Fortification of Bread with Hulls and Cotyledon Fibers Isolated from Peas, Lentils, and Chickpeas

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ABSTRACT

Bread was prepared from wheat flour and wheat flour fortified with either 3, 5, and 7% legume hulls or insoluble cotyledon fibers, or with 1, 3, and 5% soluble cotyledon fibers isolated from pea, lentil, and chickpea flours. Incorporation of hulls or insoluble fibers resulted in increases in dough water absorption by 2–16% and increases in mixing time of dough by 22–147 sec. Addition of soluble fiber resulted in decreases in water absorption as the substitution rate increased and similar mixing times to the control dough. Loaf weights of breads containing hulls or insoluble fibers were generally higher than that of control bread at 149.4–166.5 g. However, the loaf volume of breads fortified with legume hulls and fibers (685–1,010 mL) was lower than that of the control bread (1,021 mL). Breads containing soluble fibers were more attractive in terms of crumb uniformity and color than breads containing either hulls or insoluble fibers. Breads fortified with legume hulls and fibers were higher in moisture content than control bread regardless of the type, source, or fortification rate. Bread fortified with up to 7% hulls or insoluble cotyledon fibers or up to 3% soluble cotyledon fibers, with the exception of 7% insoluble pea fiber, exhibited similar firmness after seven days of storage compared with the control bread, despite their smaller loaf volume. Breads containing hull fibers exhibited the lowest starch transition enthalpies as determined by DSC after seven days of storage, while the starch transition enthalpies of breads containing added soluble or insoluble fiber were not significantly different from the control bread.

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Recent trends in the American diet have shown increases in the utilization of animal-based foods, resulting in a decrease in the consumption of fiber-rich plant-based foods. The current recommendation for the daily intake of fiber is 25 g, however, the average intake of fiber in the United States is only 10–15 g (Gelroth and Ranhotra 2001). Lack of sufficient fiber in the diet has been reported by many researchers as a probable cause of chronic diseases in the Western world (Selvendran 1984; Eastwood 1987; Schneeman 1989; Walker 1993; Asp 1994; McDougall et al 1996). Fiber is commonly added to foods to increase the fiber content for health promotion and to improve functional properties such as water and oil retention, viscosity, texture, and mouthfeel. Foods containing added fiber include bakery products, breakfast cereals, pasta and noodles, beverages, meat products, and dairy products (Gelroth and Ranhotra 2001).

The practice of manufacturing high-fiber bread products requires very close attention to formulation and processing. Addition of too much fiber produces bread of poor quality in terms of texture, loaf volume, and appearance (Dubois 1978). High levels of fiber dilute gluten, thus lowering gas retention causing a decrease in loaf volume. High levels of fibers also result in modification of mixing times and water absorption of doughs (Pomeranz 1977).

The replacement of portions of wheat flour with legume fiber in breadmaking has typically utilized ground legume hulls (Dubois 1978; Shogren et al 1981; Sosulski and Wu 1988; Sievert et al 1990;). Results indicate that bread fortified with pea hulls decreases loaf volume, increases water absorption, and decreases the overall bread quality sequentially with increases in substitution level (Sosulski and Wu 1988). Further research in conjunction with the production of legume cotyledon fibers should provide more information regarding the functionality of legume fiber in breadmaking. The higher water-holding capacity and better sensory properties of cotyledon fibers compared with hulls should yield bread products of higher acceptability. The objective of this research was to evaluate the effects of fortifying wheat flour with legume cotyledon fibers on mixing and baking characteristics of dough and bread staling during storage.

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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 pilot-scale roller mill (Miag Multomat, Buhler, Uzwil, Switzerland). The bran fraction separated from milling was ground as legume hulls using a cyclone mill (Udy Co., Fort Collins, CO) fitted to a 0.25-mm screen. A hard white spring wheat flour (cv. Macon) of 16.5% protein (db) was provided by the Western Wheat Quality Laboratory (Pullman, WA).

Isolation of Cotyledon Fibers

The soluble and insoluble cotyledon fibers of legumes were isolated according to the procedure of Dalgetty and Baik (2003). Legume flours (200 g) were fractionated into prime starch, tailings starch, and solubles. Tailings starches (≈26 g) were wet-screened in 2 L of water through sieves with openings of 53 μm. Insoluble fiber concentrates on top of the sieve were further purified by digesting residual starch with heat-stable α-amylase (100 μL/50 mL) at pH 6 for 30 min in a 100°C water bath with occasional shaking. The resultant mixture was centrifuged (10 min at 1,500 × *g*) and the pellet was lyophilized as insoluble fiber.

