Oligosaccharide Content and Composition of Legumes and Their Reduction by Soaking, Cooking, Ultrasound, and High Hydrostatic Pressure

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Cereal Chem. 83(4):428–433

ABSTRACT

Oligosaccharides, including raffinose, stachyose, ciceritol, and verbascose, are commonly found in legumes and often result in flatulence in humans. Effects of soaking, soaking with ultrasound (47 MHz), soaking with high hydrostatic pressure (HHP, 621 MPa), and subsequent cooking on the oligosaccharide content of lentils, chickpeas, peas, and soybeans were investigated. Legumes were soaked for 3 or 12 hr in water, soaked for 1.5 or 3 hr with ultrasound, or soaked for 0.5 or 1 hr with HHP. Oligosaccharides of lentils and chickpeas were mainly composed of raffinose, ciceritol, and stachyose, while those of peas and soybeans were raffinose and stachyose. Verbascose was the minor oligosaccharide in lentils and peas and was absent in chickpeas and soybeans. Ciceritol was not detected in peas and soybeans. Total oligosaccharide content of raw legumes ranged from 70.7 mg/g in yellow peas to 144.9 mg/g in chickpeas. Soaking was effective for the reduction of oligosaccharides in the tested legumes. Compared with soaking for 3 hr, soaking legumes with ultrasound for 3 hr in all tested legumes or soaking legumes with HHP for 1 hr, with exception of soybeans, appeared to be more effective for the reduction of oligosaccharides. The effect of cooking on the reduction of oligosaccharide content of presoaked legumes was evident in lentils, while oligosaccharide content of chickpeas, peas, and soybeans was either unchanged or even increased by cooking after presoaking, with or without ultrasound, probably due to the leaching of other soluble components and the release of bound oligosaccharides during cooking. During soaking or cooking of legumes, raffinose leached out faster than other oligosaccharides.

Legumes are a good source of proteins, carbohydrates, thiamin, niacin, calcium, and iron. On the other hand, legumes possess undesirable flavors and may contribute to flatulence upon consumption. Flatulence is considered one of the most influential factors that deter consumers from eating more legumes.

α-Galactosides, characterized by the presence of α (1→6) links between the galactose moieties, may induce flatulence. α-Galactosides rank next to sucrose as the most widely distributed soluble carbohydrates in the plant kingdom. The α-galactosides constitute 6–18% of the dry weight of mature legumes (Reddy et al 1984; Frias et al 1999). One group of α-galactosides is the raffinose family of oligosaccharides (RFO) including raffinose [*O*-α-D-galactopyranosyl-(1→6)-α-D-glucopyranosyl-(1→2)-β-D-fructofuranoside], stachyose (tetramer), and verbascose (pentamer) (Frias et al 1999; Sako et al 1999; Gulewicz et al 2000; Peterbauer and Richter 2001). The other group of α-galactosides is the galactosyl cyclitols. The most common galactosyl cyclitol is ciceritol [*O*-α-D-galactopyranosyl-(1→6)-*O*-α-D-galatopyranosyl-(1→2)-1D-4-*O*-methyl-*chiro*-inositol], which was first isolated from chickpeas (Bernabé et al 1993) and more recently from lentils (Frias et al 1999; Peterbauer and Richter 2001).

Because we lack α-galactosidase, humans are not able to hydrolyze oligosaccharides, which are then passed to the large intestine and fermented anaerobically by intestinal microorganisms. This bacterial fermentation produces various gases including carbon dioxide, hydrogen, and methane which may induce discomfort in humans (Reddy and Salunkhe 1980; Frias et al 1996; Granito et al 2001). The production of gases after consumption of beans or oligosaccharides has been reported in many studies (Rackis et al 1970; Murphy et al 1972; Reddy et al 1980). The positive correlation between gas production and consumption of legumes or oligosaccharides is reported by Savitri and Desikachar (1985) and Fleming (1981).

