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FINAL REPORT

PRODUCTION OF WAXY HULL-LESS BARLEY

AND ITS UTILIZATION IN FOODS

WDATC CONTRACT NO. 8032

Frank E Weber

Contractor: Frank E. Weber, Ph.D.

April 14, 1995

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PROGRAM SUMMARY

A. INTENT OF THE PROJECT

The project objectives were:

- to plant and observe growth, field performance, and yield of several waxy hull-less barley varieties.

- evaluate barley quality, analyze nutrient composition and compare performance for food uses.

- report findings to Director, ADD Grant Program, and seek publication in food research literature.

B. PROJECT ACHIEVEMENTS

- This project demonstrated that waxy hull-less barley, a new crop to Wisconsin, can be grown in the State.

A total of four varieties were grown during this project; these were suggested by plant breeders developing this barley for growing conditions of Minnesota, Montana and North Dakota. Adaptation or selection of varieties especially suited to Wisconsin growing conditions may improve performance and yields reported here. Variety R-2 is not recommended.

- Nutritional properties of waxy hull-less barley grown for this project were determined using standardized laboratory methods; as anticipated the high levels of dietary fiber, vitamin E and tocotrienol were achieved. Some differences in nutrient levels between the varieties were noted.

- Uses were examined for waxy hull-less barley in traditional foods, food ingredients and new applications. Several new products are suggested.

- Basic milling equipment was found capable of grinding hull-less barley to a whole meal and flour without wasteful pearling of hulls as practiced with conventional covered barley. The milled forms were suitable for use in many foods.

Several problems were encountered with harvesting and cleaning barley grown in the large plots; this limited quantity available for trial in production scale milling equipment.

C. RESULTS AND BENEFITS

1. <u>Production Experience - Waxy Hull-less Barley - 1993 and 1994.</u>

<u>1993</u> - Three waxy-hull-less varieties: Apollo, Merlin and Wanubet were grown in small plots consisting of six 12ft rows each at the Badger Rd. site, Town of Liberty Grove, Door County. Apollo, a 6 row, medium height variety from Ross Seed Co., Fisher MN showed the most promise. Merlin, from Western Plant Breeders, Bozeman, MT, a 2 row variety had the shortest straw height and largest largest number of tillers; it held up under pressure of weeds in a wet growing season. Wanubet, obtained from the Small Grain Dept., UW Madison, a 2 row variety had the tallest straw height and lodged severely before reaching maturity. Three covered varieties know to produce well in Wisconsin were planted also: Chilton, Excel and Hazen.

Periodic photographic and video records were made during the growing season. Copies were provided to Director, ADD Grant Program in 1994.

1994 - Adequate seed of two varieties was available: Merlin (Western Plant Breeders) and R-2 a six row, long straw variety (developed from Robust by Ross Seed Co.). R-2 was not grown in 1993 and suggested to replace Apollo. Ross Seed Co. was unable to supply enough Apollo seed for 1994 planting.

Planting locations were at Badger Rd. and Peninsula Agricultural Research Station (PARS), Sturgeon Bay, WI. PARS has small grain trial plots and agreed to plant waxy hull-less barley in four row replicate plots. This follows a standardized procedure enabling comparison of yield data for Merlin and R-2 to a number of covered barley varieties grown at this site.

PARS also agreed to plant half acre plots that would produce sufficient barley for milling and utilization studies.

Agronomic Data and Results for Plantings at PAR Appear in Appendix A

Comparison of yield and bushel weight for hull-less and covered barley must take into account both bulk and weight of hulls removed in harvesting covered barley. The yield of hull-less barley is reported to be 10-15% less because of hulls left in the field, while covered barley retains hulls.

Yield - Increasing yield of the hull-less barley by 15% puts this on comparable footing. Yields for Merlin of 26.1 Bushel/Acre and R-2 of 29.8 Bushel/Acre become 30.7 Bushels/Acre and 35.0 Bushels/Acre respectively. Yields for barley grown at PARS are shown on page 2 of Appendix A. As can be seen these adjusted yields are still 10-15 Bushels, or, 27% below the average for the covered varieties in the study.

1994 was a dry season and yield for the covered varieties is somewhat lower than averages shown for them in "Small Grain Varieties for Grain and Forage in Wisconsin" 1992 by E. S. Oplinger and R. A. Forsberg, Agronomy dept., University of Wisconsin.

Bushel weight - for Merlin and R-2 are 55.9 Lbs. and 52.8 Lbs with an average 54.3 Lbs.; this compared to 47.6 Lbs, the average for covered varieties in the study. This is 12.4% higher than for covered varieties.

Market Value - Hull-less barley as indicated by its descriptive name, comes from the field in a ready-to-process form like wheat. Whereas covered barley has tightly adhering hulls which are removed before processing by pearling. Pearling grinds off the hull by action of abrasive surfaced mill; this reduces grain volume by 20-30% to achieve hull free endosperm. This hull-free advantage has impact to both producer and processor of hull-less barley. As already described production yield in bushels per acre is lower and bushel weight higher than covered barley. A higher commodity price for hull-less barley can be justified and paid because the yield of salable processed barley will be significantly higher than for covered barley. And, nutrient value is enriched by retaining the aleurone layer

Harvesting Barley plots at PARS

Combining operation for R-2 was difficult because grain heads broke loose and were not completely threshed. Reasonable grain separation was achieved only with repeated threshing. This property is a serious defect in small grain varieties and reason for rejection by plant breeders. Growing conditions of 1994 may have led to severity; Ross Seed Co. did not have this experience with R-2 in Minnesota. Merlin was combined without difficulty.

Use of a production combine at PARS led to accidental mixing of the two hull-less variety and mixing of one variety with previously combined rye. Obscure pockets of grain remained in the machine which became mixed with the following harvested grain. This problem limited usefulness of the major supply of grain to this project and planned research. Because of similarity of size and shape of mixed grain it was impractical to get adequate separation on seed cleaning equipment.

Results at Badger Rd. Site

Plots of Merlin and R-2 measuring 20x60 ft were planted by broadcasting weighed amounts of seed on prepare beds followed by surface tilling. Smaller plots of Wanubet and Apollo seed left from 1993 were planted in similar manner. Distribution and germination were reasonably uniform. In contrast to the previous year, 1994 proved to be a very dry growing season. Spray irrigation was available using oscillating yard sprinkler. It was accomplished several times to insure grain development to complete this project. Uniform application was controlled by timing.

Plots were cut and bundled by small machine used by PARS for this purpose; it worked well despite the broadcast planting versus rows. The bundles were dried in cover of barn and threshed by Almaco small bundle thresher. R-2 straws broke off allowing most of the heads came through unthreshed as in the case of the production combine. Repeated threshing was necessary. Merlin threshed without difficulty.

Photographic and Video Records

Periodic photographic and video records were made of barley during stages of development at both Badger Rd. and PARS; these were edited and included as part of the report.

Grain Evaluation

Barley produced at Badger Rd. in 1994, about 25 Lbs of each variety, was prepared for evaluation at USDA/ARS Laboratory Madison using awn breaker, aspirator and dockage separator.

On examination Merlin was found to have 6% of grain with hulls remaining (weight on removal 1.8%) while 30% of R-2 retained hulls (4.8% weight on removal). Perhaps the dry growing conditions adversely effected R-2.

Hulling - In order to analyze properties on a hull-less basis barley was dehulled by Satake Rice Huller. This huller rubs grain between two rubber surfaced counter rotating drums that turn at slightly different rpms. The freed hull is drawn off by aspirator and hulled grain collected separately. This was effective and less than 1% were found to retain hulls.

Physical Properties- were determined for Merlin and R-2.