To isolate soluble fiber from the water-soluble fraction, protein in the water-soluble fraction was precipitated at pH 4 using 1*N* HCl. Following precipitation of protein, the water-soluble fraction was centrifuged for 10 min at 1,500 × *g*. The supernatant was recovered and lyophilized as soluble fiber concentrate. The fiber content of insoluble and soluble fiber concentrates was estimated by difference following determination of starch, ash, and protein.

Following isolation, all fibers were milled using a Udy cyclone mill fitted with a perforated screen with openings of 0.25 mm. Protein contents (N × 6.25) were determined according to Approved Method 46-30 (AACC International 2000) using a Leco FP-428 nitrogen analyzer 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 (AACC International 2000), respectively.

Mixing and Baking Characteristics of Flour Fortified with Legume Fibers

Optimum mixing time and water absorption of wheat flour and wheat flour substituted with varying levels of legume fibers were determined using a 10-g mixograph (National Mfg., Lincoln, NE) according to Approved Method 54-40A (AACC International 2000). Hulls and insoluble cotyledon fibers were added to flour at 3, 5, and 7% levels of substitution on a 14% moisture basis. Soluble cotyledon fibers were added at 1, 3, and 5% levels of replacement on a 14% moisture basis.

Bread was baked from wheat flour and wheat flour substituted with 3, 5, and 7% hulls or insoluble fibers and 1, 3, and 5% soluble fibers according to the modified optimized straight-dough breadbaking method of Approved Method 10-10B (AACC Inter-

TABLE I
Proximate Composition of Isolated Legume Fibers[a,b]

Fiber	Starch (%)	Protein (%)[c]	Ash (%)	Fiber (%)
Hull				
Pea	2.6b	5.2c	3.3b	88.9a
Lentil	1.3b	9.7b	2.3c	86.7b
Chickpea	7.4a	12.1a	5.7a	74.8c
Insoluble fiber				
Pea	4.3b	8.4b	4.4a	82.9ab
Lentil	5.1a	9.4a	4.0b	81.5b
Chickpea	2.9c	10.1a	3.3c	83.7a
Soluble fiber				
Pea	nd[d]	23.6a	11.7b	64.7b
Lentil	nd	24.0a	11.6b	64.4b
Chickpea	nd	16.1b	13.3a	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 × 6.25.
[d] Not determined.

TABLE II
Mixograph Absorption and Mixing Time of Wheat Flour and Wheat Flour Substituted with Varying Proportions of Hulls, Insoluble or Soluble Cotyledon Fibers from Pea, Lentil and Chickpea Flours[a]

	Water Absorption (%)			Mixing Time (sec)		
Sample	Pea	Lentil	Chickpea	Pea	Lentil	Chickpea
Wheat flour + fibers						
Hull fiber						
3%	66h	70e	72d	255h–k	263g–j	270e–i
5%	66h	74c	72d	298d	362a	380a
7%	68fg	80a	74c	285d–f	267f–i	280e–g
Insoluble fiber						
3%	69ef	69ef	70e	260g–k	262g–k	274e–h
5%	75c	74c	78b	310b–d	323b	274e–h
7%	78b	80a	80a	320bc	328b	300cd
Soluble fiber						
1%	68fg	67gh	67gh	222no	244j–m	253h–k
3%	62j	62j	66h	231l–o	218o	241k–n
5%	62j	61j	64i	250i–l	240k–n	283d–g

[a] Mean values within water absorption or mixing time followed by the same letter are not significantly different ($P < 0.05$). Control (wheat flour) values: water absorption (%) 64i and mixing time (sec) 2,33l–o.