To reduce oligosaccharide content of legumes, conventional processing methods of legumes including soaking, cooking, germination, and fermentation have been investigated (Pazur et al 1962; Rao and Belavady 1978; Reddy and Salunkhe 1980; Reddy et al 1980; Labaneiah and Luh 1981; Kuo et al 1988; Frias et al 1996; El-Adawy 2001). Mulimani and Devendra (1998) reported 33–55% reduction of raffinose, stachyose, and verbascose by soaking and 80–87% by cooking in red grams. Ultrasound breaks cell membranes and promotes the leaching of cell components (Burits and Bucar 2000). High pressure accelerates extraction of tea leaves and increases water uptake rate of rice (Esmelindro et al 2005; Ahromrit et al 2006). Accordingly, both ultrasound and high pressure applied during soaking legumes could further promote the leaching of oligosaccharides.

In this study, we determined the oligosaccharide content and composition of lentils, chickpeas, peas, and soybeans, as well as the effects of ultrasound and high hydrostatic pressure applied during soaking on the reduction of oligosaccharides in legumes.

MATERIALS AND METHODS

Two lentils (*Lens culinaris*) cvs. Pardina and Crimson; chickpea (*Cicer arietinum* L.) cv. Dwelly; yellow pea (*Pisum sativum* L.); and green pea (*P. sativum* L.) cv. Joel were provided by Genesee Union Warehouse Co. (Genesee, WA). Soybeans (*Glycine max* L.) were purchased from a local retail store (Moscow, ID). Legumes were ground with a cyclone mill (Udy Corp., Fort Collins, CO) equipped with a screen with 0.5-mm openings and subjected to oligosaccharide determination.

Extraction of Oligosaccharides

Extraction of oligosaccharides was conducted according to the procedure of Labaneiah and Luh (1981) and Sánchez-Mata et al (1998), with modifications. Ground legume flour (1.5 g) was blended in 80% ethanol (40 mL) for 45 min at 57 ± 2°C and added with another 80% ethanol (40 mL) with stirring. The mixture of 80% ethanol and legume flour was centrifuged for 30 min at 1,500 × *g*, and supernatant was collected and filtered through filter paper (Whatman #40). The extract was concentrated using a rotary vacuum evaporator at 50°C by the removal of the ethanol. The concentrate was made up to 10 mL with distilled water. The extract was passed through a Sep-Pak C18 cartridge (Waters, Milford, MA) that was previously washed with methanol (5 mL) and water (5 mL). The eluent (3 mL) was mixed with acetonitrile

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DOI: 10.1094/CC-83-0428

(7 mL) and filtered through a 0.45-µm nylon membrane filter. Aliquot (90 µL) of filtered eluent was injected to HPLC to quantify oligosaccharide content.

HPLC Analysis

An HPLC system was equipped with an auto-sampler (model 1050, Hewlett Packard, Wilmington, DE), a gradient programmer (model 2360, ISCO, Lincoln, NE), a solvent pump (model 2350, ISCO), and a diode array detector (model 1040A, Hewlett Packard). The mobile phase was a mixture of acetonitrile and water (70:30). The flow rate was 1.0 mL/min. A carbohydrate analysis column (10 µm × 3.9 mm × 30 cm) filled with aminopropylmethylsilyl bonded amorphous silica (Waters) was used.

Commercially available standard raffinose and stachyose were purchased from Sigma Co. (St. Louis, MO). Ciceritol and verbascose were not available commercially. Ciceritol and verbascose were identified by comparing the retention time of ciceritol and verbascose, as reported by Gulewicz et al (2000), with those collected from HPLC analysis of lentils and peas. The collected fractions of ciceritol and verbascose were evaporated to remove acetonitrile and water (70:30) by blowing a stream of nitrogen gas. The remaining ciceritol or verbascose were then weighed. Raffinose, stachyose, ciceritol, and verbascose were then dissolved in the mixture of acetonitrile and water (70:30) and injected into HPLC to acquire an equation between the concentration and the area in a HPLC chromatogram. The obtained equations were used to estimate oligosaccharide content in legumes.

Water Imbibition and Cooking of Soaked Seeds

Legumes were soaked in water at 22°C for the selected durations to determine the soaking time of legumes. Lentil cv. Pardina, yellow peas, green peas, and soybeans (100 g) were soaked in distilled water (400 mL) for 3–18 hr. Lentil cv. Crimson was soaked from 1 to 6 hr because of its small seed size. Chickpeas, due to their larger seed size compared with other legumes, were soaked 3–24 hr. During soaking, the weight increase of legumes was determined every 3 hr, except for lentil cv. Crimson, for which the weight increase was determined every 1 hr. Water imbibition was expressed as the percentage of weight increase during soaking.