	Merlin 94	R-2 94
Hull-on:		
after threshing (%)	6	30
after huller (%)	1	1
Kernel weight (mg)	47.0	44.5
On 6/64 sieve (%)	84.5	73.1
Color (Agtron Color)	21	15
Bushel Wt. (Lbs.)	55.9	52.8

Composition- obtained by commercial laboratory using methods of the American Association of Cereal Chemists or, USDA-ARS Laboratory, Madison *.

	Merlin 94	R-2 94	Apollo 93	Wanubet 93
Moisture	10.8	10.10	10.50	10.10
Protein	14.00	15.40	15.60	15.00
Fat (E.E.)	2.60	2.80	2.20	2.30
Ash	1.83	2.12	2.19	2.07
Carbohydrate	70.77	69.58	69.51	70.53
Starch	69.52	71.08	70.09	71.08
Total Dietary Fiber	17.21	17.98	17.90	16.05
Soluble Fiber	7.71	7.32	7.16	3.61
Insoluble Fiber	9.50	10.66	10.74	12.44
Beta glucan *	6.32	6.85	NA	NA
Total Tocols (ppm) *	85.56	75.76	"	"
Tocopherols (ppm)	22.71	14.78	"	"
Tocotrienols (ppm)	62.85	61.95	"	"

2. Barley Quality Assessment

Aside from the high percentage of hulls-on for R-2, all the other traits of waxy hull-less barley produced in this project were similar to traits reported for hull-less barley grown in North Dakota and Minnesota (1992 Regional Barley Crop Report of the North Dakota Barley Council & Minnesota Barley Research & Promotion Council).

	Reported Ranges	Merlin 94	R-2 94
Test Weigh Lbs./Bu	49.4 - 58.6	55.9	52.8
Kernel Weight mg	36.0 - 50.5	47.0	44.5
Protein Content %	14.8 - 16.1	14.0	15.4
Beta Glucan %	6.81 - 7.65	6.32	6.85
covered six row	5.11 ave.		
two row	4.15		
Plump, % on 6/64	28.3 - 96.1	84.5	78.0

Color - Color values for waxy hull-less barley 15-22 are low reflectance values representing the brown surface color of the grain. Values approaching 100 are expected of hulls of unweathered covered barley. Variation in color is apparent on individual grains; it is unclear if this relate to weathering and mildew of hull-less barley.

Beta Glucan - Despite the relatively small contribution to the total weight of the grain, beta glucan has a disproportionate impact on barley nutritional value and processing properties. The beta glucan of both Merlin and R-2 is high compared to covered barley and oats commonly grown in the US. Waxy hull-less barley is an excellent source of this soluble fiber.

Vitamin E/Antioxidant Content of Waxy Hull-less Barley - Vitamin E activity of waxy hull-less barley is significant and the result of the tocols found in even smaller measure than beta glucan. Tocols are commonly measured in parts per million. Many biological activities of vitamin E are a result of its antioxidant property. Some of the tocols, specifically tocotrienols occur in high level in barley compared to other grains and have been shown to be especially effective antioxidants in human nutrition and capable of reducing serum cholesterol.

The tocol content of Merlin and R-2, 85.56 ppm and 75.76 ppm respectively, exceeds the average contents for covered barley and oats reported by Peterson and Qureshi 1993*. Total tocol concentration of 12 oats ranged from 19 to 30 ppm. Barley in their study included 30 genotypes averaging 58 ppm with a range of 42-80 ppm. Only one type exceeded that of the barley grown in this project.

* Peterson, D. A. & Qureshi, A. A. 1993 Genotype and Environment Effects on Tocols of Barley and Oats. Cereal Chem. 70(2):157-162

3. Processing Waxy Hull-less Barley

Food Uses - Waxy hull-less form of barley offers processing and nutrition advantages that may lead to increased usage in home cooking and by manufacturers consumer and food service products.

Barley consumption in the US is small; estimated to about 1.5 Lbs. per person per year for period 1986-88 by FAO. This in contrast to Algeria, Iraq, Korea, and Morocco where consumption is 15.0 to 150 Lbs per person per year. The predominant form used in the US is pearled or pot barley for cooked foods such as breakfast cereals, soups, stews, porridge, bakery blends, and baby foods. Besides pearled and pot form, grits, flakes, and flours of barley and malt are available. Malted barley and malt syrup are used in large volume in manufacture of alcoholic beverages.

Barley usage has been shaped mainly by its nature as a covered grain needing pearling to remove a tough hull which is not removed or made tender by cooking. Whether pearled or hull-less, the endosperm itself is hard and needs cooking to become tender. Barley contains a high percentage of starch grains held tightly together by beta glucan; this is soften by swelling during cooking, or, the effects of enzymes during malting.

Preparation of Hull-less Barley for Processing

While the name implies hull-less, a small percentage hulls may remain and must be removed. As mentioned earlier a Satake Rice Huller works well and does not break grain or grind away the vitamin and protein rich aleurone layer and starchy endosperm as an abrasive pearling device.

To demonstrate the undesirable effect of abrasive dehulling on nutrient content, Merlin and R-2 were subjected to pearling at two levels: 20% and 30% w/w removal. Experience with pearling of covered barley indicates that 0-11% removal is hull, 11-25% this germ and aleurone, 25% and up this mainly endosperm.

As shown by data for Merlin and R-2 significant concentrations of beta glucan and tocols are lost from barley by removing 20% and 30% pearlings (waste stream).

sample	beta glucan %	total tocols ppm
Merlin	6.32	85.56
20% pearlings	3.50	208.35
30% pearlings	4.35	192.41
R-2	6.85	75.76
20% pearlings	3.87	226.21
30% pearlings	3.86	286.95

Milling Whole Meal Barley

Clean hulled and hulled barley can be milled by simple grits mill and sifted through a 12 mesh or finer screen. The coarse particles on the screen are simply returned to mill until all pass the screen. A hand operated Corona grits mill can be used for in-home milling and sifting done by flour sifter or related device. A grits mill of this type resembles a hand meat grinder with stationary grooved disc mounted on body and another attached to the end of the feed screw and turning handle.

On a commercial basis barley meal can be produced at a rate of several thousand pounds per hour using a hammer mill such as a Micropulverizer and Great Western Box Sifter with conveyer to return coarse material to the mill. Several granulations can be produced simultaneously using multiple size screens in the sifter. Barley does not sift as easily as wheat flour, apparently due to the presence of beta glucan and sifter must be sized accordingly.

Uses of Whole Meal Barley

Hot Breakfast cereal - Meal ground through 12 mesh screen can become hot breakfast cereal; cook 1 part barley meal to 2 parts water for 7 minutes.

Uses of fine barley meal in Cooking - this can be used in place of wheat flour and corn starch to thicken gravies and sauces. Waxy starch present in this barley is resistant to break down and separation.

It can be used to flour meats before pan browning.

As a meat extender/fat replacer it can replace bread crumbs in hamburger and meat loaf. It will retain added water which protects tender/moist eating quality of low fat ground meat during cooking. Beta glucan and waxy starch of this barley are particularly well suited to this role in fresh and frozen entrees.

Baking - Meal ground to pass through finer screens: 60 to 120 mesh, can be used to replace portions of wheat flour in baking recipes to increase dietary fiber and vitamin E in the diet. Care must be exercised in replacing wheat flour in bread; to protect loaf volume limit replacement to 15-20%. Barley can weaken loaf structure as it contains no gluten which is the basis of bread crumb structure. Two references included in Appendix B contain information about use of barley in bread, biscuits, cookies and muffins, pasta and granola.