TABLE III
Loaf Weight and Volume of Bread Baked from Wheat Flour and Wheat Flour Substituted with Varying Proportions of Hulls, Insoluble or Soluble Cotyledon Fibers from Pea, Lentil, and Chickpea Flours[a]

	Loaf Weight (g)			Loaf Volume (mL)		
Sample	Pea	Lentil	Chickpea	Pea	Lentil	Chickpea
Wheat flour + fibers						
Hull fiber						
3%	149h–k	153d–g	152e–h	950cd	948cd	978bc
5%	149h–k	155d	154de	905e–g	903e–h	918d–f
7%	150g–j	158c	159c	888f–h	895e–h	788jk
Insoluble fiber						
3%	154d–f	152e–h	154de	875gh	898e–h	888f–h
5%	160c	160c	160c	818ij	750kl	868h
7%	165ab	167a	163b	690m	685m	745l
Soluble fiber						
1%	151f–i	150h–k	149i–l	980bc	1,010ab	1,003ab
3%	148j–l	147l	146l	913d–g	930de	923d–f
5%	150h–j	147kl	149j–l	790ij	828i	803ij

[a] Mean values within loaf weight or loaf volume followed by the same letter are not significantly different ($P < 0.05$). Control (wheat flour) values: loaf weight (g) 148j–l and loaf volume (mL) 1,021a.

national 2000). The formula for bread dough included 6 g of sugar, 4 g of nonfat dry milk, 1.5 g of salt, 3 g of shortening, 1.8 g of yeast, and 5 mL of malt solution. The malt solution was prepared by extraction of malt (60 g) with distilled water (1 L). Bread dough was fermented for 90 min and proofed for 30 min at 30°C, and then baked for 21 min at 218°C. Bread was weighed and loaf volume was determined by rapeseed displacement immediately after baking. After cooling at 22°C for 3 hr, bread was initially stored in a paper bag for one day at 22°C and subsequently in a plastic bag for the next six days at 4°C.

Physical Characteristics of Bread

Moisture content and firmness of bread crumb was determined at one day of storage at 22°C and after six subsequent days of storage at 4°C. Moisture contents of bread crumb were measured by oven drying at 105°C for 12 hr. Crumb firmness was determined by compression with a texture analyzer (TA-XT2, Stable Micro Systems, Haslemeres, England) equipped with a 25-kg load cell. Two slices of bread (≈2 cm thick) were cut from the center of a loaf. Each slice was placed on the flat metal surface of the texture analyzer and compressed to 25% of its thickness at a rate of 1.0 mm/sec using the flat side of a 2.5-cm cylindrical plastic probe.

Differential Scanning Calorimetry of Bread Crumb

Bread fortified with 5% hull or insoluble and 3% soluble fibers was stored for one day at 22°C and for the next six days at 4°C and then subjected to thermal analysis using differential scanning calorimetry (Pyris1, Perkin-Elmer Corp., Norwalk, CT). Portions of each crumb were removed, lyophilized, and ground in a cyclone mill (Udy, Fort Collins, CO) to pass a 0.25-mm screen for differential scanning calorimetry (DSC). Lyophilized bread crumb (10 mg) was mixed with 20 µL of distilled water in a stainless steel capsule. The capsule was sealed and left for 24 hr at 24°C to allow the mixture to equilibrate. The capsule was then heated from 20 to 180°C at 10°C/min. A capsule containing aluminum oxide and water (1:2) served as the reference. Onset and peak temperature were determined using data analysis software (Pyris manager, v.3.72). The transition enthalpy of retrograded starch in bread crumb was determined from the peak area and expressed as J/g of dry matter.

Statistical Analysis

Statistical analyses were performed (v.8, SAS Institute, Cary, NC) by analysis of variance and Fisher's least significant difference (LSD). Statistically significant differences were determined at $P < 0.05$. All measurements were performed in duplicate.

RESULTS AND DISCUSSION

Hull and Fiber Composition

Table I displays the proximate composition of hulls and cotyledon fibers used to fortify wheat flour for bread production. The fiber content of hulls ranged from 74.9 to 88.9%, with chickpea hulls containing the lowest amount of fiber due to difficulty in separating the hull from the cotyledon during milling. The purity of insoluble cotyledon fibers ranged from 81.5 to 83.7%. Various levels of starch, ash, and protein comprised the other 16.3–18.5% of the insoluble fiber isolates. The purity of soluble cotyledon fibers ranged from 64.5 to 70.6%. Protein represented the major contaminant in these fibers ranging from 16.1 to 24.0%, while ash comprised 11.6–13.3% of the soluble fiber concentrates.

