

Isolation and Characterization of Cotyledon Fibers from Peas, Lentils, and Chickpeas

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ABSTRACT

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Methods were developed to efficiently isolate legume cotyledon fibers with relatively high yields and purities. Seeds of pea (*Pisum sativum*), chickpea (*Cicer arietinum*), and lentil (*Lens culinaris*) were roller milled into flour and fractionated into prime starch, tailings starch, and water solubles. Insoluble dietary fiber was isolated from tailings starch by wet screening on sieves with openings ranging from 53 to 90 μm . Yield of insoluble fiber using a sieve with 53- μm openings ranged from 49.7 to 59.2% of insoluble fiber in flour with purities ranging from 85.5 to 87.3%. Soluble dietary fiber was isolated from the water-soluble

fraction following acid precipitation of soluble protein at pH 4. Soluble fiber yield ranged from 83.3 to 89.6% of flour soluble fiber with purities ranging from 64.5 to 70.6%. Glucose was the most common sugar component of hulls and soluble cotyledon fibers, while arabinose was the main sugar in insoluble fibers. Insoluble fiber exhibited significantly higher swelling capacities and water and oil binding capacities in comparison to hulls and soluble cotyledon fibers. Apparent viscosities of soluble cotyledon fibers ranged from 3.13 to 3.43 Pa \cdot sec and exhibited Newtonian characteristics.

Legumes are a good source of unique starch, highly soluble protein and dietary fiber. Typically utilized as whole seeds, legumes have a stable but low market value. By fractionating legumes into major constituents, both utilization and market value can be increased. One way to achieve this is to mill legume seeds into flour and fractionate the flour into prime starch, tailings starch and a water-soluble fraction. Czuchajowska and Pomeranz (1994) patented a method to isolate these components through wet fractionation. This method requires no chemicals and requires much less water than other commonly used methods (Otto et al 1997). Dietary fiber is a major component of both the water-soluble and tailings starch fractions along with large amounts of protein and starch.

Extensive research has been conducted on the extraction and use of pea hulls as sources of dietary fiber in cereal and meat products (Ralet et al 1993; Weightman et al 1994; Goff et al 2001). Ralet et al (1993) determined total dietary fiber contents of raw pea hulls ranged from 89.9 to 91.6% as measured by the Prosky (1985) method. Little research has focused on isolating cotyledon fibers of legumes. The major difference between cotyledon fibers and hulls is the concentration of cellulosic and noncellulosic polysaccharides. Hulls typically consist mainly of cellulose, varying levels of hemicelluloses and lignin, which serve as cell wall structure modifiers. Cotyledon fibers are typically composed of nonstructural polysaccharides such as hemicelluloses, pectins and gums (Pfoertner and Fischer 2001).

Commercially available pea cotyledon fibers contain \approx 30% starch, 5% protein, and 4% ash (Pfoertner and Fischer 2001). However, many researchers have produced pea cotyledon fibers ranging from 35 to 63% dietary fiber (Bertelsen et al 1991; Hansen et al 1992; Sandstrom et al 1994; Leterme et al 1996, 1998; Anderson and Berry 2000). Hughes et al (1996) isolated cotyledon fibers from common beans containing \approx 55 to 60% total dietary fiber. To increase the purity of legume cotyledon fibers, methods need to be developed to more efficiently and effectively remove the contaminating starch and protein components. Purification of legume cotyledon fiber will help provide insight into the true functionality of legume fibers.

The purpose of this research was to develop methods to isolate water-soluble and water-insoluble dietary fiber from legume flour

fractions. Following isolation, the fibers were characterized by HPLC and functional properties were evaluated to determine practical uses of the fibers.