Table Syrup and a Sweetener Alternate to Refined Sugar - Barley meal can also be used to make syrup when mixed with a portion of malted barley to convert starch to sugar extract. An extract with as much as 20% solids can be prepared using a process resembling the mashing step in formation of beer wort. After filtering to remove insolubles and adjustment of pH this extract can be concentrated to stable 68% solids using a maple syrup evaporator in the off season. Or, a low temperature evaporator can be used to concentrate the extract without producing flavor and dark color of traditional table syrups. Commercial enzymes are also available to assist in conversion of starch and beta glucan to sugar.

Puffed Barley - Both Merlin and R-2 were subjected to puffing by microwave energy after tempering to raise moisture from 10 up to 20% in stages. While both grains exhibited some irregular expansion and could be easily chewed, the texture and density were considered disappointing. Better expansion might be achieved by puffing gun.

Flaked Barley - No flaking was done because of specialized equipment required; it can be achieved by two processes: extrusion and hot rolling steamed grain. Extruded flakes of waxy hull-less barley were obtained from Don Alexander, Nu-Grain Products and Dr. Joel Dick, Roman Meal Milling Co.

Roller Milling Flour from Waxy Hull-less Barley

Hull-less barley has not been roller milled on a commercial basis to obtain a flour and bran similar to wheat, but, in 1993 Ron Bhatty, Crop Development Centre, University of Saskatchewan reported both the feasibility and properties of barley flour and bran milled by this process. It was an aim of this project to roller mill barley, however, this was prevented by problems encountered to clean grain produced at PARS in 1994. This study is included in Appendix B and highlights listed here.

Sixteen barley samples were milled by Allis-Chalmer experimental mill and waxy hull-less found to produce flour with least starch damage. This study concludes that waxy hull-less barley can be milled with consistent results using equipment routinely used to mill wheat flour.

Pearling for the Sake of Pearlings - as describe earlier, pearling of waxy hull-less barley was accomplished by laboratory pearler and makes a product comparable in appearance to traditional pearled covered barley. The by-product pearlings from waxy hull-less barley have great potential as a new product. These pearlings have tocols in higher concentration ~~then~~ making them a valuable source of natural vitamin E and antioxidant. This material can be marketed to consumers as barley bran in a manner similar to wheat bran. It can be eaten by simple addition to conventional foods such a breakfast cereals, salads and other dishes.

Tocotrienol of barley has been shown to reduce serum cholesterol when maintaining a low fat diet; a clinical study of this is included in Appendix B.

Malting - of Merlin and R-2 was accomplished by USDA ARS Laboratory Madison and values compared to brewers specification and values for malted Robust, the parent of R-2. Use of malted hull-less barley could be advantageous to production of malt base for manufacture of coolers and could be done without capital expense of traditional brewhouse equipment. Spent grain from such a process would be an excellent source of tocols.

Malt Trait	Ave. Brewer Spec.	Malted Robust	Malted R-2	Malted Merlin
On 6/64	85% min.	87.9	78.0	81.0
Extract	78.5% min.	78.9	78.4	81.0
Wort color	1.6-2.0	1.72	1.7	1.7
Malt Protein	13.5 max	12.8	17.7	16.3
Wort protein	5.4-5.8	5.54	5.21	4.86
% Sol/Total	40 - 45	43.3	31.2	32.9

D. DESCRIPTION OF INFORMATION AND EDUCATIONAL MATERIALS DEVELOPED

This report contains written information, photographs and edited video that can serve as basis of presentations at seminars and field days.

E. FUTURE PROJECTIONS RESULTING FROM THIS GRANT AND PROJECT

Production of waxy hull-less barley will be repeated by PARS in 1995 andthe barley used to study commercial feasibility of new products described here.

F. BACKGROUND USED TO ACHIEVE ORIGINAL OBJECTIVE

Personal background in food and beverage industry spurred along by interest in new uses for agricultural products and barley.

G. ACKNOWLEDGMENT OF THOSE ASSISTING IN THIS PROJECT

Dr. Robert A. Forsberg, Agronomy Dept. University of Wisconsin

Richard Weidman, Supt. Peninsular Agriculture Research Station

Dr. David M. Peterson, Supervisory Plant Physiologist, USDA ARS, Madison

Dr. Asaf A. Qureshi, Advanced Medical Research, Madison

Dr. Dale Clark, Western Plant Breeders, Bozeman, MT

Dr. Gregg Fox, Phoenix Seed Co., Fargo, ND

Steve Ross, Ross Seed Co., Fisher, MN

Drs. Rosemary and Walter Newman, Montana State Univ.

Dr. Patricia T. Berglund, Food & Nutrition Department, N. D. State Univ.

Dr. Rattan S. Bhatty, Dept. Crop Science, Univ. of Saskatchewan

Don Alexander, Nu-Grain Products, Martin, ND

Dr. Joel Dick, Roman Meal Milling Co. Fargo, ND

Tom Edgett, Video Information Services, Mequon, WI

12-1

SMALL GRAIN VARIETY TRIALS

Location: Peninsular Agriculture Research Station, Sturgeon Bay, WI

Personnel: R. Forsberg, R. Duerst, F.Weber, R. Weidman

Objective: Evaluation of named and numbered selection of oats, barley,and winter wheat.

Plot Size: Four rows 12" spacing 10' long, replicated 4 times.

Materials and Methods: Planting Date: Oats - 4/19/94
Barley- 4/17/94
Winter Wheat - 9/24/93
Fertilization: All grains 40#N, 40#P, 40#K broadcast at planting:Winter wheat 45# N supplement, 4/18/94
Herbicide: Oats and barley,MCPA.5# AIA
Harvest Dates: Oats - 8/2/94
Winter Wheat ,Barley 8/2/94
Yield projections based on two 8' row samples taken from each replication.

Two- and Three-Year Summary of Oat Variety Yields

Variety or Selection	Two Year Yield Summary Bu/A ~~1992~~ 1993-1994	Three Year Yield Summary Bu/A ~~1991~~ 1992 1993-1994
Dane	106.9	86.2
Hazel	110.0	86.3
Horicon	114.8	97.1
Ogle	91.5	81.1
Prairie	137.3	112.2
Porter	112.0	93.1
Troy	103.3	
Bay	144.6	117.4
X5673-2	137.4	107.5
X5976-8	132.0	104.7
X6045-4	103.0	
X6161-1	114.0	91.5
X6166-2	121.5	
X6396-1	114.4	
Average	117.4	97.6

Yield and Agronomic Data For Barley Varieties 1994

Variety or Selection	Yield Bu/A	Yield Rank	Bu. Wt. Lbs.	Ht. in.
Bounty	47.5	3	46.3	24.3
Chilton	46.6	4	48.0	25.0
Chopper	53.7	1	50.3	23.0
Excel	38.3	8	47.2	22.8
Hazen	53.5	2	47.6	25.0
Morex	43.3	5	46.3	24.8
Robust	40.6	7	47.3	26
Stander	41.4	6	47.9	22.8
Average	45.6		47.6	24.2

Mean = 45.6 Bushels Per Acre
L.S.D. .05 = 7.31 Bushels Per Acre
Standard Error = 3.52 Bushels Per Acre
C. V. = 10.90 Percent

Hulless Barley Trials

Variety	Yield Bu./A	Bushel Wt. (Lbs.)	Height (In.)
Merlin	26.1	55.9	17.5
R-2 Robust	29.8	52.8	25.8

CFW
Research

Food Uses of Waxy Hull-less Barley[1,2]

P. T. BERGLUND, C. E. FASTNAUGHT, AND E. T. HOLM[3]

ABSTRACT

Waxy, hull-less barley in the form of flour, flakes, quick-cooking cereal, or extruded cereals was substituted for 25-100% of wheat flour and/or oats or rice cereals in a variety of food products, which were evaluated by sensory panels. Scores for most sensory characteristics were similar for the following products made with wheat or whole wheat flour and those in which barley was substituted at the indicated level: breads (26% barley vs. whole wheat flour), carrot-spice bars (100% barley vs. wheat flour), no-fat blueberry muffins (70% barley vs. 70% whole wheat vs. 100% wheat flour), chocolate chip cookies (50% barley vs. 100% wheat flour). Raisin cookies made with barley or oat cereal were liked equally for most sensory characteristics, including flavor. Granola bars made with barley flakes were rated higher for appearance and flavor than those made with oat flakes. There was no difference in flavor and overall acceptability ratings for 25 or 35% barley and 100% wheat-flour biscuits. The flavor of barley noodles compared favorably with commercial whole wheat noodles. Waxy, hull-less barley can be successfully used in many foods to produce higher-fiber food products.