Legumes (100 g) soaked for 3 and 12 hr were cooked for 30 min in boiling water (500 mL). Water used to soak or cook legumes was discarded, and soaked or cooked legumes were dried at 55°C for 12 hr. The dried seeds were ground with a cyclone mill (Udy) and used for determination of oligosaccharide content.

Soaking with Ultrasound and High Hydrostatic Pressure

To determine the effects of ultrasound and HHP during soaking on oligosaccharide content, legumes were soaked in water with or without ultrasound or HHP. Legumes were soaked for 3 or 12 hr in distilled water, or soaked with ultrasound (47 kHz) for 1.5 or 3 hr and with high hydrostatic pressure (621 MPa) for 0.5 or 1 hr. Soaked legumes (50 g) were cooked in water (250 mL) for 30 min at 98°C. Water used to soak or cook legumes was discarded, and soaked or cooked legumes were dried at 55°C for 12 hr. The dried legumes were ground with a cyclone mill (Udy) to determine oligosaccharide content.

Statistical Analysis

The experiments were replicated and all determinations were made at least in duplicate. Data were statistically analyzed using analysis of variance and Duncan's multiple range test using Statistical Analysis System software (SAS Institute, Cary, NC). Significant differences were determined at $P < 0.05$.

RESULTS AND DISCUSSION

Oligosaccharide Composition and Content

Figure 1 presents an HPLC chromatogram of the oligosaccharide extract from lentil cv. Pardina. The order of the elution in HPLC analysis of the oligosaccharides was raffinose at 7.5 min of retention time, ciceritol at 8.6 min, stachyose at 11.4 min, and verbascose at 17.6 min.

The oligosaccharide compositions of the selected legumes are summarized in Table I. Raffinose and stachyose were detected in lentils, chickpeas, yellow peas, green peas, and soybeans. Ciceritol was observed in lentils and chickpeas, and verbascose was observed in lentils, yellow peas, and green peas. The presence of raffinose and stachyose in all legumes tested was also reported by Reddy et al (1984), who also reported the presence of verbascose (0–0.3%) in soybeans. Chavan et al (1989) reported a trace to 4.5% of verbascose in chickpeas. In this study, verbascose was not detected in chickpeas or soybeans, possibly due to low concentration. The presence of ciceritol in lentils and chickpeas was also reported by Frias et al (1999) and Peterbauer and Richter (2001).

Total oligosaccharide content of legumes ranged from 70.7 mg/g in yellow peas to 144.9 mg/g in chickpeas. In lentils, ciceritol was the major oligosaccharide comprising ≈41% of the detected oligo-

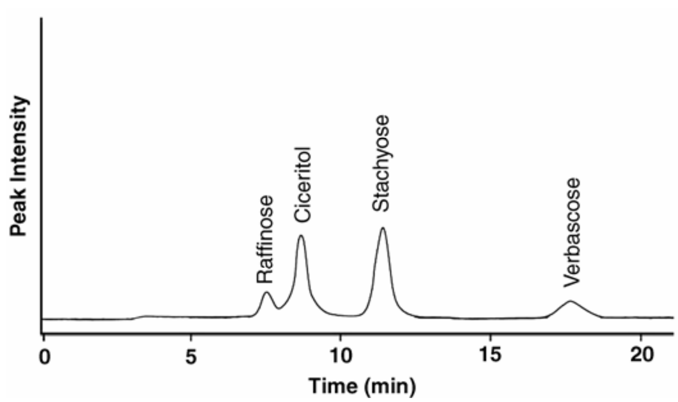

Fig. 1. HPLC chromatogram of raffinose, ciceritol, stachyose, and verbascose extracted from lentil cv. Pardina.