MATERIALS AND METHODS

Materials

Pea (*Pisum sativum* cv. Columbian), chickpea (*Cicer arietinum* cv. Dwelley), and lentil (*Lens culinaris* cv. Pardina) seeds were purchased locally (Moscow Seed Co., Moscow, ID) and milled into flour using a MIAG pilot-scale roller mill. Hulls were separated as the bran fraction during milling and ground using a cyclone mill (Udy Co., Fort Collins, CO) through a screen with openings of 0.25 mm. Flours were further fractionated into prime starch, tailings starch and water-solubles using the wet fractionation method of Czuchajowska and Pomeranz (1994). Flour (200 g) 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 1,500 \times g for 15 min. The same procedure was repeated once more. Solubles were collected after each centrifugation and used for isolation of soluble fiber. The tailings starch was then separated from the bottom prime starch and used for isolation of insoluble fiber.

Chemical Analyses

Compositional analysis was performed on seeds, flours, hulls, prime starch, tailings starch, water solubles and isolated fibers. Prime starch, tailings starch and water solubles from wet fractionation, and isolated fibers were lyophilized and ground using a cyclone mill through a screen with openings of 0.25 mm. Protein contents ($N \times 6.25$) were determined using a nitrogen analyzer (FP-428, Leco Corp. St. Joseph, MI) coupled to a thermoconductivity detector with helium as the carrier gas. Moisture, ash, free lipids, and starch contents were determined according to Approved Methods 44-15A, 08-01, 30-25 and 76-13, respectively (AACC 2000). Total insoluble and soluble dietary fiber of whole seeds and flours was determined using Approved Method 32-07 as described by Prosky (1988).

Fiber Isolation

Following fractionation, tailings starches (\approx 26 g) were wet-screened in 2L of water through sieves with openings ranging from 53 to 90 μm . The recovered material from the top of the sieve was freeze-dried as insoluble fiber concentrate. Fiber content of insoluble fiber concentrates was determined by difference following determination of ash, protein and starch. The percent yield of insoluble fiber was calculated based on the insoluble fiber content of the

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flour following subtraction of residual starch, ash and protein. Starch was collected from washings passed through the sieve after centrifugation (10 min, 1,500 × g) of the washings and removal of any tailings on top of the starch pellet. The yield of starch was determined after subtraction of residual ash and protein and based on the total starch content of flour.

Insoluble fiber concentrates were further purified by digesting the remaining starch after sieving. The recovered insoluble fiber concentrate was dispersed in 400 mL of water and treated with heat stable α-amylase (Termamyl, 50 μL/100 mL) at pH 6 for 30 min in a 100°C water bath with occasional shaking. Following centrifugation of the mixture for 10 min at 1,500 × g, the pellet was lyophilized as purified insoluble fiber.

To isolate soluble fiber from the water soluble fraction, protein was precipitated by adjusting the pH of the soluble fraction from 3 to 9 using 1N HCl or 1N NaOH. Following precipitation of protein, the soluble fraction was centrifuged for 10 min at 1,500 × g. The pellet was recovered and lyophilized as a protein concentrate and the supernatant lyophilized as soluble fiber concentrate. Fiber content of soluble fiber concentrates was determined by difference following determination of ash and protein. The percent yield of soluble fiber was determined based on the soluble fiber content of the flour after subtracting the weight of the residual ash and protein.

Sugar Composition of Fibers

Soluble fibers, insoluble fibers and hulls were hydrolyzed according to the methods of Doner and Johnston (2001). Before hydrolysis, residual starch and protein was digested and removed according to the total dietary fiber determination procedure (Prosky 1988). Primary hydrolysis was conducted by mixing purified fiber (300 mg) with 12N H₂SO₄ (150 μL/20 mg of fiber) and vortexing periodically for 45 min at 24°C. Secondary hydrolysis was achieved by adding water (1.65 mL) to dilute the acid to 1N H₂SO₄ and heating the mixture in an oven at 100°C for 90 min. After cooling, BaCO₃ was steadily added to the mixture until a neutral pH was achieved as measured by pH paper. BaSO₄ resulting from pH adjustment was removed by vacuum filtration and the filtrate was dried under a stream of nitrogen. The dried filtrates containing hydrolyzed neutral

sugars were diluted in 500 μL of water and filtered through a 0.2-μm syringe filter.