Barley has long been used in the United States in the malting and brewing industry and for animal feed. Only about 2% of U.S. barley is used for food. Although barley is available in both hulled (covered) and hull-less variants, hull-less barley, which does not require dehulling, offers some advantages for food uses. Bhatty (1) reported that hull-less barley can be milled directly to obtain a meal or can be pearled and ground (1). Hull-less barley, particularly cultivars with 100% amylopectin (waxy) starch, has high total and soluble fiber contents; it also has a higher β-glucan level than most covered barley and oats (2-4). However, gumminess has been reported when high levels of hull-less barley have been incorporated into food (5), probably due to the high water-holding capacity of the soluble fiber. Newman and Newman (3) reported a number of studies in which hull-less barley was incorporated into food. The objective of this study was to determine the acceptability of a wide variety of food products in which waxy hull-less barley was incorporated.

MATERIALS AND METHODS

Barley Products

Twenty-nine barley cultivars selected for genetic diversity of hull and starch types were grown in North Dakota and screened for β-glucan content in 1989. The hull-less cultivars having waxy starch had the highest average β-glucan content (6.71%) compared with hull-less normal starch (5.42%), covered waxy starch (5.34%), and covered normal starch (4.27%) cultivars. Wanubet, a hull-less, waxy starch cultivar, had an average β-glucan content of 6.87% (10 environments) and was selected for use in all of the barley products in this study.

The barley flour was ground from whole hull-less barley at Natural Way Mills (Middle River, MN). Whole barley flakes were obtained from NuGrain Technologies (Martin, ND) and a quick-cooking cereal (Hot Barley Cereal) from NuWorld Nutrition (Fargo, ND). Cereals made of 50% barley and 50% rice, 100% barley, and 100% rice were extruded using a twin-screw extruder (Wenger Manufacturing, Sabetha, KS) with the crispy rice die.

Flour Analysis

Analyses, except particle-size determinations, were done according to AACC methods (6). Whole-grain barley flour and all-purpose wheat flour were analyzed by Method 46-12 for protein, 30-25 for ether extract, and 32-07 for total, soluble, and insoluble dietary fiber. Levels of β-glucan in the barley flour, all-purpose flour, and oat-bran cereal were determined using Method 32-22. Starch content of the barley flour was determined using Method 76-11. The particle-size distribution of the whole-grain barley flour was determined by sifting 175 g of flour using sieves (nos. 80, 100, and 140, W. S. Tyler Co., Cleveland, OH) in a Ro-Tap shaker (W. S. Tyler Co., Cleveland, OH) for 30 min. The overs and throughs were weighed, and percent of total was calculated for each fraction.

Product Formulations

Eight products were formulated with barley flour, flakes, quick-cooking cereal, or extruded cereals substituted for all-purpose or whole wheat flour, oatmeal, oat-bran cereal, or extruded rice cereal. Optimal levels of barley substitution for each product were determined in preliminary experiments. Test products containing barley were compared to controls prepared using the original recipes based on wheat, oats, or rice, except for the barley noodles, which were compared to commercially prepared whole wheat noodles. In substituted products that did not include cereals, percentages of flour reported are based on total flour weight. All-purpose flour made up the remainder of the flour component in all products except bread, in which bread flour was used. All baking was done in a conventional household-type oven.

Bread. The test bread contained 26% of barley, and the control contained 26% whole wheat flour. Other ingredients listed in Table I were the same for both barley and whole wheat breads. Yeast was dispersed in 20% of the water; egg, oil, molasses, and remaining water were mixed well. Barley or whole wheat flour, gluten, and salt were added and mixed with the yeast and egg mixtures. Bread flour was gradually added, and the dough was mixed to optimal development in a mixer (model K45SS, Kitchen Aid, Greenville, OH) with a dough hook. The dough was kneaded until smooth and elastic (10 min), allowed to rise until doubled in an oven (prewarmed on low setting for 5 min and then turned off) with a shallow pan of water on the bottom rack to increase the relative humidity, then punched down and molded by hand into 450-g loaves. The loaves were proofed until doubled in size and baked at 190°C for 35 min. Loaves were covered with aluminum foil after the first 15–20 min of baking to prevent the crusts from becoming too dark. Breads were baked the day before sensory evaluation. On the day of sensory evaluation, breads were sliced, and vertically cut half slices were placed into individual plastic bags, which were then sealed. Two slices at both ends of the loaves were not used for sensory evaluation. Panelists were served the bread slices in the plastic bags to maintain optimal freshness.

Carrot-Spice Bars. Carrot-spice bars were prepared with 100% barley flour or 100% all-purpose flour and other ingredients listed in Table I. The dry ingredients were blended together; the egg and oil were mixed well. The water (100°C) was poured over the shredded

[1]Presented at the AACC 76th Annual Meeting, Seattle, WA, October 13-16, 1991.
[2]Published with the approval of the director of the Agricultural Experiment Station, North Dakota State University, as Journal Series 2038.
[3]Food and Nutrition Department, North Dakota State University, Fargo, ND 58105.

carrots, and they were then combined with the liquid ingredients and beaten with the Kitchen Aid mixer (low speed) for 1 min. The dry ingredients were added and mixed until completely blended before addition of the walnuts. The batter was spread into a 23 × 33-cm glass baking pan that was sprayed with nonstick spray. The bars were baked for 35 min at 177°C, cooled, covered, and stored overnight at room temperature. The following day the bars were cut into 2.5-cm squares and served to sensory panelists.

Blueberry Muffins. Muffins were prepared with either 70% barley flour, 70% whole wheat flour, or 100% all-purpose flour. Other ingredients listed in Table I were the same for the three muffin formulations. The dry ingredients were mixed together. Liquid ingredients were mixed together and then stirred into the dry ingredients just until moistened. Blueberries (which were frozen and rolled lightly in flour) were folded into the muffin mixture. The muffin batter (25 g per muffin) was placed in small muffin tins coated with nonstick spray, baked at 204°C for 8 min, and cooled for 2 hr before serving to the sensory panel.

Chocolate Chip Cookies. Cookies were prepared with 50% barley flour or 100% all-purpose flour and other ingredients that were the same for both products (Table I). The dry ingredients were blended. Margarine, sugars, and vanilla were creamed for 50 sec at high speed with a Kitchen Aid mixer. The eggs were added to the creamed mixture and blended for 30 sec. The flour mixture was added gradually and mixed for 2.5 min before the chocolate chips were added and mixed in. Cookie dough was placed on the ungreased cookie sheet with a no. 100 scoop, baked at 177°C for 9 min, and cooled on racks. All cookies were baked the day before sensory evaluation and stored in plastic bags.

Biscuits. Biscuits were prepared with 25% or 35% barley flour or 100% all-purpose flour. Other ingredients listed in Table I were the same for the test and control biscuits. The shortening was cut into the blended dry ingredients with a pastry blender until it was the size of small peas. The milk was stirred into the dough and mixed until the dough formed a ball and picked up the flour on the sides of the bowl. The dough was kneaded 15 times on a lightly floured surface, rolled 1.25 cm thick, and cut with a 6.35-cm biscuit cutter. Biscuits were baked about 2.5 cm apart on an ungreased cookie sheet for 12 min at 218°C, then cooled on racks, and stored in plastic bags until sensory evaluation the following day.

