Physicochemical Properties of Roller-Milled Barley Bran and Flour[1]

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ABSTRACT

Grain hardness, determined by grind time in 16 diverse barleys, showed waxy starch (low amylose) genotypes to be softer (grind time 39–64 sec) than the normal starch genotypes. Bran and flour obtained from the 16 barleys, milled in an Allis-Chalmer experimental mill, showed significant differences in bran and flour color (white) among varieties. Bran and flour milled from Scout, a registered two-rowed Canadian hull-less barley, were compared for physicochemical properties with commercial oat bran and straight-grade wheat flour. Barley bran was whiter than oat bran. It had, like oat bran, high water-holding capacity (WHC) due to its high β-glucan (7.7%) content. Barley bran had 20% total dietary fiber (TDF) and 7% soluble fiber (SF) compared to 14% TDF and 5% SF in oat bran. The ratio of SF to TDF in barley bran, as in oat bran, was 1:3. Barley flour was darker than wheat flour but had higher WHC (2.5-fold), farinograph absorption (75%), and viscoamylograph peak viscosity (660 BU). Barley flour had higher ash (1.8%), ether extract (2.5%), β-glucan (4.5%), TDF (8.7%), SF (2.7%), and insoluble fiber (4.7%) than wheat flour. The ratio of SF to TDF was 1:3 in barley flour and 1:2 in wheat flour. Phosphorus and potassium were the major minerals, and iron and zinc were the major trace minerals of Buhler-milled Scout barley flour. β-Glucan and pentosans were the major components; resistant starch, Klason lignin (only TDF), and pectin were the minor components of TDF and SF of barley bran and flour.

Hull-less (naked) barley has been rediscovered as a food grain (Bhatty 1986a, Newman and Newman 1991). Although barley was eaten in many countries throughout history, its decline in human foods was recent, due mainly to increased intake of baked products, for which wheat is more suitable. A redeeming feature of barley for use in human foods may be the range and concentration (3–11%) of β-glucan, a major component of soluble dietary fiber implicated in hypocholesterolemia (Newman et al 1989).

Hull-less barley has been dry-milled or milled after tempering to obtain composite flour and bran yields of about 70 and 30%, respectively (Bhatty 1986b, 1987, 1992). A small amount of barley flour (5–10%) can be added to wheat flour without affecting loaf volume and bread appearance (Bhatty 1986b), and the level could be increased to 20% by increasing salt concentration in the baking formula (Swanson and Penfield 1988). Barley flour may be suitable for use as a food thickener and wheat-flour additive and for making cookies, noodles, muffins, pancakes, waffles, doughnuts, flour snacks, and extruded cereal products. The use of barley flour in bread and nonbread bakery products needs development research.

Barley bran offers a source of natural fiber in food products. Although cereal brans can be eaten in various forms, reduced-calorie high-fiber yeast-leavened bread and ready-to-eat breakfast cereals are areas of rapidly growing commercial interest. Fiber-enriched breads containing 20% corn or wheat bran and 15% field pea hulls or wild oat bran have been satisfactorily prepared (Sosulski and Wu 1988). Bread formulations containing α-cellulose produce a desirable off-white, light cream color typical of regular pan breads. However, because use of α-cellulose in bread formulations may not be acceptable in some countries, use of natural fibers in bread formulations may provide an alternative. Furthermore, purified cellulose is not hypocholesterolemic, although it does provide bulk to the food. Its digestibility in humans is low (about 14%), and its effect is akin to that of wheat bran (Stephen 1989).

Barley has not been traditionally roller-milled on a commercial scale to obtain bran and flour, as have wheat or oats. In many cases, pearl and pot barley have been milled to produce barley flour, and brewers' spent grain has been milled to produce barley bran. In the pearling process, bran is lost as part of the outer coverings that are mixed with hulls and used as livestock feed. True barley bran and flour have rarely been produced and investigated. The present paper reports the physicochemical properties of roller-milled barley bran and flour. The objective of this research, like that published previously (Bhatty 1986a,b, 1987, 1992), was to provide analytical data on barley bran and flour, and, ultimately, to promote their use in human foods.