Neutral sugars of the hydrolyzed fibers were separated by HPLC equipped with a BioRad Aminex HPX-87P heavy metal carbohydrate analysis column (300 mm × 7.8 mm). The column was fitted to a BioRad Carbo-P guard cartridge housed in a standard cartridge holder. Column temperature was held at 85°C using a Varian column heater. Degassed milli-Q water represented the mobile phase and was pumped through the system by an ISCO model 2350 HPLC pump at a flow rate of 0.6 mL/min. Hydrolyzed fibers (10 μL) were introduced into the mobile phase using an HP1050 auto-injector. Sugars eluted from the column were measured using a refractive index detector (model R401, Waters Associates) at an attenuation of 16x.

Data analysis was conducted using HP chemstation software. Quantification of sugars was conducted based on retention times and standard curves of external standards. Retention times of standards were 11.4 min for cellobiose, 13.9 min for glucose, 15.0 min for xylose, 16.0 min for galactose, 17.2 min for arabinose-rhamnose, and 19.1 min for mannose. Uronic acid contents of sugar hydrolysates were quantified according to the method described by Meseguer et al (1998).

Physical Properties of Fibers

Direct density and bulk density of hulls, soluble fibers and enzyme purified insoluble fibers were determined using the methods described by Parrott and Thrall (1978). Direct density was determined by adding fiber to the 5-mL mark on a calibrated 10-mL graduated cylinder. Care was taken to avoid shaking the cylinder to prevent settling of the fibers. The fiber was then emptied and weighed. The direct density was expressed as grams per milliliter. Bulk density was determined by adding 2 g of fiber to a graduated syringe and applying sufficient pressure to pack the contents in the syringe. The volumetric measure of the fiber in the syringe was then recorded and bulk density was expressed as grams per milliliter.

Swelling capacity of hulls and purified insoluble fibers was quantified according to the method of Auffret et al (1994). Dry fiber (500 mg) was weighed into a 50-mL graduated cylinder and

TABLE I
Composition of Legume Seeds and Flours^{a,b}

Legume	Protein ^c (%)	Ash (%)	Lipids (%)	Starch (%)	IDF ^d (%)	SDF ^e (%)
Seeds						
Pea	24.7a	3.44b	0.96b	45.6a	11.3a	8.7a
Lentil	25.6a	3.06c	0.81c	47.2a	11.4a	6.9a
Chickpea	22.5b	3.76a	6.07a	42.8a	10.0b	8.4a
Flour						
Pea	27.6a	3.39b	1.11b	48.2a	5.3a	8.7a
Lentil	26.8a	3.10c	0.90c	52.1a	4.1a	7.4a
Chickpea	23.6b	3.59a	6.42a	43.8a	6.5a	9.1a

^a Results expressed on a dry weight basis.

^b Mean values for seeds or flours with different letters in the same column are significantly different ($P < 0.05$).

^c N × 6.25.

^d Insoluble dietary fiber.

^e Soluble dietary fiber.

TABLE II
Yield and Composition of Tailings Starch and Water Solubles Fractionated from Legume Flours^{a,b}

Fraction	Legume	Yield (%)	Starch (%)	Protein ^c (%)	Ash (%)	Fiber (%)
Tailings Starch	Pea	26.6a	72.6ab	4.8a	1.07a	21.5b
	Lentil	28.0a	69.9b	4.4a	0.75c	24.9a
	Chickpea	24.9a	73.9a	5.0a	0.82b	20.2b
Water Solubles	Pea	40.7b	nd ^d	70.6a	6.56a	19.0b
	Lentil	39.9b	nd	71.7a	6.16c	17.4b
	Chickpea	43.5a	nd	65.3b	6.27b	21.8a

^a Results expressed on a dry weight basis.