Noodles. The barley noodles were prepared with 75% barley flour, 25% semolina flour, egg, and water (Table I). The barley and semolina flours were blended at low speed for 2 min; the egg and water, which had been mixed together, were gradually added, and the dough was mixed to optimal consistency. The dough was sheeted and cut in a noodle machine (Atlas 150 Lusso, Compodarsego, Italy). The thickness of the sheeted dough was reduced gradually by passing it through the machine with the settings consecutively adjusted from one to six. The noodles were air dried at room temperature for 20 hr and stored in plastic bags. Immediately before sensory evaluation, the noodles were cooked to optimal doneness (7 min for barley noodles, 10 min for whole wheat noodles) and mixed with a commercial spaghetti sauce. Samples of approximately 30 g were served to each panelist.

Raisin Cookies. Raisin cookies were prepared using a formula of flour and cereal ingredients (Table II) plus other ingredients listed in Table I, which were the same for both barley and oat-bran raisin cookies. The dry ingredients, except the raisins, were blended. The margarine and sugar were creamed for 3 min, corn syrup was added and mixed for 50 sec, and egg white and vanilla were added and mixed at high speed with a Kitchen Aid mixer for 45 sec. The dry ingredients were added gradually and mixed for 1.5 min. The raisins were stirred in until evenly distributed. Cookie dough was placed on the ungreased cookie sheet with a no. 70 scoop, baked at 190°C for 10 min, and cooled on racks. All cookies were baked the day before sensory evaluation and stored in plastic bags.

Granola Bars. Granola bars were prepared using a formula of cereals (Table II) and raisins mixed with a binder (Table I). The cereals and raisins were combined. The binder was prepared by combining dry and liquid ingredients separately, then adding liquid ingredients to dry ingredients with stirring. This mixture was cooked until it reached 82°C, at which time it was thick and pulled away from the sides of the pan. The binder was poured over the cereal-raisin mix. The mixture was stirred for 1 min and pressed with a rolling pin into a 23 × 33 × 1.6-cm metal pan so that the bars were 1.6 cm thick. Bars were prepared the day before sensory evaluation, covered, and cut into 2.5-cm squares before serving.

Sensory Evaluation

All products were subjected to sensory evaluation. Seventy-five or more untrained consumer panelists evaluated the breads, carrot-spice bars, blueberry

Table I. Nonflour Ingredients[a]

Ingredient	Bread	Carrot-Spice Bar	Blueberry Muffin	Chocolate Chip Cookie	Biscuit	Noodle	Raisin Cookie	Granola Bar[b]
Sugar[c]	15.9	137.9	43.1	90.6	...	...	114.3	54.0
Corn syrup[d]	...	...	...	...	...	...	71.4	76.0
Egg[e]	9.9	84.2	25.5	34.6	...	26.7	55.7	...
Oil, fat[f]	8.5	47.4	...	72.8	29.7	...	52.9	...
Water	56.1	29.0	...	...	...	66.7	...	...
Skim milk	...	...	101.3	...	74.3	...	...	100.0
Leavening[g]	1.4	4.5	8.1	1.8	3.9	...	1.4	...
Salt	2.5	3.2	1.4	1.9	1.9	...	...	1.6
Vanilla	...	3.2	...	1.1	...	...	2.5	...
Spice mix[h]	...	3.6	...	...	...	...	0.9	...
Raisins	...	...	...	...	...	...	57.1	32.0
Other[i]	6.4	160.5	30.0	81.1	...	...	...	40.0

[a] Amounts are percents of flake weights for granola bars and percents of total flour weights for other products.
[b] All ingredients except raisins are for granola-bar binder.
[c] Sugar source was molasses for breads, 60.3% granulated sugar and 30.3% brown sugar for chocolate chip cookies, and granulated sugar for all other products.
[d] Light corn syrup was used in the raisin cookies, high-fructose corn syrup in the granola bars.
[e] Egg refers to egg whites in the blueberry muffins and raisin cookies and to whole egg in other products.
[f] Corn oil was used in the breads and carrot-spice bars, corn oil margarine in the chocolate chip and raisin cookies, shortening in the biscuits.
[g] Yeast was used in the breads; baking soda in the carrot-spice bars, chocolate chip cookies, and raisin cookies; baking powder in the blueberry muffins and biscuits.
[h] Spice mix consists of 1.6% cinnamon, 1.0% cloves, and 1.0% nutmeg in the carrot-spice bars and consists of cinnamon in the raisin cookies.
[i] Other consists of gluten in the breads, 100% carrots and 60.5% walnuts in the carrot-spice bars, blueberries in the blueberry muffins, chocolate chips in the chocolate chip cookies, and 20% each barley flour and Lodex 5 (American Maize-Products Co., Hammond, IN) in the granola-bar binder.

muffins, chocolate chip cookies, raisin cookies, granola bars, and biscuits. Samples of the noodle products were evaluated by six panelists on three different days. Sensory panelists were students, staff, and faculty volunteers from North Dakota State University who responded to on-campus advertisements.

Sensory quality attributes were evaluated using a nine-point hedonic rating scale (1 = dislike extremely, 9 = like extremely) for all products, except biscuits (7). A score of five was considered a neutral score, and scores above five were in the "like" range. Biscuits were evaluated using a paired-preference test in which panelists were asked to select the biscuit they preferred from the two biscuits presented.

Sensory evaluation sessions for each product were conducted on separate days from midmorning to midafternoon. The tests were performed in partitioned booths with overhead fluorescent lighting. Samples were coded with three-digit random numbers and presented together with a scorecard in a randomized order. Panelists were supplied with water (22°C) for mouth rinsing between samples.

Table II. Flour-Cereal Variations for Raisin Cookies and Granola Bars[a]

Ingredient	Raisin Cookies		Granola Bars		
			Oatmeal with Rice Cereal	Barley Flakes	
	Barley	Oat		Barley-Rice Cereal	Barley Cereal[b]
Flour					
All-purpose	100.0	100.0	...	...	...
Cereal					
Barley flakes	36.4	...	...	100.0	100.0
Old-fashioned oatmeal	...	36.4	100.0	...	...
Hot barley cereal	94.3	...	...	...	...
Oat-bran cereal	...	94.3	...	...	...
Extruded crisp cereal					
Barley	...	...	...	...	32.0
Barley-rice (50% each)	...	...	...	30.0	...
Rice	...	...	30.0	...	...

[a] Amounts are percents of flour weights for raisin cookies and percents of flake weights for granola bars.
[b] Amount of extruded barley crisp cereal was increased to compensate for reduced volume of the cereal as compared to the other crisp cereals.

Table III. Composition of Wanubet Barley Flour and Selected Ingredients[a]

Component	Wanubet Barley Flour	All-Purpose Wheat Flour	Whole Wheat Flour[b]	Oat-Bran Cereal[c]
Protein	13.90	13.50	14.10	21.43
Lipid	2.82	0.89	1.80	7.14
Carbohydrate (starch)	65.26	81.70[d]	68.80	60.71
Total dietary fiber	16.05	1.65	8.80	14.64
Insoluble dietary fiber	9.68	1.22	ND[e]	ND
Soluble dietary fiber	6.37	0.43	ND	ND
β-Glucan	6.56	0.14	ND	7.48

[a] Amounts are percents of total weight (g/100 g).
[b] Calculated from whole wheat flour package label (Gold Medal, General Mills, Minneapolis, MN).
[c] Calculated from oat bran hot cereal package label (Quaker Oats, Chicago, IL).
[d] Calculated from all-purpose wheat flour package label (Gold Medal).
[e] ND = not determined.