MATERIALS AND METHODS

Materials

Six Canadian-registered cultivars of barley, four hulled and two hull-less (Abee, Deuce, Ellice, Harrington, Scout, and Tupper), and nine genotypes of hull-less barley with normal or waxy (low amylose) starch were used in the study. This collection of barley was used in a previous study (Bhatty 1992). All of the barleys, except Scout and Azhul, were grown in 1989 at the experimental plots, University of Saskatchewan, Saskatoon, Canada. Azhul, a nonregistered, high β-glucan barley developed by R. T. Ramage, U.S. Department of Agriculture, University of Arizona, Tuscon, was a gift from C. W. Newman, Montana State University, Bozeman. Scout, a Canadian two-rowed hull-less barley, was purchased in bulk from B. Neudorf, Rosthern, SK, and mechanically cleaned of residual hulls. All other hull-less barleys were cleaned manually. The 16 barley samples, including cultivar Tupper grown at two locations, were used for the determination of grain hardness and, after milling, for bran and flour color. Scout hull-less barley bran (Allis-Chalmer-milled) was used for determining particle-size distribution; bran and flour samples were used for determining physicochemical properties and composition of total dietary fiber (TDF) and soluble fiber (SF) fractions. Wheat flour (straight-grade) and oat bran were commercial samples (grain varieties unknown) obtained locally (CSP Foods and Robin Hood Multifoods Inc., Saskatoon, SK, respectively). For laboratory analyses, oat bran was ground in a Wiley mill to pass 1-0-mm screen.

Methods

The 16 barley samples were dry milled (9–10% seed moisture) in 300-g quantities in an Allis-Chalmer experimental mill using a modified short-flow procedure described previously (Bhatty 1987) with the following exceptions. The final sieve size in the three break and reduction rolls was 70 GG (240 μm). Most of the coarse bran was retained on the 50-GG (375 μm) sieve, the fine bran and shorts on the 70-GG sieve. The break, reduction, and clear flour fractions were combined to obtain flour in about 70% yield; the bran and shorts were combined to obtain bran in 30% yield of the recovered product. The milling yields of the individual fractions were reported previously (Bhatty 1986b). Scout hull-less barley (500 kg) was milled in a Buhler mill at the Canadian International Grains Institute, Winnipeg, to yield

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72, 20 and 8% for flour, bran, and shorts, respectively. Bran and flour samples were stored at 5°C.

Grain hardness was determined with a Brabender micro-hardness tester (C. W. Brabender Inc., South Hackensack, NJ) that automatically recorded time required to mill 4 g of flour. Bran and flour color (white) were measured with HunterLab ColorQuest spectrocolorimeter (Hunter Associates Laboratory, Reston, VA) standardized with a white tile. Particle-size distribution in barley bran was determined by shaking samples for 5 min in a sieve shaker (Ro-Tap, C. E. Tyler Engineering, Inc., Bessemer, NC). Fractions obtained were expressed as percent of the sample weight. AACC methods (AACC 1983) were used to determine water-holding capacity (88-04), falling number (56-81B), damaged starch (76-30A), moisture (44-19), total nitrogen (46-13), ether extract (30-20), and ash (08-01).

Farinograph (C. W. Brabender) absorption was determined on 300 g of flour (14% moisture basis) in a large bowl. Different levels of water were added to reach a consistency of 500 farinograph units at the center. Dough development time (peak time or time of maximum consistency) and arrival time were recorded from the farinogram. Pasting and gelling properties of the flour samples were determined with a Brabender viscoamylograph (700-cm cartridge). Slurry concentration was 10% in a total volume of 500 ml (pH 5.5) and contained 200 mg of mercuric acetate as an α-amylase inhibitor. Temperature rise was 1.5°C/min. Peak viscosity, viscosity at the end of a 30-min holding period, and viscosity after cooling to 50°C were determined from the amylogram. Starch concentration was determined by the method of Holm et al (1986) on samples boiled with 80% ethanol for 30 min and centrifuged at 2,000 $\times$ g for 10 min. β-Glucan content was determined by the method of McCleary and Glennie-Holmes (1985), using an assay kit from Biocon (Lexington, KY). TDF, SF, and insoluble fiber content were determined according to the method of Prosky et al (1988). Gross energy content was determined with a Paar bomb calorimeter. Mineral composition of Buhler-milled flour, bran, and shorts was determined after sequential acid hydrolysis of the materials with nitric and perchloric acids, using an ICP model 3410 spectrophotometer (Soil Testing Laboratory, University of Saskatchewan, *personal communication*).

In some experiments, TDF and SF fractions were freeze-dried for compositional analysis. Arabinoxylans (pentosans) were calculated from the sum of (arabinose + xylose) $\times$ 0.9. The pentose sugars were determined by gas-liquid chromatography after acid hydrolysis of the bran and flour samples, followed by reduction and acetylation (Blakeney et al 1983). The alditol acetates were separated under the following conditions: J & W DB-23 fused silica capillary column, 30-m $\times$ 0.25-μm $\times$ 0.25-μm film thickness (Chromatographic Specialties, Brockville, ON); Hewlett-Packard 5890-A gas chromatograph equipped with a flame ionization detector and a 7673-A automatic injector; carrier gas (helium) flow rate 1 ml/min; injection port and detector temperatures 250°C; oven temperature 220°C (isothermal); 1 μl of sample injected with a split flow ratio of 25:1. Klason lignin was determined gravimetrically on 200 mg of the freeze-dried fractions of TDF and SF as described by Theander and Westerlund (1986). Essentially, this material was insoluble in 72% (12M) sulfuric acid. Uronic acid content (pectin) was determined colorimetrically using galacturonic acid as standard (Ahmed and Labavitch 1977). β-Glucan was determined as described above.