^b Mean values for tailings starch or water solubles in the same column with different letters are significantly different ($P < 0.05$).

^c N × 6.25.

^d Not determined.

left for 12 hr at 24°C in 50 mL of water. Results were expressed as volume of swollen sample per gram of dry sample.

The water holding capacity of hulls and purified insoluble fibers was determined using the method of McConnell et al (1974). Fibers were dried for 12 hr at 95°C in an air oven and cooled in a dessicator. The fibers were weighed (1 g) into 50-mL centrifuge tubes and mixed with water in a ratio of 1:30. The tubes were covered and held for 6 hr to allow sufficient hydration of the fibers. After hydration, the tubes were centrifuged at $14,000 \times g$ for 1 hr. After centrifugation, the supernatant was removed and weighed. Water holding capacity was expressed as milliliters of water per gram of fiber by calculating the difference between the original volume of water and the volume of supernatant after centrifugation.

Oil binding capacity of fibers was determined following the method described by Auffret et al (1994). Fibers were mixed with corn oil (24 g of oil/4 g of fiber) in 50-mL centrifuge tubes and stirred for 30 sec every 5 min for 30 min using a vortex mixer. The mixtures were centrifuged for 25 min at $1,600 \times g$ and the free oil following centrifugation was decanted and weighed. Oil binding capacity was expressed as grams of oil retained per gram of fiber.

The viscosity of 3% (w/v) soluble fiber solutions was measured with an AR-1000N rheometer (TA Instruments). Measurements were made at 24°C with shear rates ranging from 1 to 100/sec.

Statistical Analysis

Data from all experiments was analyzed with SAS v. 8 using analysis of variance and Fisher's least significant difference (LSD) procedure. Statistically significant differences were determined at $P < 0.05$. All measurements were made with a minimum of duplicate replications.

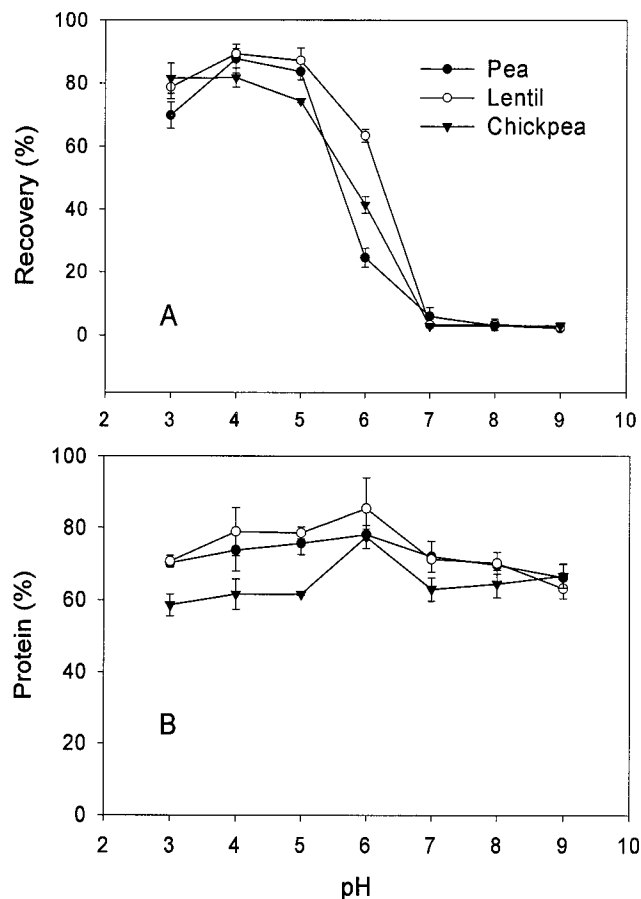


Fig. 1. Recovery (A) and purity (B) of protein following adjustment of the water solubles from pH 3 to 9 using 1N HCl or 1N NaOH. Recovery and purity were calculated based on the protein content of each legume flour.