Mixing Characteristics of Dough

Table II illustrates the mixing characteristics of wheat flour (control) dough and dough prepared from wheat flour fortified with varying levels of legume hulls and soluble and insoluble cotyledon fibers. Dough containing hulls or insoluble cotyledon fiber exhibited increases in water absorption as a function of increased rate of substitution. Substituting flour with 3% hull or insoluble fiber increased the water absorption by 2–8%, while increasing the fiber substitution to 7% resulted in increases in water absorption of up to 16%. Mixing times of doughs containing hulls and insoluble cotyledon fibers also increased as a function of increased water absorption. Addition of hulls increased the dough mixing time by 22–147 sec, while addition of insoluble cotyledon fibers increased mixing times by 27–95 sec. The longest mixing times were seen at the 5% level of replacement for hulls. The shorter mixing time of dough fortified with 7% hulls compared with dough with 5% hulls was probably due to the decreased mixing tolerance of dough from increased substitution of hulls. Mixing times increased as a function of increased fiber for doughs containing insoluble cotyledon fibers. Similar increases in mixing time and water absorption were observed in dough fortified with pea hulls by Shogren et al (1981) and Sosulski and Wu (1988).

Water absorption of doughs increased with the incorporation of pea, lentil, and chickpea soluble fibers at 1% substitution. Increasing the soluble fiber substitution to 3 and 5% lowered the water absorption of doughs. Water absorption of doughs fortified with 3 or 5% pea or lentil soluble fibers were lower than that of the control dough, while dough fortified with soluble chickpea fiber exhibited similar or higher water absorption than the control dough.

Mixing times of doughs containing soluble fibers had a range of 222–283 sec, while dough fortified with hull or insoluble fibers exhibited mixing times of 255–380 sec. Incorporation of legume soluble fibers displayed inconsistent changes in mixograph mixing time of doughs. Despite decreases in water absorption of dough fortified with 5% pea or lentil soluble fibers, they still required longer mixing times than the control dough.

The stability and resistance of doughs fortified with 5% legume hulls or insoluble fibers or 3% soluble fibers were evaluated by observing mixograph patterns (Fig. 1). Doughs fortified with soluble fibers exhibited less resistance to mixing and lower stability than the control dough and doughs fortified with hulls or insoluble fibers. Doughs fortified with insoluble fibers exhibited similar resistance to mixing and stability to the control dough. Dough fortified with lentil hull fiber exhibited less resistance to mixing and lower stability than the control dough and doughs fortified with pea or chickpea hulls.

Baking Properties

The properties of breads immediately after baking are displayed in Table III. Loaf weights of breads containing added hulls or fibers appeared to correspond to the water absorption of dough. Breads containing insoluble cotyledon fibers exhibited the highest loaf weights, increasing as the level of substitution increased. Adding 7% insoluble fiber increased loaf weight by up to 18.9 g. Similar trends were seen for breads containing added hull fibers, however, increases in loaf weight of only 2.6–11.5 g were seen at 7% substitution. Breads containing soluble fibers exhibited the lowest loaf weights relative to the control, with a maximum increase in loaf weight of 3.4 g for bread containing 1% soluble pea fiber. Loaf weights of breads containing soluble fibers showed a decreasing trend when increasing the level of substitution 1–3% but increased with 3–5% soluble fibers. Water absorption of doughs fortified with 3–5% pea or lentil soluble fibers was lower by at least 2% than control dough (Table II). However, bread baked from dough containing 3–5% pea or lentil soluble fiber exhibited similar or even higher loaf weight than the control bread, probably due to greater water retention during baking of breads fortified with soluble fibers.

Breads fortified with legume hulls and cotyledon fibers generally exhibited lower loaf volumes than the control bread. Loaf volumes of breads containing 1% soluble fiber were comparable