Data reported are means of at least duplicate determinations unless stated otherwise. Standard errors of mean, standard error of difference (t test), and analysis of variance of the data were calculated using a Minitab software program.

RESULTS AND DISCUSSION

Barley Hardness and Color of Milled Products

The milling quality of hull-less barley and the quality of resulting flour is affected by, among other factors, grain hardness. Grain hardness has been measured by many methods including grind time (Norris et al 1989). Grain hardness determines the degree of damaged starch that, in turn, affects water absorption, diastatic power, and gassing power during the fermentation process. Consequently, starch from hard grain flour is more susceptible to diastatic enzymes than starch from soft grain flour (Williams 1967). Such information, obtained from wheat milling, is equally applicable to barley milling. As far as the author is aware, comparative grain hardness of hull-less barley has not been reported in the literature. Data in Table I show that grain hardness in 16 barleys varied in grind time from 20 to 64 sec and was significantly different among most of the samples of barley. Azhul, a hull-less waxy barley, was the softest; SB88490, a hull-less normal starch barley, was the hardest. The grind time of SB88490 (about 20 sec) was closer to those of Canadian durum wheats (24–26 sec), as reported by Kosmolak (1978), who divided wheats according to grind time: 24–45 sec (very hard to hard), 46–63 sec (medium hard), and 64–200 sec (soft). According to this division, the 16 barleys used in this study were a mixture of hard and soft types and showed significant variations in grain hardness. Two Canadian malting barleys, Ellice and Harrington, were soft; this type of endosperm promotes grain modification during the malting process. Among the 12 hull-less samples of barley, those with normal starch (n = 7) were harder (grind time of 20–42

TABLE I
Grain Hardness and Brain and Flour Color (White) of 16 Diverse Cultivars and Genotypes of Hulled and Hull-less Barley[a]

Cultivar/Genotype	Type	Grain Hardness (sec)	Rank	L Values	
				Bran	Flour
Abee	Hulled, feed	41.5 ± 2.1	7	68.9 ± 0.3	84.1 ± 0.2
Deuce	Hulled, feed	39.5 ± 0.7	6	70.9 ± 0.1	84.0 ± 0.1
Ellice	Hulled, malt	51.0 ± 1.4	11	71.9 ± 0.4	83.6 ± 0.1
Harrington	Hulled, malt	60.0 ± 1.4	12	74.9 ± 0.4	85.7 ± 0.1
Scout	Hull-less normal	42.0 ± 0.0	8	81.2 ± 0.2	86.7 ± 0.1
Tupper (location 1)	Hull-less normal	30.0 ± 1.4	3	77.5 ± 0.3	86.6 ± 0.0
Tupper (location 2)	Hull-less normal	41.5 ± 2.1	7	76.2 ± 0.2	86.3 ± 0.1
Azhul	Hull-less, waxy	64.0 ± 1.4	13 (softest)	82.4 ± 0.1	85.1 ± 0.1
SB85738	Hull-less, waxy	44.5 ± 2.1	9	79.8 ± 0.1	85.5 ± 0.3
SB85740	Hull-less, waxy	49.5 ± 2.1	10	79.5 ± 0.1	85.1 ± 0.0
SB85745	Hull-less, waxy	39.5 ± 0.7	6	79.2 ± 0.1	85.5 ± 0.1
SB85751	Hull-less, waxy	38.5 ± 0.7	5	79.3 ± 0.0	84.8 ± 0.0
SB86106	Hull-less normal	38.5 ± 0.7	5	74.9 ± 0.5	85.7 ± 0.1
SB87697	Hull-less normal	28.5 ± 0.7	2	74.8 ± 0.4	84.8 ± 0.0
SB88490	Hull-less normal	19.5 ± 0.7	1 (hardest)	71.1 ± 0.2	78.8 ± 0.2
SR86132	Hull-less normal	35.5 ± 2.1	4	76.2 ± 0.4	85.2 ± 0.0
LSD ($P < 0.05$)[b]		3.1		0.5	0.2

[a] Values are means ± SEM of duplicate analyses. L values (100 white, 0 black) of bran and flour are reported on as is basis.
[b] Least significant differences calculated from analysis of variance of the data.

sec); those with waxy (low-amylose) starch ($n = 5$) were softer (grind time 39–64 sec). The waxy starch barleys are higher in β-glucan than are normal starch barleys (Bhatty 1992). It is not known whether β-glucan has any direct influence on grain hardness in barley. In one cultivar of barley (Tupper), growth location significantly influenced grain hardness. The location 2 Tupper sample had 1.3% higher grain protein. Studies on wheat hardness have shown that protein-starch interaction and continuity of protein matrix in the endosperm strongly affect grain hardness (Anjum and Walker 1991).