Chemical Composition of Legumes

The chemical compositions of legume seeds and flours are presented in Table I. Protein contents of seeds and flours ranged from 22.5 to 25.6% and 23.6 to 27.6%, respectively. Chickpeas exhibited significantly lower protein contents in both seeds and flours than peas and lentils. These values correspond to those reported by Otto et al (1997) for peas and chickpeas. The ash content ranged from 3.06 to 3.76% for seeds and from 3.10 to 3.59% for flours. Free lipids content of chickpea seeds and flour was significantly higher than that of peas and lentils. Free lipids content of chickpea was 6.07% for seeds and 6.42% for flour. Free lipids of pea and lentil seeds and flours ranged from 0.81 to 1.11%. Total starch contents of legumes were similar for both whole seeds and flours with the highest starch content in lentils.

The insoluble fiber content of chickpea seeds was lower than that of peas and lentils, while insoluble fiber content of roller milled flours was similar among legumes. No significant differences were determined for soluble fiber content among seeds or flours. Total dietary fiber content ranged from 18.3 to 20.0% for seeds and from 11.5 to 15.6% for flours. Decreases in total and insoluble dietary fiber contents and increases in soluble dietary fiber contents were observed for all legumes because of hull removal during milling. Hulls comprised a significant portion of insoluble fiber in legumes.

Flour Fractionation

The highest yields following fractionation were seen for water solubles ranging from 39.9 to 43.5%. Prime starches made up 31.6 to 32.7%, while the yield of tailings starches ranged from 24.9 to 28.0% of the total flour weight (Table II). Pea and lentil flours displayed significantly higher tailings starch contents than chickpea flour; however, chickpea flour exhibited a significantly higher content of water solubles.

As described by Otto et al (1994), prime starch fractions from legume flour contain $\approx 99\%$ pure starch. Soluble and insoluble fibers are thus concentrated in the tailings starch and water soluble fractions. The compositions of tailings starch and water solubles from pea, chickpea and lentil flour are shown in Table II. Starch made up the major portion (69.9 to 73.9%) of the tailings starch fraction, with the highest starch content in chickpea tailings. Protein was the major component of the water-soluble fraction in all legume flours, ranging from 65.3 to 71.7%, while protein constituted only 4.4 to 5.0% of tailings starches. Ash contents were significantly higher in water soluble fractions than in tailings starches, ranging from 6.16 to 6.56%. Fiber contents of tailings starches ranged from 20.2 to 24.9%, with lentil tailings containing significantly more fiber than those of pea and chickpea. The fiber contents of water-soluble fractions ranged from 17.4 to 21.8%, with chickpeas containing the highest level.

Fiber Isolation

Insoluble fiber was separated from tailings starches by sieving through sieves with openings ranging from 53 to 90 μm . For all three legumes, the highest recovery of insoluble fiber was obtained using the sieve with openings of 53 μm (Table III). Starch and protein contents in recovered insoluble fibers remained similar upon increasing or decreasing the size of sieve openings, and fiber contents were similar as a result. This indicates that the yield of insoluble fiber was mainly a function of its size in relation to the size of sieve openings, since increases in yield were observed by decreasing sieve opening size. The primary inhibitor to the purity of insoluble fiber was starch, which was believed to be entrapped in the fiber matrix as shown previously in common bean dietary fiber (Hughes and Swanson 1989). Legume starches are noted for an irregular granular structure and adherence to protein (Colonna et al 1980; Stute 1990). Other authors have also noticed the adherence of such granules to one another, thus forming clusters that make separation difficult (Kooistra 1962; Gujska et al 1994). Insoluble fibers

separated using the sieve with 53- μm openings were purified by reducing residual starch levels with α -amylase.