Table IV. Evaluation of Bread Made with 26% Barley or Whole Wheat Flour[a]

Flour	Sensory Scores[b]				Weight (g)	Specific Volume (cm^3/g)
	Texture	Flavor	Color	Overall		
Barley	6.30 A	6.58 A	6.62 B	6.70 A	443.3 A	3.26 A
Whole wheat	6.52 A	6.61 A	6.87 A	6.82 A	427.4 B	3.75 A

[a] Means within a column having different letters are significantly different ($P < 0.05$) (n = 92 for sensory scores; n = 4 for weight and specific volume).
[b] Hedonic rating: 1 = dislike extremely; 9 = like extremely.

Objective Tests

Bread loaf volume was determined 2 hr after baking using rapeseed displacement in a loaf volumeter. Each loaf was weighed and the specific volume was calculated. Spice bars, muffins, and granola bars were evaluated for color differences by means of a Gardner Tristimulus XL-23 colorimeter (Bethesda, MD) using the *L, a, b* scale compared to a white standard (XL-23-246-D). Pans of spice bars were cut into four sections and weighed before volume measurement by rapeseed displacement in a volumeter. The weights and volumes of all four sections were added to calculate total weight and volume, respectively. The volumes of muffins and biscuits were determined by rapeseed displacement. Cookie spread was determined by the following formula:

$$\% \text{ spread} = \frac{d_f - d_i}{d_i} \times 100$$

where d_f is the diameter after baking and d_i is the diameter before baking. Cooked weight of noodles was determined by weighing after draining for 2.5 min. Cooking loss was determined by collecting the combined cooking and wash water in a preweighed beaker, evaporating to dryness in an air oven at 110°C, and weighing the residue.

Analysis of Data

Sensory and objective tests were statistically analyzed using the analysis of variance procedure of the Statistical Analysis System (SAS) computer package (8). Duncan's multiple range test ($P = 0.05$) was used as the post hoc procedure when the analysis of variance of three or more treatments indicated significant differences. Results from the paired-preference test for biscuits were compared to tables estimating significance for that test (9). Descriptive statistics are reported for some objective analyses.

RESULTS AND DISCUSSION

Flour and Cereal Composition

Results of proximate analysis of whole-grain barley flour and all-purpose wheat flour are compared to information

Table V. Evaluation of Carrot-Spice Bars Prepared with 100% Barley or All-Purpose Wheat Flour[a]

Flour	Sensory Scores[b]			Volume (cm^3)	Weight (g)	Color		
	Appearance	Texture	Flavor			L	a	b
Barley	6.57 A	6.73 A	6.52 A	1,035 A	470.9 A	30.67 B	6.88 B	9.08 A
All-purpose wheat	6.80 A	6.45 A	7.05 A	1,140 A	471.4 A	34.26 A	7.92 A	11.20 A

[a] Means within a column having different letters are significantly different ($P < 0.05$) (n = 74 for sensory scores; n = 2 for volume, weight, and color scores).
[b] Hedonic rating: 1 = dislike extremely; 9 = like extremely.

from package labels of whole wheat flour and oat-bran cereal in Table III. The oat-bran cereal had the highest protein and lipid levels. Total dietary fiber was highest for barley flour, followed by oat-bran cereal. Oat-bran cereal and barley flour ground from whole waxy, hull-less barley had the highest β-glucan levels. The particle size distribution of the barley flour was 41.5, 5.5, 6.1, and 46.9% on sieve sizes 80, 100, 140, and through 140, respectively.

Table VI. Evaluation of Blueberry Muffins Prepared with Barley/Wheat Flour Variations[a]

Flour	Sensory Scores[b]					Volume (cm^3)
	Appearance	Texture	Flavor	Sweetness	Aftertaste	
Barley (70%), all-purpose wheat (30%)	6.37 A	5.87 A	5.64 A	5.48 A	4.93 A	109.2 B
Whole wheat (70%), all-purpose wheat (30%)	6.32 A	5.68 A	5.70 A	5.64 A	5.32 A	124.2 A
All-purpose wheat (100%)	6.46 A	5.62 A	5.66 A	5.64 A	5.18 A	124.2 A

[a] Means within a column having different letters are significantly different ($P = 0.05$) (n = 73 for sensory scores; n = 6 for volume).
[b] Hedonic rating: 1 = dislike extremely; 9 = like extremely.

Sensory Analysis

Most of the products prepared with barley compared favorably with the products prepared using the wheat, rice, or oat products specified in the original formulas.

Breads. Sensory scores for texture, flavor, and overall acceptability were not significantly different when 26% barley bread was compared with 26% whole wheat bread (Table IV). The sensory color score for barley bread was between "liked slightly" and "liked moderately" but was significantly lower than the color score for whole wheat bread. Barley bread weighed more than the whole wheat bread after baking, suggesting that the barley bread retained more moisture. The specific volume of the whole wheat bread was not significantly greater than that of the barley bread.

Although Bhatty (10) reported that no more than 10% barley flour could be incorporated into white pan bread without seriously affecting loaf volume and appearance, Swanson and Penfield (11) developed an acceptable formula for a whole-grain bread containing 20% barley flour and 30% whole wheat flour. Perhaps whole-grain breads, such as barley bread, should be compared to other whole-grain breads rather than to white-pan breads.

Spice Bars. Hedonic scores for appearance, texture, and flavor were not significantly different for carrot-spice bars formulated with 100% all-purpose wheat flour or 100% whole-ground barley flour (Table V). The volumes and weights of both types of bars did not differ significantly. The L and a values of the bars made with all barley flour were lower, indicating a slightly darker color and slightly less redness.

Blueberry Muffins. The panelists' scores for appearance, texture, flavor, sweetness, and aftertaste of a no-fat blueberry muffin formulation made with 70% whole-ground barley and 30% all-purpose wheat flour were not different from scores for the same muffin formula prepared with 100% all-purpose flour or 70% whole wheat and 30% all-purpose wheat flours (Table VI). Newman and coworkers (12) also conducted a sensory evaluation of waxy hull-less barley muffins. Although they did not evaluate muffins on a hedonic scale, they found that panelists could not detect differences between muffins made with waxy, hull-less barley or wheat when the color was masked. The low scores (less than 6) for flavor, sweetness, and aftertaste in this study may be related to indications by the judges that they would have liked all muffins to be sweeter than the formula used.

Of the three types of blueberry muf-

Table VII. Color of Blueberry Muffins Prepared with Barley/Wheat Flour Variations[a]

Flour	Top L	Top a	Top b	Bottom L	Bottom a	Bottom b	Slice L	Slice a	Slice b
Barley (70%), all-purpose wheat (30%)	55.70 B	7.48 B	19.65 B	63.32 B	6.04 B	20.63 B	63.53 B	4.55 B	18.15 B
Whole wheat (70%), all-purpose wheat (30%)	56.18 B	9.08 A	18.83 B	59.22 C	7.80 B	21.61 B	63.10 B	7.73 C	16.78 B
All-purpose wheat (100%)	70.59 A	5.69 C	24.83 A	68.98 A	10.65 A	26.31 A	82.09 A	1.78 A	21.95 A

[a] Means within a column having different letters are significantly different ($P = 0.05$) (n = 5 for top; n = 4 for bottom; n = 2 for slice).

fins, the barley muffins had a lower volume than either of the wheat muffins. When color was determined at all three locations—the top, bottom, and inside of the muffin—higher L values for all-purpose muffins indicated a lighter color, as would be expected (Table VII). Likewise, b values were higher for the 100% all-purpose wheat flour muffins, indicating more yellow coloration.