Table I also shows L values for barley bran and flour. Barley flour samples significantly varied in color (white) as shown by the L values. SB88490 had the lowest L value and was, therefore, the darkest. The average L value for the flour samples was 85, which was lower than the 91 obtained for hard red Canadian spring wheat (Neepwa) flour milled to 76% yield under identical conditions (Bhatty 1986b). Barley flour color varies not only with different cultivars (as shown in Table I) but also within the same cultivar grown in different seasons and at different growth locations. Flour color in barley can be improved by selecting two-rowed, white aleurone genotypes. There was a larger variability in bran color than in flour color; cultivar differences were significant (Table I). Bran from the two malting barley cultivars (Harrington and Ellice) was darker because of hull fragments in the bran. Bran of SB88490, like the flour, was the darkest.

TABLE II
Particle-Size Distribution in Laboratory-Milled Hull-less Barley (Scout) Bran

Screen Size		Distribution[a]
U.S. Standard	μm	(%)
12	1,700	0.0
16	1,180	0.1 ± 0.1
20	825	0.5 ± 0.3
30	600	0.7 ± 0.1
40	425	5.3 ± 0.5
60	250	41.6 ± 0.4
< 60	< 250	51.8 ± 0.5

[a] Mean + SEM of duplicate determination.

Bran and flour color in barley are influenced by anthocyanin pigments in the pericarp. These pigments are purple, blue, or dark (melanins).

Particle Size

About 93% of barley bran had particle size smaller than 425 μm (Table II). However, commercial cereal bran samples are quite variable in particle size: coarse or medium particle size varies from 425 to 825 μm. Frolich and Nyman (1988) divided oat bran into coarse, fine, and bran flour with particle sizes >1,050 μm, 650–1,050 μm, and 250–650 μm, respectively. Using this classification, barley bran obtained in this study was more like a bran flour; almost all of it had particle sizes smaller than 600 μm. Particle size can be adjusted in commercial milling of grain. The breadmaking industry prefers larger particle-size bran to obtain a coarser loaf texture. Bran particle size has many implications in the baking industry (Posner 1991).

Hull-less Barley Bran and Flour: Composition and Properties

Table III gives data on the physicochemical properties of barley bran and flour and, for comparison, of commercial oat bran and wheat flour. Comparisons of barley bran with oat bran and barley flour with wheat flour are necessary because barley bran and flour can substitute, or partially replace, oat bran and wheat flour in some food applications. Both oat bran and wheat flour were commercial products, and barley bran and flour were laboratory-prepared. Such comparisons are routinely reported in the literature (Ranhotra et al 1991, Berglund et al 1992). It is not practical to mill barley and oats to obtain similar bran and flour yields, even under laboratory conditions. Because of the higher oil content, oats do not mill like barley or wheat. Barley can be milled, with or without tempering, like wheat. The 70% composite barley flour yield obtained in laboratory milling is comparable to commercial wheat flour yields. Most of the data given in Table III are self-explanatory; comparison with literature values where available, particularly for barley bran and flour, was difficult because of variability in the products. In comparing cereal brans, bran must be recognized as a heterogeneous product. Even within the same grain species, no two samples are alike due to several factors contributing to heterogeneity, such as particle size, TDF,

TABLE III
Physicochemical Properties of Hull-less Barley (Scout) and Oat Brans and Hull-less Barley and Wheat Flours[a,b]

	Bran		Flour	
Property/Component	Barley	Oat	Barley	Wheat
Color (white), L	81.2 a	78.4 b	86.7 a	90.5 b
Water-holding capacity, ml/g	3.7 a	3.6 a	2.5 a	1.0 b
Oil absorption, ml/g	3.3 a	0.8 b	1.3 a	1.2 b
Gross energy, Kcal/kg	4,802 a	4,724 b	4,652 a	4,524 b
Falling number, sec	...	...	792 a	547 b
Damaged starch, %	...	...	14.8 a	19.7 b
Farinograph				
Absorption, %[c]	...	...	74.8	65.0
Dough development time, min[c]	...	...	2.0	3.5
Arrival time, min[c]	...	...	1.5	2.0
Visoamylograph				
Peak Viscosity, BU[c]	...	...	660	270
Viscosity at end of hold, BU[c]	...	...	390	210
Viscosity after cooling, BU[c]	...	...	950	510
Protein, %[d]	18.7 a	18.6 a	12.7 a	13.5 b
Ash, %	3.7 a	2.8 b	1.8 a	0.6 b
Ether extract, %	3.8 a	7.7 b	2.5 a	0.8 b
Starch, %	51.0 a	52.3 b	74.0 a	78.1 b
β-Glucan, %[e]	7.7	7.7	4.5 a	0.4 b
Total dietary fiber, %[e]	20.4	13.9	8.7 a	4.4 b
Soluble fiber, %[e]	6.9	4.7	2.7 a	2.2 b
Insoluble fiber, %[e]	11.7	9.2	4.7 a	1.4 b