Table III shows the yield and composition of insoluble fiber concentrates before and after treatment with α -amylase. Starch contents were reduced by 22% in pea, 26% in lentil and by 22% in chickpea insoluble fibers, making up <5.1% of the insoluble fibers. Reduction in starch content resulted in increases of insoluble fiber purity from 61.4 to 68.4% before enzymatic digestion to 83.7 to 87.3% after treatment.

Figure 1 illustrates the recovery and purity of precipitated protein from pH 3 to 9. Legume proteins consist of both albumins that precipitate at pH 6 and globulins that precipitate around pH 4 (Swanson 1990). As a result, it is not possible to determine a single isoelectric point for legume protein. The maximum recovery of soluble protein was achieved at pH 4. The highest purities of precipitated protein were obtained at pH 6; however, the recovery of protein was much lower than at pH 4. By increasing the recovery and purity of protein from water solubles, the fiber concentration in the supernatant also increased. The inability to completely separate protein during precipitation was probably due to interactions of protein with soluble fiber or differences in isoelectric points of the different types of legume proteins.

Table IV displays the compositions of hulls and soluble cotyledon fibers. Fiber contents of legume hulls after milling ranged from 74.9 to 88.9%. The lower fiber content of chickpea hulls was likely due to surface irregularities of chickpea seeds making separation of the hull from the cotyledon difficult during milling. Soluble fiber concentrates exhibited fiber contents of 64.5 to 70.6%.

The yield and purity of legume cotyledon fibers isolated by our methods are higher than those reported by other researchers working with legume cotyledon fibers. The purity of pea cotyledon fibers, ranging from 35 to 63%, has been reported by Anderson and Berry (2000), Leterme et al (1996, 1998), Sandstrom et al (1994), Hansen et al (1992), and Bertelsen et al (1991). Pfoertner and Fischer (2001) reported production of insoluble lupine and soybean cotyledon fibers containing 75 to 80% dietary fiber.

Separation of fiber from tailings starch and water-solubles also resulted in the production of starch and a soluble protein concentrate. The purity of starches isolated from tailings starch ranged from 97.2 to 97.7%. Yield of starches during fiber isolation ranged from 33.2 to 42.9%, thus increasing the total yield of starch from legume flour to 75.6% for pea, 65.3% for lentil, and 72.3% for chickpea. The purity of protein concentrates isolated from water

solubles ranged from 66.5 to 79.8%, with recoveries ranging from 74.6 to 83.3%. Chickpeas had the lowest yield and purity of protein, which may explain the lower yield of soluble fiber from chickpea flour.

Sugar Composition

Table V presents the sugar composition of soluble fibers, insoluble fibers and hulls as determined by HPLC. The highest concentrations of glucose were observed in the hulls, likely due to the high concentrations of cellulose. Arabinose and rhamnose consistently co-eluted and constituted between 45.7% and 51.4% of insoluble fiber sugars. Slavin and Martlett (1983) reported co-elution of rhamnose with galactose on a lead-form cation exchange column. Theander (1986) reported a 22:1 ratio of arabinose to rhamnose in pea fiber, indicating that arabinose makes up a major portion of the co-eluted sugars. Pfoertner and Fischer (2001) described fibers of lupine cotyledons as consisting mainly of nonstructural polysaccharides, with a rhamnogalacturonan backbone with galactose and arabinose containing side chains. This may also help explain the association of arabinose and rhamnose in chickpea hulls and insoluble cotyledon fibers. Arabinose and xylose together often represent hemicellulosic constituents known as arabinoxylans. Xylose composed significant portions of hulls and insoluble fibers, with the exception of chickpea hulls, which contained high concentrations of arabinose-rhamnose. Galactose and cellobiose were found primarily in soluble fibers, and mannose was not detected in any of the fibers, as supported by the findings of Neilson and Martlett (1983). Higher uronic acid contents were observed in hulls and insoluble fibers than soluble fibers. Chickpeas exhibited lower uronic acid contents in hull, insoluble and soluble fibers than peas and lentils.