TABLE I
Oligosaccharide Composition and Content of Raw Legumes[a,b]

	Content (mg/g)				
Legumes	**Raffinose**	**Ciceritol**	**Stachyose**	**Verbascose**	**Total**
Lentils					
cv. Pardina	28.6c	38.6b	24.6c	3.9c	95.5bc
cv. Crimson	37.0bc	50.0ab	28.8abc	7.2b	122.9ab
Chickpeas	50.2ab	67.7a	27.0bc	nd	144.9a
Yellow peas	34.0c	nd	31.7ab	4.9c	70.7c
Green peas	30.1c	nd	35.4a	15.0a	80.4c
Soybeans	60.1a	nd	35.0a	nd	95.1bc

[a] Values within a column followed by the same letter are not significantly different at $P < 0.05$.
[b] Not detected.

saccharides, while raffinose, stachyose, and verbascose constituted ≈30%, ≈24%, and 5%, respectively. The stachyose and verbascose content of lentils agrees with the results reported by Reddy et al (1984). Ciceritol was also the major oligosaccharide in chickpeas, comprising 47% of the detected oligosaccharides. Raffinose and stachyose constituted 35 and 18% of the detected oligosaccharides in chickpeas, respectively. Raffinose, stachyose, and verbasecose contents of chickpeas were comparable to reports by Chavan et al (1989). Raffinose and stachyose constituted similar proportions of the detected oligosaccharides in yellow peas (47%) and green peas (40%). Verbascose constituted 6% of detected oligosaccharides in yellow peas and 19% in green peas. In soybeans, raffinose and stachyose constituted 63 and 37%, respectively, of detected oligosaccharides.

Water Imbibition of Legumes

Water imbibition of legumes during soaking is depicted in Fig. 2. After 12 hr of soaking at 22°C, chickpeas, yellow peas, green peas, and soybeans were saturated. Water imbibition of legumes, indicated by the percentage of weight increase, was 108% in chickpeas, 103% in yellow peas, 102% in green peas, and 125% in soybeans. Lentil cv. Crimson was saturated with water after 6 hr of soaking, exhibiting water imbibition of 119%. Based on water imbibition patterns of legumes, soaking times of 3 or 12 hr, which give partial or full imbibition for all tested legumes, were selected to determine the effect of soaking on seed oligosaccharide content.

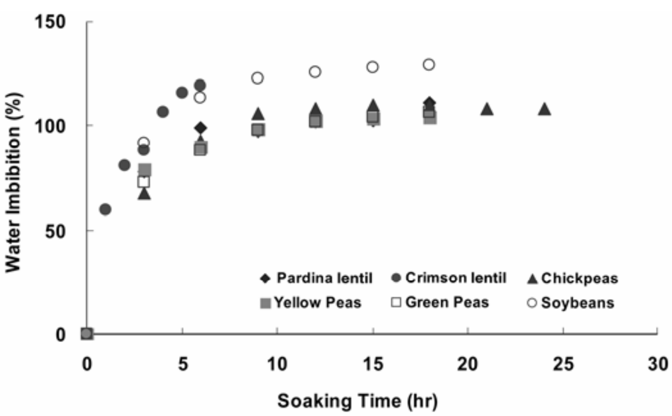

Fig. 2. Water imbibition of legumes during soaking.

Total Oligosaccharide Content

The total oligosaccharide content of legumes soaked in water and soaked in water with ultrasound or HHP is depicted in Fig. 3. After soaking, legumes generally exhibited reduction in total oligosaccharide content, probably due to leaching of oligosaccharides into soaking water (Price et al 1988). Effects of the extended soaking time from 3 to 12 hr on oligosaccharide content was evident in chickpeas, green peas, and soybeans, but less or not evident in lentils and yellow peas. Significant reduction of oligosaccharides by soaking has also been reported in red gram (Mulimani and Devendra 1998), soybean (Mulimani et al 1997), and various legumes including lentils and faba beans (Abdel-Gawad 1993).

Compared with raw legumes, total oligosaccharide content of lentils was reduced by 22.9–50.1% after soaking in water for 12 hr; reduced by 55.9–58.7% after soaking with ultrasound for 1.5 hr; and reduced by 34.5–55.9% after soaking with HHP for 1 hr. Abdel-Gawad (1993) reported a 28% reduction in oligosaccharide content of lentils after soaking in tap water for 12 hr and a 37% reduction after soaking in sodium bicarbonate solution for 12 hr.