Cookies. Test and control chocolate chip cookies received similar ratings for texture, flavor, and overall appeal (Table VIII). Flavor and overall scores for all chocolate chip cookies were in the "moderately like" category. The appearance of the 100% wheat cookies was rated significantly higher than for that of the 50% barley cookies. The top surface of the barley cookies was described as more "cracked" and slightly more "grainy." The control cookies spread more than those with 50% barley.

Scores for texture, flavor, and overall appeal of raisin cookies made with barley or oats (Table IX) were also not significantly different. The appearance of the oat-bran raisin cookie was rated higher than that of the barley-cereal raisin cookie. Cookies made with barley spread significantly more than oat-bran cookies.

Biscuits. No significant differences in preference were observed for flavor or overall acceptability when 25% and 35% barley biscuits were compared to a 100% all-purpose wheat flour control (n = 75). Consumer panelists preferred the appearance of the 100% all-purpose biscuit more than that of the 35% barley biscuit ($P = 0.05$); panelists preferred the texture of the 100% all-purpose flour biscuit compared with that of the 25% barley biscuit ($P = 0.05$). The biscuit volume was greatest for the control (63.25 cm^3) and decreased as barley content increased from 25% (59.75 cm^3) to 35% (57.50 cm^3).

Noodles. Barley noodles (75% barley, 25% semolina) and commercially prepared whole wheat noodles were evaluated by the same panel on three different occasions (Table X). Scores for the flavors of the two noodles were similar, but the whole wheat noodles received higher scores than did the barley noodles for appearance and texture. The starch in the air-dried barley noodles was not gelatinized to the same degree as that in the commercial wheat noodle. This factor probably contributed to the less-desirable texture and appearance of the barley noodles and to the reduced cooking time necessary to achieve optimal doneness. The reduced cooking time resulted in less cooking loss and slightly higher cooked weight for the barley noodles.

Several other workers have reported acceptable pasta products prepared with barley. Melland and coworkers (13) prepared acceptable spaghetti with bleached barley flour, and Nakamura (14) reported lower stickiness and higher values of cohesiveness, softness, and chewiness for barley pasta compared with wheat pasta.

Granola Bars. Granola bars (Table XI) formulated with barley flakes and an extruded crisp cereal made of 50% barley and 50% rice or of 100% barley were compared with a granola bar made with oatmeal and an extruded crisp-rice cereal. Panelists rated the appearance and flavor of both granola bars made with the barley flakes significantly higher than those made with oatmeal. The texture of the bar prepared with barley flakes and crisp barley-rice cereal was rated highest. All the flavor scores were in the neutral (neither like or dislike) range, probably due to lack of optimal binder flavor and not to the cereals used in the bars, indicating that further development is warranted for the binder. The only difference in color scores, a higher *b* value for the oatmeal-crisp rice cereal bars, indicated a slightly yellower color.

CONCLUSIONS

Most of the food products prepared with waxy, hull-less barley and evaluated in this experiment were liked as well as products prepared using the original formulas that contained wheat, oats, or rice. Waxy, hull-less barley can be successfully substituted for wheat flour in many food products in amounts ranging from 25 to 100%. When waxy, hull-less barley is incorporated, both total fiber and soluble fiber content are increased to produce higher-fiber food products. Foods containing barley may appeal to consumers who are interested in whole-grain and higher-fiber food products.

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Table VIII. Evaluation of Chocolate Chip Cookies Prepared with Barley and All-Purpose Wheat Flour Variations[a]

Flour	Sensory Scores[b]				Spread (%)
	Appearance	Texture	Flavor	Overall	
Barley (50%), wheat (50%)	6.76 B	6.40 A	7.01 A	6.88 A	64.1 ± 0.16
Wheat	7.03 A	6.64 A	7.19 A	7.16 A	76.2 ± 0.10

[a]Means within a column having different letters are significantly different ($P < 0.05$) (n = 95 for sensory scores; n = 12 for spread).
[b]Hedonic rating: 1 = dislike extremely; 9 = like extremely.

Table IX. Evaluation of Raisin Cookies Prepared with Barley or Oat-Bran Cereal[a]

Ingredients	Sensory Scores[b]				Spread (%)
	Appearance	Texture	Flavor	Overall	
Barley	5.99 B	5.44 A	6.34 A	6.08 A	65.2 A
Oat-bran cereal	6.36 A	5.66 A	6.69 A	6.45 A	58.5 B

[a]Means within a column having different letters are significantly different ($P < 0.05$) (n = 80 for sensory scores; n = 30 for spread).
[b]Hedonic rating: 1 = dislike extremely; 9 = like extremely.

Table X. Evaluation of Barley and Whole Wheat Noodles[a]

Flour	Sensory Scores[b]			Cooked Weight (g)	Cooking Loss (%)
	Appearance	Texture	Flavor		
Barley (75%), semolina (25%)	5.11 B	4.94 B	5.67 A	27.62 A	5.50 B
Whole wheat	6.56 A	5.50 A	5.17 A	26.58 A	9.85 A

[a]Means within a column having different letters are significantly different ($P < 0.05$) (n = 18 for sensory scores, n = 3 for cooked weight and cooking loss).
[b]Hedonic rating: 1 = dislike extremely; 9 = like extremely.

Table XI. Evaluation of Granola Bars Prepared with Barley Flakes or Oatmeal and Extruded Cereals[a]

Ingredients	Sensory Scores[b]			Color		
	Appearance	Texture	Flavor	L	a	b
Barley flakes with crisp barley rice cereal	7.44 A	6.51 A	5.82 A	67.68 A	5.34 A	17.15 B
Barley flakes with 100% crisp barley cereal	7.13 A	5.71 B	5.42 A	67.57 A	5.36 A	17.23 B
Oatmeal with 100% crisp rice cereal	6.39 B	5.21 B	4.48 B	66.77 A	5.06 A	18.02 A

[a]Means within a column having different letters are significantly different ($P = 0.05$) (n = 85 for sensory scores; n = 3 for color scores).
[b]Hedonic rating: 1 = dislike extremely; 9 = like extremely.

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Barley Bran Flour Evaluated as Dietary Fiber Ingredient in Wheat Bread

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ABSTRACT

Barley bran flour (BBF), one of the newer cereal fiber sources, was compared for composition and baking performance to other commercial fiber ingredients such as oat bran, corn bran, wheat bran, soy bran, cellulose, and whole wheat flour. Significant differences in both composition and quality of bread were realized by 15% replacement of wheat flour by individual fiber ingredients. Baking characteristics of breads were obtained by subjective scoring by trained panelists and by specific volume measurement. BBF outperformed other fiber ingredients in producing a bread with substantially increased dietary fiber, highest loaf volume, and highest quality score of the fiber-enriched breads. BBF bread was scored the highest for flavor. Water absorption and mixing requirements for experimental doughs containing each fiber were obtained using the mixograph. The bread formulation and method of baking used was the one commonly known as the Kansas State Process.

The nutritional benefit of dietary fiber from different sources has been the subject of numerous research studies (1-13). All kinds of conventional and non-conventional sources of fiber are available as commercial ingredients. Among the common cereal sources of dietary fiber available on a commercial scale are wheat, corn, and oats. Until now barley bran has not been used extensively because comparatively small quantities of barley were milled and pearled to provide by-product bran.

Recently however, malted barley from the brewing of beer (brewers grain) was milled by a new process to produce a bran flour with high total dietary fiber (TDF) (14). Brewers grain consists of the pericarp, embryo, and hull portions of barley. The resulting bran flour contained 67% insoluble and 3% soluble dietary fiber, 18.5% protein, 6.8% fat, and 4.6% ash. This barley flour was not commercially available when Prentice and D'Appolonia (15) and Dreese and Hoseney (16) investigated production of fiber-enriched breads using barley flour recovered from brewers grain.

