSO_4$	0.5	172.0^{A}	85.8^{A}	2.4^{C}	0.94^{A}	0.54^{C}
	1	132.5^{B}	80.0^{B}	5.4^{B}	0.92^{B}	0.60^{B}
	1.5	120.5^{C}	80.0^{B}	7.8^{A}	0.92^{B}	0.66^{A}
	2	115.3^{C}	79.5^{B}	9.2^{A}	0.91^{B}	0.66^{A}

[a] Values within a column with the same letter were not significantly different ($p \leq 0.05$).

Table 6. Effect of Protein Concentrations on the Yield, Moisture, and Texture of Chickpea Curds[a]

protein concn (%)	yield (g/100 g of flour)	moisture (%)	hardness (N)	springiness (ratio)	cohesiveness (ratio)
1	76.1^{B}	71.2^{C}	15.9^{A}	0.92^{B}	0.72^{A}
2	103.3^{A}	77.6^{AB}	7.7^{B}	0.94^{A}	0.72^{A}
2.3	109.4^{A}	78.9^{A}	6.7^{BC}	0.93^{AB}	0.68^{B}
2.5	105.5^{A}	77.7^{AB}	7.1^{BC}	0.93^{AB}	0.68^{B}
2.6	100.4^{A}	75.5^{B}	9.0^{B}	0.93^{AB}	0.69^{B}
3	105.3^{A}	77.6^{AB}	6.9^{BC}	0.93^{AB}	0.67^{B}
4	99.3^{A}	76.4^{AB}	4.1^{C}	0.91^{C}	0.59^{C}
9	no curds				

[a] Values within a column with the same letter were not significantly different ($p \leq 0.05$).

Table 7. Yield, Moisture, and Texture of Curds Prepared from Different Legumes[a]

	yield (g/100 g of flour)	moisture (%)	hardness (N)	springiness (ratio)	cohesiveness (ratio)
soybean	146.9^{BC}	76.6^{B}	10.2^{A}	0.95^{A}	0.79^{A}
chickpea	128.5^{C}	76.6^{B}	7.7^{AB}	0.93^{BC}	0.68^{B}
lentil	169.1^{ABC}	84.5^{A}	3.5^{B}	0.92^{CD}	0.57^{C}
smooth pea	154.8^{ABC}	83.4^{A}	3.8^{B}	0.93^{BCD}	0.59^{C}
mung bean	192.9^{A}	83.6^{A}	4.9^{AB}	0.92^{D}	0.59^{C}
faba bean	178.3^{AB}	81.4^{AB}	6.0^{AB}	0.93^{B}	0.67^{B}

[a] Values within a column with the same letter were not significantly different ($p \leq 0.05$).

solubles of different protein concentrations ranged from 75.5 to 78.9%. No simple trend of variations in moisture content of the curd was observed as a result of variation in protein concentration. The moisture content of curd prepared from solubles with 1% of protein concentration was 71.2%, much lower than that of curds prepared from solubles with higher protein concentrations. There were significant effects of protein concentration on the hardness of the curds. Curd hardness generally decreased as protein concentration increased. Solubles with 1% protein concentration produced the hardest curd (15.9 N). Hardness of curds, ranging from 6.7 to 9.0 N, was not significantly increased as the protein concentration increased from 2.0 to 3.0%. Hardness of curd prepared from solubles with a protein concentration of 4.0%, however, was only 4.1 N. Hardness of curds at a protein concentration of 3% was 6.87 N, a value close to that of soybean tofu, as reported previously (*26*, *27*). Springiness of the curd was also significantly affected by protein concentration. Protein concentrations of 2.0–3.0% exhibited a higher springiness, 0.93–0.94, than did concentrations of 1.0 or 4.0%, which gave springiness values of 0.92 and 0.91, respectively. On the other hand, cohesiveness decreased significantly from 0.72 to 0.59 as protein concentration increased from 1.0 to 4.0%. Still, there were no significant differences in cohesiveness of curds prepared from solubles with protein concentrations between 2.3 and 3.0%. Overall, 2.3–3% was considered to be the optimum protein concentration for curd preparation. Curd was not formed at 9% protein concentration.

Characteristics of curds prepared from six legumes are shown in Table 7. Legume type had a significant effect on the yield of curds. Mung beans had the highest yield with 192.9 g/100 g of flour, whereas chickpeas had the lowest yield with only 128.5 g/100 g of flour. The curd yield of soybeans was 146.9 g/100 g of flour. The relatively low yield of soybean curd in light of the higher protein content of the seed in comparison with other legumes was attributed to the protein fractionation procedure. The extraction procedure for soybean milk has been adopted from the procedure developed for high-starch legumes (*25*), which may give a lower yield of protein fractions for soybeans containing no starch. The moisture content of curds from mung beans, lentils, and smooth peas ranged from 81.4 to 84.5%, significantly higher than the moisture content of the chickpea and soybean curds, both having a moisture content of 76.6%. Soybean tofu had the highest springiness and cohesiveness, 0.95 and 0.79, respectively. The textural property of curds from faba beans and chickpeas ranked second in springiness and cohesiveness. Curds from mung beans, lentils, and smooth peas exhibited the lowest springiness and cohesiveness. The hardness of soybean tofu was the highest, whereas that of lentils and smooth peas was the lowest.

In conclusion, the use of the first and second solubles for curd preparation utilized >90% of the total protein of legumes. A protein concentration of 2.3–3% and a coagulant dosage of 1.5% $CaSO_4$ produced the best curd for the protein fraction from chickpeas. Although soybean curd had the highest springiness and cohesiveness, curd prepared with chickpeas and faba beans showed comparable textural properties, indicating their potential for commercialization.

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