The oligosaccharide content of chickpeas was effectively reduced by soaking for 12 hr (74.6%), soaking with ultrasound for 3 hr (64.7%), and soaking with HHP for 1 hr (67.6%). Oligosaccharide content of chickpeas decreased more by soaking with ultrasound for 3 hr or by HHP for 1 hr than by just soaking. With soaking with ultrasound for 3 hr or with HHP for 1 hr, the oligosaccharide content of yellow peas was reduced by 39.2 and 36.1%, respectively. The reduction in oligosaccharide content of green peas was largest after soaking in water for 12 hr and soaking with ultrasound for 3 hr. Up to 56.3% of oligosaccharides in soybeans was removed by soaking in water for 12 hr; 45.8% was removed by soaking with ultrasound for 3 hr.

It appears that the application of ultrasound during soaking is generally helpful for the reduction of oligosaccharides, especially when soaking time reduction is considered. Ultrasound may promote the leaching of oligosaccharides to soaking water. Ultrasound

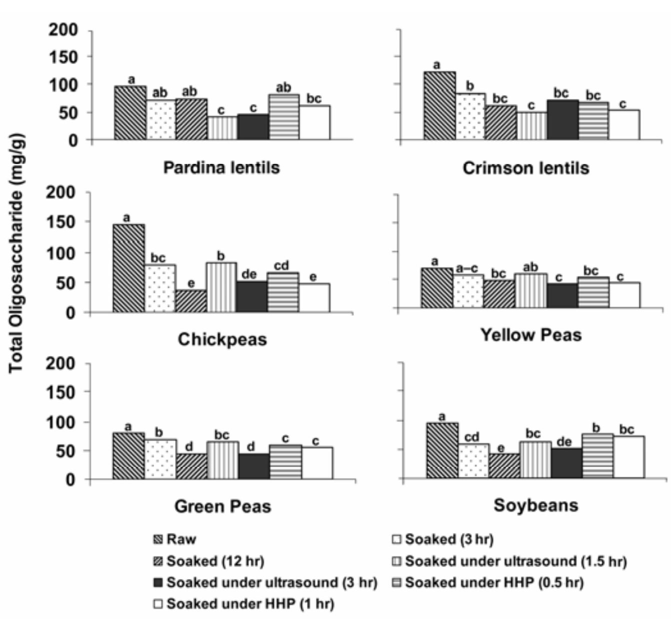

Fig. 3. Effect of ultrasound and high hydrostatic pressure during soaking on total oligosaccharide content of legumes. Bars with the same letters in the same group are not significantly different ($P < 0.05$).

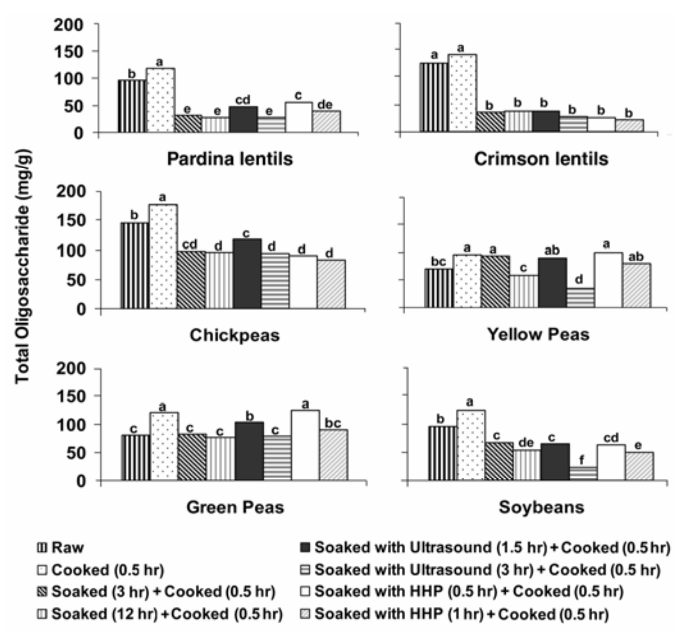

Fig. 4. Effect of ultrasound and high hydrostatic pressure during soaking on total oligosaccharide content of cooked legumes. Bars with the same letters in the same group are not significantly different ($P < 0.05$).

could break cell structure (Burits and Bucar 2000), and broken cells may provide more pathways for oligosaccharides to leach out from legumes.