[a] Mean of duplicate determinations reported on moisture-free basis unless indicated otherwise.
[b] Values with different letters between pairs are statistically significant at least at the 5% level.
[c] Reported on 14% moisture basis; single determinations.
[d] Barley and oat brans N × 6.25; barley and wheat flours N × 5.7.
[e] Taken from Ranhotra et al (1991) for oat bran used in the present study.

and phytic acid, which influence use of wheat bran in foods (Posner 1991). The same three factors probably apply in barley bran.

Barley bran was significantly whiter (higher L value) than oat bran due to differences in grain color and milling conditions. Scout hull-less barley, a source of barley bran, is a yellow aleurone barley milled to 70% extraction. Oats are commercially milled to obtain 50–60% bran yield. Thus, oat bran contains a higher proportion of the whiter inner endosperm. In spite of differences in milling conditions, barley bran was whiter than oat bran. However, color may not be an impediment to use of bran in foods, although pigments may contribute to product flavor. Light brans may be preferred for use in food and may be less astringent. Chaudhary and Weber (1990) reported satisfactory production of bread, including flavor, by adding 15% barley bran flour prepared from brewer's spent grain to the baking formula. Brewer's bran flour is not a true barley bran.

Barley and oat brans had similar water-holding capacity (WHC). WHC is influenced by protein, but it was largely due to the high and identical (7.7%) β-glucan content of barley and oat brans. Barley bran had an oil absorption fourfold higher than that of oat bran. There did not appear to be any relationship between protein content and oil absorption in the brans. The higher oil absorption of barley bran was more likely due to lower indigenous oil (ether extract) content, although there may be other reasons, such as finer particle size. Higher ether extract content of oat bran (7.7%) did not cause a higher gross energy, which varied only about 2% between the two brans and was significantly lower in oat bran. Barley and oat brans had similar protein concentrations (18.6–18.7%). Bran protein is influenced by grain protein and by extraction yield of bran. Barley bran had higher ash content and lower starch content than that of oat bran. The most noticeable differences between the two brans were in dietary fiber fractions. Barley bran had 20.4% TDF and 6.9% SF compared to 13.9% TDF and 4.7% SF in oat bran. Barley bran, like oat bran, had the desirable 1:3 SF-TDF ratio. Thus, barley and oat brans had identical β-glucan concentration, but barley bran had 47% higher TDF and SF, due most likely to its higher arabinoxylan concentration (data for oat pentosans not given in Table V). Several TDF and SF values for cereal brans have been reported in the literature (Chaudhary and Weber 1990; Kahlon et al 1990; Ranhotra et al 1990, 1991; Newman and Newman 1991). All report higher SF in oat bran and insoluble fiber in wheat bran. Barley bran was more hypocholesterolemic than oat bran was, as determined by a rat-feeding experiment (Ranhotra et al 1991).

Barley flour was darker than wheat flour as shown by L values (Table III). None of the 16 barley flours reported in Table I had an L value similar to that of the wheat flour. However, in a previous study (Bhatty 1986b), barley flour milled under conditions identical to those for wheat flour had similar whiteness. A major attraction of barley flour was its WHC (2.5-fold higher than that of wheat flour), making it more suitable for use as a food thickener, food binder, or ingredient in foods such as oriental noodles. Oil absorption of barley flour was slightly higher than that of wheat flour, despite differences in their ether extract contents (0.8–2.5%). The higher WHC of barley flour was confirmed by higher farinograph absorption (75%) and viscoamylograph peak viscosity (660 BU). These properties were apparently the result of β-glucan, although protein, gluten strength, and damaged starch may be contributing factors. Barley flour had shorter dough development time (2.0 min) and shorter farinograph arrival time than did wheat flour. Arrival time indicates the rate of water uptake. The rate may be influenced by flour protein content, β-glucan, and pentosans. Thus, barley flour absorbs or binds water rapidly. The swollen gel of barley flour was less stable than wheat flour gel, indicated by larger drop in BU on holding at 95°C for 30 min. Barley flour starch granules may be more fragile because they formed viscous gels on cooling to 50°C (higher setback viscosities), indicating hot paste starch granules retrograded on cooling. Neither flour showed α-amylase activity (high falling numbers). Damaged starch was significantly higher in wheat flour (20%) than in barley flour (15%), suggesting a harder wheat or different milling procedure was used for obtaining these flour samples. Barley flour had about 3% higher gross energy than did wheat flour. Proximate composition showed barley flour contained more ash, ether extracts, β-glucan, and fiber fractions, but less protein and starch. The ratio of SF to TDF was 1:3 in barley flour and 1:2 in wheat flour. High ash content of barley flour has little practical significance and does not indicate lower quality. Ash content may vary widely and is more indicative of grain quality or grain cleanliness. Because of low ether extract content (2.5%), barley flour, like wheat flour (<1%), may be used full-fat in foods.