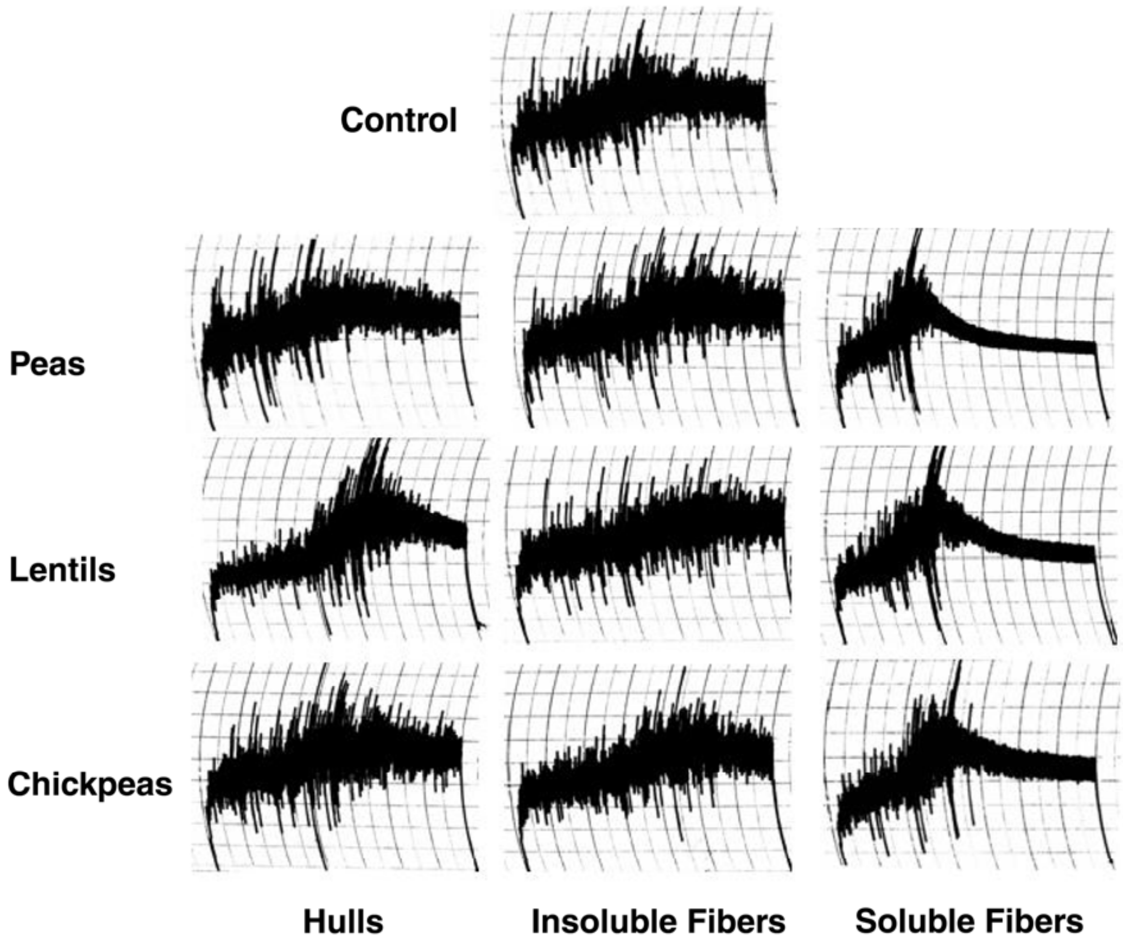

Fig. 1. Mixograms of wheat flour (control) and wheat flour fortified with 5% of legume hulls or insoluble fibers or 3% of soluble fibers.

to the loaf volume of the control bread at 980–1,010 mL. Increasing the substitution rate of fibers resulted in decreases in loaf volume of breads. Loaf volume was lowest in bread when fortified with insoluble fibers when compared at the same levels of substitution. At 5% substitution, loaf volume of breads containing hulls ranged from 903 to 918 mL, from 750 to 868 mL when fortified with insoluble fibers, and from 790 to 828 mL when fortified with soluble fibers. Loaf volume of bread fortified with hulls, insoluble, and soluble fibers exhibited little variation among different legume sources.

Breads containing added soluble fibers exhibited the most desirable appearance in terms of crumb uniformity and appearance. However, the crust of breads containing soluble fibers was much darker than the other breads. Residual protein and short chain carbohydrates in the soluble fiber concentrates probably contributed to the darker crust color through the development of Maillard reaction pigments. Breads containing hulls and insoluble fibers exhibited a less uniform crumb structure when compared with the control bread. Sosulski and Wu (1988) concluded that substituting flour with up to 5% pea hulls produced bread of quality comparable to that of the control. Results from this study, however, exhibited lower bread loaf volume at the 5% level of substitution, possibly a function of wheat flour quality. The addition of lentil hulls produced a darker crumb because of the naturally dark appearance of the lentil hull.