Legumes cooked for 30 min without presoaking exhibited significantly higher oligosaccharide content than raw seeds, except in Crimson lentil (Fig. 4). The increased seed oligosaccharide content could be due to comparably higher leaching of soluble components including protein, monosaccharides, disaccharides, and soluble fibers than oligosaccharides during cooking, and to the release of bound oligosaccharides during cooking. Rao and Belavady (1978) and Jambunathan et al (1994) reported that some oligosaccharides are bound either to proteins or other macromolecules, or are present as constituents of high molecular weight polysaccharides. Jambunathan et al (1994) also reported that bound oligosaccharides go through nonenzymatic hydrolysis and release oligosaccharides from bound macromolecules during cooking, resulting in an increase in oligosaccharide content.

Cooked chickpeas and peas, after soaking in all selected conditions, generally exhibited higher oligosaccharide content than seeds soaked in corresponding conditions without subsequent cooking (Figs. 3 and 4). Presoaked and cooked soybeans exhibited a 12–29% higher oligosaccharide content compared with presoaked soybeans, while cooked soybeans after presoaking with ultrasound or HHP exhibited a 17–54% reduction compared with presoaked soybeans in the same conditions. The total oligosaccharide content in cooked lentils after soaking in all selected conditions was lower by 32–61% compared with uncooked lentils soaked in the same conditions. Abdel-Gawad (1993) also reported further decrease in oligosaccharide content after cooking of presoaked lentils. It was assumed that the inconsistent changes in oligosaccharide content after cooking among legumes may result from differences in the amount of oligosaccharides lost during soaking or cooking versus release of bound oligosaccharides during cooking. Detected oligosaccharide content of legumes could increase if the amount of bound oligosaccharides released during cooking is larger than the amount of oligosaccharides leached out during soaking or cooking. The oligosaccharide content of presoaked and subsequently cooked legumes was lower compared with that of cooked legumes without soaking, except in yellow peas.

Raffinose, Ciceritol, Stachyose, and Verbascose Content of Legumes

Raffinose, ciceritol, stachyose, and verbascose contents of legumes soaked at selected conditions and those of cooked legumes are depicted in Tables II–V. Decrease in raffinose content of legumes during soaking was much greater than decreases in other oligosaccharides. Abdel-Gawad (1993) also reported larger reduction in raffinose content than stachyose and verbascose in red gram. Raffinose content of lentils, chickpeas, yellow and green peas, and soybeans was reduced by 39–83% after soaking for 3 hr with ultrasound (Table II). Raffinose content of lentils, chickpeas,

TABLE III
Ciceritol Content (mg/g) of Legumes Soaked with Ultrasound and High Hydrostatic Pressure and Subsequently Cooked for 30 min[a]

Treatment	Lentil cv. Pardina	Lentil cv. Crimson	Chickpeas
Uncooked seeds			
Unsoaked	38.6a	50.0a	67.7a
Soaked			
3 hr	21.8b	29.1b	33.5b
12 hr	25.7b	21.5b	12.1d
Soaked under ultrasound			
1.5 hr	10.0c	18.1b	33.1b
3 hr	12.8c	25.9b	19.5cd
Soaked under HHP			
0.5 hr	24.5b	22.4b	24.3c
1 hr	18.8bc	18.8b	17.3cd
Cooked seeds			
Unsoaked	46.3a	56.8a	72.2a
Soaked			
3 hr	13.4e	12.0c	54.3bc
12 hr	14.2de	12.6bc	52.4cbd
Soaked under ultrasound			
1.5 hr	19.1c	14.9b	59.9b
3 hr	12.0e	12.9bc	46.9cd
Soaked under HHP			
0.5 hr	23.4b	11.5c	46.6cd
1 hr	17.3cd	8.8d	41.6d

[a] Values within a column of uncooked seeds or cooked seeds followed by the same letter are not significantly different at $P < 0.05$.