Scout hull-less barley was milled in a Buhler mill to separate bran and shorts. The physicochemical properties of the three milling fractions obtained (flour, bran, and shorts) are reported in Table IV. Flour yields of 72 and 74% were obtained on milling Scout barley in the Buhler mill. Larger variabilities were reported in yields of bran (11 and 20%) and shorts (8 and 15%). Data in Table IV are given for 72, 20, and 8% yields of flour, bran, and shorts, respectively. The physicochemical properties of the Buhler-milled flour were, as expected, generally similar to those of the Allis-Chalmer-milled flour reported in Table III. The shorts fraction was whiter and had higher WHC, oil absorption, ether extract, ash, pentosans, β-glucan, TDF, insoluble fiber, and SF than did the bran or flour fractions. The Buhler-milled bran contained more protein, starch, and gross energy than did the shorts fraction. The milled barley flour, bran, and shorts were analyzed for phosphorus, potassium, sulfur, calcium, magnesium, and trace minerals (copper, iron, manganese, zinc, and boron). Phosphorus and potassium were the major minerals, and iron and zinc were the major trace minerals of the flour. All of the minerals except sulfur and calcium had higher concentrations in the bran and shorts fractions than in the flour fraction; the shorts fraction was generally richer in mineral content than the bran fraction. Mineral composition of barley products may be affected by several factors. Data for roller-milled barley products have not been reported in the literature.

TABLE IV
Physicochemical Properties of Flour, Bran, and Shorts of Hull-less Barley (Scout) Milled in a Buhler Mill[a,b]

Property/Component	Flour	Bran	Shorts
Milling yield, %	72.0	20.0	8.0
Color (white), L	88.1 b	77.7 c	79.5 d
Water-holding capacity, ml/g	2.5 b	2.7 b	3.5 c
Oil absorption, ml/g	1.4 b	2.7 c	3.4 d
Protein, N × 6.25	13.9 b	19.8 c	19.2 d
Ash, %	2.1 b	3.6 c	3.9 d
Ether extract, %	2.0 b	2.0 b	3.1 c
Starch, %	73.1 b	54.4 c	44.9 d
Pentosans, %	2.0 b	4.8 c	7.0 d
Gross energy, Kcal/kg	4,462.1 b	4,585.7 c	4,547.3 d
β-Glucan, %	4.3 b	6.3 c	8.4 d
Total dietary fiber, %	9.4 b	20.3 c	24.5 d
Soluble dietary fiber, %	3.1 b	5.8 c	8.1 d
Insoluble dietary fiber	4.4 b	12.9 c	15.0 d
Minerals, mg/g			
Phosphorus	4.0 b	8.0 c	10.0 d
Potassium	4.0 b	8.0 c	9.0 d
Sulfur	2.0 b	2.0 b	2.0 b
Calcium	0.2 b	0.3 b	0.5 b
Magnesium	1.0 b	3.0 c	4.0 d
Trace minerals, μg/g			
Copper	4.5 b	6.2 b	13.4 b
Iron	76.4 b	148.4 b	255.9 c
Manganese	17.4 b	19.7 b	31.3 c
Zinc	44.4 b	70.9 b	116.8 c
Boron	6.7 b	7.9 b	15.1 b

[a] Mean of duplicate determinations reported on moisture-free basis.
[b] Values with different letters between columns are statistically significant at the 5% level.