Physical Characteristics of Bread

Table IV summarizes the moisture contents and crumb firmness of bread baked from control wheat flour and flour fortified with legume fibers. Moisture contents of bread fortified with hulls and insoluble cotyledon fibers at one day of storage were 43.9–48.6% and decreased to 38.2–46.4% after seven days of storage. Control bread lost 9.0% moisture, while breads fortified with legume hulls or insoluble fibers lost a maximum of 7.7% moisture during seven days of storage. The addition of hull or insoluble fibers increased the moisture content of bread as a function of increased substitution. Breads containing lentil hull fibers exhibited the highest moisture content following storage (40.1–44.0%).

Breads fortified with soluble cotyledon fibers exhibited lower moisture contents at one day and seven days after baking than breads fortified with hull or insoluble cotyledon fibers. At one day after baking, breads incorporated with soluble fibers contained 42.9–46.0% moisture, while the moisture content of the control bread was 44.5%. After seven days of storage, the control bread contained 35.5% moisture, while breads baked with soluble fibers exhibited moisture contents of 35.9–39.1%. Moisture contents of bread fortified with soluble fibers were similar to or lower than control bread at one day after baking and decreased as the substitution rate increased. After seven days of storage, however, bread fortified with soluble fibers retained more moisture than the control bread regardless of the level of substitution or the source of soluble fiber.

Firmness of bread crumb is a good indicator of the degree of bread staling. At one day after baking, the firmness of bread crumbs had a range of 1.02–2.80N (Table IV). After seven days of storage, firmness of bread crumb had a range of 3.40–8.99N. Breads containing added hulls exhibited firmness similar to that of the control bread. Firmness of bread containing added hulls was 1.02–1.72N one day after baking and from 4.29–5.45N after seven days of storage. Significant differences in firmness from the control were not seen at any level of substitution for any source of hull, despite the lower loaf volumes of bread containing hulls.

TABLE IV
Crumb Moisture Content and Firmness of Bread Baked from Wheat Flour and Wheat Flour Substituted with Varying Proportions of Hulls, Insoluble or Soluble Cotyledon Fibers from Pea, Lentil, and Chickpea Flours Stored for 1 and 7 Days of Storage at 4°C[a]

	Crumb Moisture (%)						Crumb Firmness (N)					
	Day 1			Day 7			Day 1			Day 7		
Sample	Pea	Lentil	Chickpea	Pea	Lentil	Chickpea	Pea	Lentil	Chickpea	Pea	Lentil	Chickpea
Wheat flour + fibers												
Hull fibers												
3%	43.9g	45.9d	46.6c	38.2d	40.1c	39.7cd	1.0d	1.0d	1.1cd	5.4a	4.4c	4.4cd
5%	44.6f	47.2b	46.7bc	38.5cd	42.9ab	42.2b	1.5b	1.0d	1.2cd	5.1ab	4.3c	4.3cd
7%	45.3e	48.6a	47.2b	38.8cd	44.0a	43.2ab	1.1cd	1.2cd	1.7a	5.5a	4.6bc	5.3a
Insoluble fibers												
3%	45.5f	45.8e	46.3d	40.4d	39.9d	40.7d	1.4de	1.9b	1.4de	6.2b	4.7cd	5.2bc
5%	47.1c	47.3c	48.4b	41.8cd	43.9bc	45.5ab	2.3a	1.6cd	1.5c–e	4.5cd	6.2b	4.0d
7%	48.4b	48.9a	48.9a	45.9ab	46.4a	46.3a	2.3a	2.1a	1.7bc	9.0a	5.1b–d	5.3bc
Soluble fibers												
1%	46.0a	45.2b	45.1b	38.5a	39.1a	38.0a	2.8a	2.5b	1.9c	3.8de	3.7de	3.4e
3%	43.6de	43.6e	44.7c	35.9c	36.3bc	37.9ab	1.9fg	1.1g	1.1fg	5.6a–c	4.5b–e	4.5c–e
5%	42.6f	42.9f	43.9d	38.9a	36.3bc	38.0a	1.5d	1.3e–g	1.3d–f	6.2ab	5.9a	4.8a–d

[a] Mean values within each storage time in hull, insoluble or soluble fibers followed by the same letter are not significantly different ($P < 0.05$). Control (Wheat Flour) values: crumb moisture (%) 44.5 at Day 1 and 35.5 for Day 7; and crumb firmness (N) 1.3 at Day 1 and 5.0 at Day 7.