Physical Properties

The physical properties of legume fibers are shown in Table VI by fiber type. Bulk density measurements yielded higher values than direct density as a result of packing for the measurement of bulk density. Hulls and soluble fibers exhibited much higher densities than did insoluble fibers. Lentils exhibited the highest density in hulls and insoluble fibers, while chickpea soluble fiber was the densest of the soluble fibers. The high concentrations of protein in soluble fibers and the dense nature of hull material may have accounted for these differences. Hardness-brittleness of the isolated fibers may also affect their observed densities by influencing particle size dis-

TABLE III
Yield and Composition of Insoluble Fiber Concentrates Isolated from Tailings Starches by Sifting Through Sieves with Various Openings^{a,b}

Legume	Sieve Opening (μm)	Yield ^c (%)	Starch (%)	Protein ^d (%)	Fiber (%)
Pea	90	50.5c	26.5a	6.1b	67.5b
	75	51.2bc	26.6a	5.8bc	67.5b
	63	57.0ab	26.8a	5.6c	67.7b
	53	60.7a	26.0a	5.6c	68.4b
	53 + Amylase ^e	59.2a	4.3b	8.43a	87.3a
Lentil	90	39.7b	28.9a	8.0bc	63.0b
	75	39.0b	30.4a	8.4b	61.1b
	63	47.3ab	28.6a	7.6cd	63.8b
	53	55.9a	31.2a	7.4c	61.4b
	53 + Amylase	49.7a	5.1b	9.4a	85.5a
Chickpea	90	32.3c	18.7b	8.4b	72.9b
	75	41.3b	19.3b	7.9c	72.8b
	63	54.8a	25.5a	7.2d	67.3c
	53	58.9a	24.5a	7.1d	68.3c
	53 + Amylase	58.4a	2.9c	10.1a	83.7a

^a Results expressed on a dry weight basis.

^b Mean values in the same column with different letters within each legume are significantly different ($P < 0.05$).

^c Yield calculated based on insoluble dietary fiber content of legume flours.

^d $N \times 6.25$.

^e Insoluble cotyledon fiber was separated using sieve with 53 μm openings and treated with α -amylase.

tribution of ground fiber. The ability of fibers to swell and to bind water is highly indicative of their physiological role in gut function and control of blood glucose levels (Wolever 1990). Swelling power and water-holding capacities of insoluble fibers were much higher than those of hulls ranging from 4.3 to 5.6% and 10.1 to 13.4%, respectively. Swelling and water-holding capacities of both pea hulls and insoluble fibers were higher than those reported by Pfoertner and Fischer (2001). Of the hulls, chickpea exhibited the highest swelling power and water retention. Lentils yielded the highest swelling power of insoluble fibers at 8.04 mL/g. Water holding capacity of insoluble fiber ranged from 10.1 mL/g in chickpea to 13.4 mL/g in pea.

Legume fibers have been utilized as fat binders and replacers in beef products because of their high oil and water binding capacities (Anderson and Berry 2000, 2001, Sandstrom et al 1994, Bertelsen et al 1991). Oil binding capacities of insoluble fibers were much higher than those of hulls and soluble fibers and ranged from 4.01 to 6.93%. Oil binding capacities of soluble fibers and hulls were significantly lower, ranging from 0.89 to 1.76%.

The viscosity of soluble fiber solutions was quite low, ranging from 3.13-3.43 Pa*s and exhibiting Newtonian characteristics. It is believed that increasing the viscosity of the digesta results in a decrease in the rate of nutrient release. This may be due to physical trapping of sugars, lipids and proteins within solid particles or hydrated networks, or simply slowing the rate of transport to the epithelium (Morris 2001). The low viscosity of soluble legume fibers isolated in this study may elicit their use in non-viscous products such as juices or other functional beverages.