TABLE II
Raffinose Content of Legumes Soaked with Ultrasound and High Hydrostatic Pressure (HHP) and Subsequently Cooked for 30 min[a]

	Raffinose Content (mg/g)					
Treatment	Lentil cv. Pardina	Lentil cv. Crimson	Chickpeas	Yellow Peas	Green Peas	Soybeans
Uncooked seeds						
Unsoaked	28.6a	37.0a	50.2a	34.0a	30.1a	60.1a
Soaked						
3 hr	24.4ab	25.0b	29.2b	30.7ab	24.2b	40.1b
12 hr	21.3ab	15.9b	15.9d	28.8ab	7.2e	26.3c
Soaked under ultrasound						
1.5 hr	18.2ab	16.0b	30.4b	31.6ab	18.1cd	32.1bc
3 hr	14.1b	21.6b	19.6cd	20.6b	5.2e	26.6c
Soaked under HHP						
0.5 hr	29.7a	22.5b	22.8c	29.2ab	21.4bc	41.0b
1 hr	22.4ab	17.0b	18.8cd	22.6ab	16.6d	39.7b
Cooked seeds						
Unsoaked	19.7a	20.7a	40.9a	42.1ab	31.8ab	69.3a
Soaked						
3 hr	3.2c	5.3b	17.6c	42.4ab	22.5c	36.2b
12 hr	4.0c	5.8b	17.3c	26.3c	22.3c	29.6cd
Soaked under ultrasound						
1.5 hr	5.9bc	5.9b	26.1b	39.4ab	30.8abc	33.5bc
3 hr	3.6c	3.3b	22.6bc	14.0d	22.0c	10.3e
Soaked under HHP						
0.5 hr	6.9b	3.9b	21.7bc	46.6a	37.8a	32.4bc
1 hr	3.8c	2.3b	19.9c	34.5bc	26.4bc	26.4d

[a] Values within a column of uncooked seeds or cooked seeds followed by the same letter are not significantly different at $P < 0.05$.

yellow and green peas, and soybeans was also reduced by 34–63% after soaking for 1 hr with HHP. After cooking, raffinose content was reduced by 31–44% in lentils and chickpeas compared with raw legumes, even though total oligosaccharide content of legumes increased after cooking, as discussed previously. Peas and soybeans exhibited an increase of raffinose content by 6–24% after cooking. The increase of raffinose content may be due to the release of bound raffinose during cooking (Jambunathan et al 1994).

Soaking legumes exhibited reduced ciceritol content by ≈42% in lentils and by 49% in chickpeas, compared with unsoaked seeds (Table III). Ciceritol content of cooked legumes without presoaking was higher by ≈18% in lentils, and by 6.5% in chickpeas, compared with raw legumes, as in total oligosaccharide content. Stachyose content of tested legumes was decreased by 24–56% after soaking for 3 hr with ultrasound (Table IV). After soaking for 1 hr with HHP, the stachyose content was also decreased by 30–59% in lentil cv. Crimson, chickpeas, and peas. After cooking, stachyose content increased by 18–133% in lentils, chickpeas, and soybeans, but reduced in green peas by 8.5%, compared with raw legumes. Verbascose content of legumes was reduced by 18–39% in lentil cv. Crimson and green peas after soaking for 3 hr with ultrasound (Table V). In cooked legumes without soaking, the verbascose content exhibited the largest increase, 178–283% in lentils and peas, among oligosaccharides. Abdel-Gawad (1993) also reported smaller reduction of verbascose than raffinose and stachyose in faba beans by soaking and cooking, and Mulimani and Devendra (1998) reported smaller reduction of verbascose by

TABLE IV
Stachyose Content of Legumes Soaked with Ultrasound and High Hydrostatic Pressure (HHP) and Subsequently Cooked for 30 min[a]