TDF and SF Composition of Bran and Flour Samples

The hypocholesterolemic effects of TDF and SF for cereal brans in humans and experimental animals have been reported (Chaudhary and Weber 1990; Kahlon et al 1990; Ranhotra et al 1990,1991; Mongeau et al 1991; Newman and Newman 1991). Few findings have been reported for cereal flours and fewer still on composition of TDF and SF in cereal brans and flours. TDF and SF of barley bran and flour were isolated and analyzed for β-glucan, pentosans, resistant starch, pectin, and Klason lignin (Table V). Barley bran TDF contained β-glucan (22.4%) as a major component; the other components were pentosans (19.7%), Klason lignin (7.8%), starch (6.3%), and pectin (1.2%). Barley flour TDF showed a similar composition, containing β-glucan (20.3%), pentosans (13.9%), starch (8.3%), Klason lignin (6.4%), and pectin (2.0%). As expected, no Klason lignin was detected in the SF fractions of barley bran and flour, which contained β-glucan, pentosans, starch, and pectin in decreasing concentrations (Table V). Increased β-glucan in barley grain is likely to increase TDF and SF. This is distinctly possible in hull-less barley because of the availability of germ plasm with a high concentration and large range of β-glucan (Aman and Graham 1987, Bhatty 1992).

CONCLUSIONS

Traditionally, barley has not been roller-milled, nor has quality criteria of barley flour for use in food products been established. However, barley for use in commercial foods would, preferably, be white, have waxy starch, and be of the soft type with an optimum grind time >40–45 sec. The flour produced from such a barley would be white, have low damaged starch, high β-glucan content (a major component of TDF and SF), and be suitable for use in nonbread bakery products and other food applications. Potential applications of barley flour in food products have been described in scientific publications (Newman and Newman 1991, Berglund et al 1992, Bhatty 1992) and in numerous recipe books.

Barley varies in grain hardness and can be dry-milled with equipment routinely used in wheat milling to obtain consistent bran and flour yields (about 30 and 70%, respectively). Roller-milled barley bran and flour have some unique physicochemical properties and offer potential for increasing use of barley in human foods. The 30% bran yield represents the outer coverings and can be defined as a true bran. It is appropriate to compare barley and oat brans. Both, unlike wheat bran, are hypocholesterolemic, have high WHC, and add bulk to foods. Barley bran has one-half the ether extract content of oat bran and may be prepared without the steaming or stabilization necessary for preparation of oat bran. Barley bran is whiter than oat bran, has similar WHC, protein, and β-glucan content but higher TDF and SF due to its higher pentosan content. These dietary fiber fractions can be further increased by using hull-less waxy barley cultivars that are high in β-glucan. Barley flour, although not suitable for making yeast-leavened bread, had 2.5-fold higher WHC, a higher farinograph absorption, and higher viscoamylograph peak viscosity (swelling power) than those of wheat flour, making it uniquely suitable in many food applications. β-Glucan, the major component of TDF and SF, is present in barley in higher concentration and greater range than it is in oats, allowing the development of high β-glucan cultivars. Barley bran and flour require development research for use in food and industrial (nonmalting) applications.

TABLE V
Compositions of Total Dietary Fiber and Soluble Fiber Obtained from Hull-less Barley (Scout) Bran and Flour

	Total Dietary Fiber[a]		Soluble Fiber[a]	
Component, %[b]	Bran	Flour	Bran	Flour
β-Glucan	22.4 ± 1.2	20.3 ± 0.6	38.4 ± 0.2	26.8 ± 0.4
Starch	6.3 ± 0.2	8.3 ± 0.1	5.4 ± 0.1	6.9 ± 0.2
Klason lignin	7.8 ± 0.2	6.4 ± 0.4	ND[d]	ND[d]
Pentosans[c]	19.7 ± 1.2	13.9 ± 0.5	6.5 ± 0.1	5.7 ± 0.0
Uronic acid	1.2 ± 0.1	2.0 ± 0.1	1.1 ± 0.1	1.2 ± 0.1

[a] Freeze-dried preparations obtained by the method of Prosky et al (1988).
[b] Mean ± SEM of duplicate analyses.
[c] Calculated as the sum of arabinose + xylose (determined by gas-liquid chromatography) × 0.9.
[d] Not detected.

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LITERATURE CITED

AHMED, A., and LABAVITCH, J. 1977. A simplified method for accurate determination of cell wall uronic content. J. Food Biochem. 1:361-365.

AMAN, P., and GRAHAM, H. 1987. Analysis of total and insoluble mixed-linked (1→3),(1→4)-β-D-glucans in barley and oats. J. Agric. Food Chem. 35:704-709.

AMERICAN ASSOCIATION OF CEREAL CHEMISTS. 1983. Approved Methods of the AACC, 8th ed. Method 08-01, approved April 1961, revised October 1976 and October 1981; Method 30-20, approved April 1961, revised October 1975, reviewed October 1982; Method 44-19, approved April 1961, revised October 1975, reviewed October 1982; Method 46-13, approved 1976, reviewed October 1982; Method 56-81B, approved November 1972, revised October 1982, October 1988, and September 1992; Method 76-30A, approved May 1969, revised November 1972, October 1982, and October 1984; Method 88-04, approved September 1978, reviewed 1982. The Association: St. Paul, MN.