TABLE V
Differential Scanning Calorimetry Characteristics of Breads Baked from Wheat Flour and Wheat Flours Substituted with 5% of Hull and Insoluble Fibers or 3% of Soluble Fibers, and Stored for 7 Days[a,b]

Fiber	T_o (°C)	T_p (°C)	ΔH (J/g)
Control (wheat flour)	41.8cd	50.0b–d	3.05a
Wheat flour + fiber			
Hull fiber			
Pea	41.9bc	49.8cd	2.45d
Lentil	41.4cd	49.4d	2.74bc
Chickpea	40.9d	48.8d	2.68cd
Insoluble Fibers			
Pea	43.2a	51.0ab	3.05a
Lentil	42.9a	51.1ab	3.00ab
Chickpea	42.7ab	50.8a–c	2.98ab
Soluble Fibers			
Pea	42.9a	50.7a–c	3.01a
Lentil	42.9a	50.7a–c	3.21a
Chickpea	43.3a	51.2a	3.15a

[a] T_o, onset temperature; T_p, peak temperature; ΔH, transition enthalpy.
[b] Mean values in the same column with different letters are significantly different ($P < 0.05$).

Firmness of bread containing insoluble fibers was 1.38–2.29N at one day after baking and 3.96–8.99N after seven days of storage. The increase in firmness of breads containing added insoluble fibers was probably due to the lower loaf volumes (Table II) that decrease the surface area of measurement for firmness and compacts the crumb structure. With the exception of bread fortified with 7% insoluble pea fiber, breads containing insoluble fibers, regardless of source or substitution rate, exhibited bread crumb firmness similar to that of the control bread after seven days of storage.

The firmness of bread containing soluble fibers decreased as a function of increased substitution one day after baking. After seven days of storage, however, the firmness of bread containing soluble fibers increased as substitution increased. Fortification with 3 or 5% soluble pea, lentil, or chickpea fibers exhibited bread crumb firmness similar to that of the control at one day after baking. Bread containing 1–5% soluble chickpea fibers, 1% soluble pea fibers, and 1–3% soluble lentil fibers exhibited lower firmness than the control bread after seven days of storage, even though these breads were much smaller than the control bread (Table II). Bread containing soluble chickpea fibers was the softest at all levels after storage. Softer crumb texture of breads fortified with soluble cotyledon fibers, despite their smaller loaf volume, was probably due to higher moisture retention compared with the control bread (Table IV).

Thermal Properties of Bread

Table V displays starch retrogradation characteristics of bread crumb made from flour containing 5% hulls, 5% insoluble fiber, or 3% soluble fiber as determined using DSC. Breads containing hulls exhibited onset temperatures similar to that of the control bread, while the onset temperatures of breads containing insoluble and soluble cotyledon fibers were significantly higher. Peak temperatures of fortified breads were not significantly different from that of control bread.

Transition enthalpy of starch in control bread crumb was not significantly different from that of bread containing soluble or insoluble cotyledon fibers. However, bread containing hulls exhibited significantly lower transition enthalpies than control bread, possibly indicating that there is a lower degree of starch retrogradation upon the addition of legume hulls. Zeleznak and Hoseney (1986) reported that retrogradation of amylopectin is highly dependent on the amount of water present in the bread. Therefore, higher retention of free water in breads containing hulls may have delayed starch retrogradation.

CONCLUSIONS

The addition of legume hulls or insoluble cotyledon fibers to bread flour resulted in increased mixing times and increases in water absorption of doughs. In contrast, the water absorption of dough containing >3% soluble fiber decreased as the amount of soluble fiber replacement increased. Mixing times of dough containing soluble fibers were similar to the control dough. Loaf weights of bread containing hulls and insoluble fibers were higher than the control, likely a result of increases in water absorption during dough mixing. Significant decreases in loaf volumes were observed when bread was fortified with hulls, insoluble, or soluble cotyledon fibers of legumes. Breads containing soluble fibers were the most attractive in terms of crumb color and uniformity. Addition of hulls or cotyledon fibers to bread flour resulted in higher levels of moisture retention than the control bread. Generally, the addition of <5% legume hulls or cotyledon fibers to bread flour did not significantly increase bread firmness. Overall, 5% hulls or insoluble fibers, or 3% soluble fibers can be successfully incorporated into bread flour to increase the total fiber content and improve the moistness of bread without significantly increasing crumb firmness during storage.

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