CONCLUSIONS

Practical isolation of insoluble and soluble cotyledon fibers from legume flour was achieved with high yield and purity compared to results presented by previous researchers. Isolation methods also resulted in an increase in the overall yield of starch and the production of a soluble protein concentrate from legume flours. Neutral sugar compositions of the fibers indicated that glucose is a common sugar moiety of hulls and cotyledon fibers. High concentrations of

TABLE IV
Composition of Hulls and Soluble Cotyledon Fibers^{a,b}

Fiber	Legume	Starch (%)	Protein (%) ^c	Ash (%)	Fiber (%)
Hull	Pea	2.6b	5.2c	3.27b	88.9a
	Lentil	1.3b	9.7b	2.26c	86.7b
	Chickpea	7.4a	12.1a	5.67a	74.9c
Soluble	Pea	nd ^d	23.6a	11.67b	64.7b
	Lentil	nd	24.0a	11.59b	64.5b
	Chickpea	nd	16.1b	13.28a	70.6a

^a Results expressed on a dry weight basis.

^b Mean values in the same column with different letters are significantly different ($p < 0.05$).

^c $N \times 6.25$.

^d Not determined.

TABLE V
Sugar Composition (% total sugars) of Legume Hulls and Cotyledon Fibers^a

Fiber	Legume	Arab/Rham ^b	Cellobiose	Galactose	Glucose	Xylose	Uronic Acids
Hull	Pea	nd ^c	1.56	nd	70.7	26.0	1.8
	Lentil	nd	nd	nd	72.3	25.2	2.5
	Chickpea	25.3	nd	nd	73.4	nd	0.9
Insoluble	Pea	46.3	nd	nd	31.3	20.8	1.7
	Lentil	45.7	nd	nd	31.7	19.8	2.8
	Chickpea	51.4	nd	nd	27.4	20.9	0.2
Soluble	Pea	nd	10.2	19.2	69.4	nd	1.3
	Lentil	nd	12.4	21.1	65.5	nd	1.0
	Chickpea	nd	10.4	16.4	41.1	32.0	0.2

^a Results expressed as % of total neutral sugars.

^b Arabinose/rhamnose.

^c Not detected.

TABLE VI
Physical Properties of Legume Hulls and Cotyledon Fibers^{a,b}

Fiber	Legume	Direct Density (g/mL)	Bulk Density (g/mL)	Swelling Capacity (mL/g)	Water Holding (mL/g)	Oil Binding (mL/g)	Viscosity (Pa*sec)
Hull	Pea	0.58b	0.75b	1.88b	5.5a	1.51a	nd
	Lentil	0.69a	0.81a	2.38b	3.6b	1.63a	nd
	Chickpea	0.36c	0.73b	3.61a	6.2a	1.76a	nd
Insoluble	Pea	0.12c	0.21b	5.56b	13.4a	6.93a	nd
	Lentil	0.21a	0.36a	8.04a	11.1ab	4.01b	nd
	Chickpea	0.17b	0.34a	4.28b	10.1b	4.25b	nd
Soluble	Pea	0.65a	0.80b	nd ^c	nd	1.15a	3.13a
	Lentil	0.57b	0.80b	nd	nd	0.89a	3.18a
	Chickpea	0.47c	0.83a	nd	nd	1.14a	3.43a

^a Results expressed on a dry weight basis.

^b Mean values among fiber types in the same column with different letters are significantly different ($P < 0.05$).

^c Not determined.

galactose were noted in soluble fiber fractions as pectin constituents, while insoluble fibers contained large amounts of hemicellulosic sugars arabinose and xylose. Insoluble fibers exhibited high swelling capacity and oil and water binding capacities, which may elicit their use in a variety of products, including meat and cereal-based products. Methods to further purify soluble legume fibers may result in additives to health promoting foods and beverages in addition to increasing the understanding of their true functionality.

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