ANJUM, F. A. and WALKER, C. E. 1991. Review in the significance of starch and protein to wheat kernel hardness. J. Sci. Food Agric. 56:1-13.

BERGLUND, P. T., FASTNAUGHT, C. E., and HOLM, E. T. 1992. Food uses of waxy hull-less barley. Cereal Foods World 37:707-714.

BHATTY, R. S. 1986a. The potential of hull-less barley. A review. Cereal Chem. 63:97-103.

BHATTY, R. S. 1986b. Physiochemical and functional (breadmaking) properties of hull-less barley fractions. Cereal Chem. 63:31-35.

BHATTY, R. S. 1987. Milling yield and flour quality of hulless barley. Cereal Foods World 32:268-272.

BHATTY, R. S. 1992. β-Glucan content and viscosities of barleys and their roller-milled flour and bran products. Cereal Chem. 69:469-471.

BLAKENEY, A. B., HARRIS, J. P., HENRY, R. J., and STONE, B. A. 1983. A simple and rapid preparation of alditol acetates for monosaccharide analysis. Carbohydr. Res. 113:291-299.

CHAUDHARY, V. K., and WEBER, F. E. 1990. Barley bran flour evaluated as dietary fiber ingredient in wheat bread. Cereal Foods World 35:560-562.

FROLICH, W., and NYMAN, M. 1988. Minerals, phytate and dietary fiber in different fractions of oat grain. J. Cereal Sci. 7:73-82.

HOLM, J., BJOREK, I., DREWS, A., and AAP, N. G. 1986. A rapid method for the analysis of starch. Starch/Staerke 38:224-226.

KAHLON, T. S., SAUNDERS, R. M., CHOW, F. I., CHICE, M. M., and BETSCHART, A. A. 1990. Influence of rice bran, oat bran, and wheat bran on cholesterol and triglycerides in hamsters. Cereal Chem. 67:439-443.

KOSMOLAK, F. G. 1978. Grinding time—A screening test for kernel hardness in wheat. Can. J. Plant Sci. 58:415-420.

McCLEARY, B. V., and GLENNIE-HOLMES, M. 1985. Enzymatic quantification of (1→3),(1→4)-β-D-glucan in barley and malt. J. Inst. Brew. 91:285-295.

MONGEAU, R., BRASSARD, R., MALCOLM, S., and SHAH, B. G. 1991. Effect of dietary cereal brans on body weight and blood lipids in a long-term rat experiment. Cereal Chem. 68:448-453.

NEWMAN, R. K., NEWMAN, C. W., and GRAHAM, H. 1989. The hypocholesterolemic function of barley β-glucan. Cereal Foods World 34:883-886.

NEWMAN, R. K., and NEWMAN, C. W. 1991. Barley as a food grain. Cereal Foods World 36:800-805.

NORRIS, K. H., HRUSCHKA, W. R., BEAN, M. A., and SLAUGHTER, D. C. 1989. A definition of wheat hardness using near infrared reflectance spectroscopy. Cereal Foods World 34:696-705.

POSNER, E. S. 1991. Mechanical separation of a high dietary fiber fraction from wheat bran. Cereal Foods World 36:553-556.

PROSKY, L., ASP, N. G., SCHWEIZER, T. F., DEVRIES, J. W., and FURDA, I. 1988. Determination of insoluble, soluble and total

dietary fiber in food products: Interlaboratory study. J. Assoc. Off. Anal. Chem. 71:10.
RANHOTRA, G. S., GELROTH, J. A., ASTROTH, K., and RAO, C. S. 1990. Relative lipidemic responses in rats fed oat bran and oat bran concentrate. Cereal Chem. 67:509-511.
RANHOTRA, G. S., GELROTH, J. A., ASTROTH, K., and BHATTY, R. S. 1991. Relative lipidemic responses in rats fed barley and oat meals and their fractions. Cereal Chem. 68:548-551.
SOSULSKI, F. W., and WU, K. K. 1988. High-fiber breads containing field pea hulls, wheat, corn, and wild oat brans. Cereal Chem. 65:186-191.
STEPHEN, A. M. 1989. The physiological effects of cellulose in the human large intestine. Anim. Feed Sci. Technol. 23:241-259.
SWANSON, R. B., and PENFIELD, M. P. 1988. Barley flour level and salt level selection for a whole-grain bread formula. J. Food Sci. 53:896-901.
THEANDER, O., and WESTERLUND, E. 1986. Studies on dietary fiber. 3. Improved procedures for analysis of dietary fiber. J. Agric. Food Chem. 34:330-336.
WILLIAMS, P. C. 1967. Relation of starch damage and related characteristics of kernel hardness in Australian wheat varieties. Cereal Chem. 44:383-392.

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