	Stachyose Content (mg/g)					
Treatment	**Lentil cv. Pardina**	**Lenril cv. Crimson**	**Chickpeas**	**Yellow Peas**	**Green Peas**	**Soybeans**
Uncooked seeds						
Unsoaked	24.6a	28.8a	27.0a	31.7a	35.4a	35.0a
Soaked						
3 hr	21.7ab	24.6ab	16.0bc	22.7bc	28.6b	18.7cd
12 hr	24.2ab	19.6b	8.8d	17.6d	23.7d	15.3d
Soaked under ultrasound						
1.5 hr	11.4c	14.3c	19.1b	24.5b	28.5b	31.1ab
3 hr	16.7bc	20.9b	12.0cd	18.5d	27.0bc	25.0bc
Soaked under HHP						
0.5 hr	23.5ab	20.2bc	18.7b	21.9c	24.1d	34.8a
1 hr	18.3abc	14.5c	11.0d	18.6d	24.8cd	32.4a
Cooked seeds						
Unsoaked	38.2a	41.7a	62.9a	37.4ab	32.4a	54.8a
Soaked						
3 hr	11.4d	13.1b	25.8c	35.7ab	22.0b	29.7b
12 hr	10.4d	13.7b	25.6c	21.1c	21.6b	24.3c
Soaked under ultrasound						
1.5 hr	17.3bc	9.6c	32.0b	36.2ab	26.1b	31.0b
3 hr	9.5d	8.0cd	24.4c	15.1c	22.0b	13.0d
Soaked under HHP						
0.5 hr	20.5b	6.9d	22.0c	38.7a	33.8a	29.9b
1 hr	14.9c	6.5d	20.6c	30.0b	23.1b	24.0c

[a] Values within a column of uncooked seeds or cooked seeds followed by the same letter are not significantly different at $P < 0.05$.

TABLE V
Verbascose Content of Legumes Soaked with Ultrasound and High Hydrostatic Pressure (HHP) and Subsequently Cooked for 30 min[a]

	Verbascose Content (mg/g)			
Treatment	**Lentil cv. Pardina**	**Lentil cv. Crimson**	**Yellow Peas**	**Green Peas**
Uncooked seeds				
Unsoaked	3.9ab	7.2a	4.9a	15.0a–c
Soaked				
3 hr	5.0a	5.7b	4.1ab	16.6ab
12 hr	2.6b	4.4c	2.9b	13.4cd
Soaked under ultrasound				
1.5 hr	2.7b	2.5d	4.6a	17.4a
3 hr	2.5b	4.4c	3.9ab	12.3d
Soaked under HHP				
0.5 hr	4.9a	3.8c	3.9ab	14.3b–d
1 hr	3.2ab	3.8c	4.0ab	14.0cd
Cooked seeds				
Unsoaked	13.2a	20.1a	15.6a	57.3a
Soaked				
3 hr	3.5d	5.1bc	14.3ab	37.8de
12 hr	0.0e	4.8bc	10.1bc	33.7e
Soaked under ultrasound				
1.5 hr	5.7b	6.9b	13.1ab	47.9bc
3 hr	3.5d	4.0bc	6.6c	35.1de
Soaked under HHP				
0.5 hr	5.5bc	2.8c	14.2ab	53.1ab
1 hr	3.9cd	3.5bc	14.6a	41.5cd

[a] Values within a column of uncooked seeds or cooked seeds with the same letter are not significantly different at $P < 0.05$.

soaking and similar reduction of raffinose by cooking in red grams. Verbascose might be difficult to leach out from legumes due to its larger molecular size than raffinose, cicertitol, and stachyose. The application of ultrasound and HHP during soaking produced similar or higher reduction in oligosaccharides, including raffinose, ciceritol, stachyose, and verbascose than did soaking alone.

CONCLUSIONS

Total oligosaccharide content differed largely among lentils, chickpeas, peas, and soybeans, and ranged from 70.7 mg/g in yellow peas to 144.9 mg/g in chickpeas. Raffinose, ciceritol, and stachyose were the major oligosaccharides of lentils and chickpeas, while oligosaccharides of peas and soybeans were mainly raffinose and stachyose. Verbascose was a minor oligosaccharide in lentils and peas and was not detected in chickpeas and soybeans.

Soaking was generally effective for the reduction of oligosaccharides in legumes. The application of ultrasound and HHP during soaking appeared to promote the leaching of oligosaccharides, whereas their effectiveness in oligosaccharide reduction of legumes during soaking varied among legume species. Ultrasound and HHP could reduce the soaking time required to reduce oligosaccharide content. The higher oligosaccharide content of cooked legumes without presoaking compared with that of uncooked legumes was probably due to the release of bound oligosaccharides and leaching of other soluble compounds, including mono- and disaccharides, and soluble fiber.

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[Received September 21, 2005. Accepted March 9, 2006.]