Barley bran flour (BBF) processed from brewers grain is plentiful, relatively inexpensive, and high in TDF (70%). In addition, the combined health benefits of BBF make it well suited to enrich the fiber content of bread and many other baked products. Specifically, BBF consumed in sufficient quantity promotes laxation, bile acid binding, and inhibition of hepatic cholesterol synthesis (13). It contains virtually no mineral-binding phytic acid and contributes only 1.2 calories/g. Phytate is lower in BBF than in unmalted barley because of phytase activity during malting. The process yields a flour of uniform granulation and composition that is low in microbial levels and without residual enzyme activity.

The investigation reported here compares performance of BBF with other commercial sources of dietary fiber used in baking high fiber and calorie reduced wheat breads.

MATERIALS AND METHODS

High gluten flour, whole wheat flour, and wheat bran were obtained from local bakery suppliers. The flour was a commercially available Pillsbury Co. bread flour from hard red wheat, containing no added gluten. Dietary fiber ingredients were obtained from commercial sources: soy bran (Nutrisoy Fiber E) from Archer Daniels Midland Co., oat bran from National Oats Co., corn bran (G-Regular) from A. E. Staley Mfg. Co., and alpha-cellulose (BW200 FCC) from James River Corp. Barley bran (Barleys Best Bran Flour) was processed by Miller Brewing Co. Protein, crude fat, ash, and moisture of these fiber ingredients were determined by AOAC methods (17). TDF was determined using the method by Prosky and co-workers (18).

Physical dough characteristics—namely water absorption and optimum mixing time for high gluten flour, whole wheat flour, and the 15% blends of each fiber ingredient with high gluten wheat flour—were determined using the AACC mixograph testing procedure (19).

Breads were prepared on laboratory scale as 1-lb loaves by conventional straight-dough baking procedure according to the Kansas State Process (20), using a Hobart A-200 mixer and with potassium bromate and sodium steroyl lactylate (SSL) in the bread formulation. The baking formula used was as follows: flour 100%, sugar 6%, salt 2.5%, yeast cake 4%, SSL-2 0.5%, and potassium bromate 60 ppm. Ingredients are expressed as percentage of flour weight. The amount of water in each formula was determined by the mixograms and appears in Table I.

Bread was baked at 425° F for 20 min. Weight and loaf volume measurements were made using scale and rapeseed displacement method. Breads were scored for external and internal properties by a five-person trained panel. The maximum score was 100 points, distributed as follows: volume 10, symmetry 5, crust color 10, break and shred 5, grain quality 10, crumb texture 15, crumb color 10, aroma 10, taste 15, and mouthfeel 10. Breads were then analyzed for moisture, protein, and TDF

[1] Miller Brewing Co., Milwaukee, WI 53201

(17,18), and calories were determined by calculation.

RESULTS AND DISCUSSION

Composition of flour and other ingredients used for making bread is very important for bakers to produce a good quality loaf and to meet nutrient objectives. Compositions of fiber ingredients and flour used in the experiment are shown in Table II. A wide range of protein, fat, and TDF contents was found among the fiber ingredients. To accommodate apparent variation in composition of fiber and flour blends, the physical dough properties were measured by mixograph to establish initially the most effective mixing time and water absorption for a given flour or a mixture of fiber and flour. While we regard this as an initial and logical step for doughs containing appreciable and varying amounts of fiber ingredients, further optimization of loaf quality could probably have been achieved for each fiber by repeated baking tests.

The amount of water needed to attain the optimum consistency and mixing time appear in Table I. All fiber ingredients except oat bran showed an increase in mixing time over the control high gluten flour, but no tendency toward dough breakdown. BBF had the least effect on mixing time, while whole wheat flour and alpha-cellulose increased mixing time by 3.0–3.5 min compared to high gluten flour. TDF contents of the flour blends and their respective mixing times are shown in Table I. There was no correlation apparent among these values. Table I also shows increases in water absorption caused by 15% replacement of fiber ingredients. Alpha-cellulose required the most water (78%), and whole wheat flour the least (70%) among the fiber ingredients. The high gluten flour required 69%.

Composition of bread and differences in TDF, moisture, calories, and protein caused by addition of each fiber ingredient are shown in Table III. TDF recovered from each bread was consistent with the TDF content of the fiber ingredients used. Percentage increase in TDF of breads ranged from 64 for oat bran to 324% for alpha-cellulose when compared to control.

All breads containing fiber ingredients

Table I. Water Absorption and Mixing Time Determined by Mixograph for Flours and Mixtures of High Gluten Flour with 15% Fiber Ingredients

Sample	Water Absorption (%)	Mixing Time (min)	TDF (% Dry Basis)
High gluten flour 100%	69.0	4.5	3.8
HG flour + barley bran	72.5	5.0	14.3
HG flour + α-cellulose	78.0	6.5	18.1
HG flour + corn bran	74.0	5.5	15.8
HG flour + oat bran	72.0	4.5	6.8
HG flour + soy bran	75.0	5.5	13.8
HG flour + wheat bran	71.0	5.5	11.2
Whole wheat flour 100%	70.0	7.0	10.2

Table II. Composition of Flours and Other Fiber Ingredients (%, dry weight basis)

Sample	TDF	Protein	Fat	Ash	Moisture
High gluten flour	3.8	14.8	1.2	0.5	10.1
Barley bran flour	70.0	18.5	6.8	4.6	3.5
α-cellulose	99.0	...	...	0.2	6.0
Corn bran	80.0	5.9	4.0	1.0	11.0
Oat bran	20.4	19.3	6.5	4.5	10.3
Soy bran	67.0	12.0	2.0	5.0	7.0
Wheat bran	49.5	16.4	3.6	5.9	8.9
Whole wheat flour	10.7	14.8	2.1	1.3	10.2

Table III. Composition of Breads Containing 15% (Flour Basis) of Various Fiber Ingredients

	TDF		Moisture		Calories		Protein	
Breads	Amount in Bread, % db	Change from Control, %	Amount in Bread, %	Change from Control, %	Amount in Bread, kCal/100 g	Change from Control, %	Amount in Bread, % db	Change from Control, %
High gluten flour (control)	2.5	...	37.8	...	236	...	9.65	...
Barley bran flour	8.9	256	38.9	2.9	208	−11.9	9.58	− 0.73
α-Cellulose	10.6	324	42.0	11.1	187	−20.7	7.87	−22.6
Corn bran	10.4	316	40.0	5.8	196	−16.9	8.50	−11.9
Oat bran	4.1	64	38.8	2.6	228	− 3.4	10.40	9.3
Soy bran	8.7	248	40.4	6.9	200	−15.2	9.06	− 6.1
Wheat bran	6.2	148	39.6	4.8	214	− 9.3	9.79	1.5
Whole wheat bran	6.1	144	39.1	3.4	218	− 7.6	9.62	− 0.31

Table IV. Characteristics of Breads Baked from Flour Mixtures with Various Fiber Ingredients

	Specific Volume[a,b] (g/c³)	Specific Volume (% of Control)	Bread Score[b,c] (Maximum Score 100)	Bread Score (% of Control)
High gluten flour (control)	6.02 A	100	91 A	100
Barley bran flour	5.54 B	92	80 B	88
α-Cellulose	3.70 E	61	47 E	52
Corn bran	3.54 F	59	42 E	46
Oat bran	4.53 C	75	73 B	80
Soy bran	3.57 F	59	57 D	63
Wheat bran	4.57 C	76	74 B	81
Whole wheat flour	4.41 D	73	68 C	75

[a]Mean values of measurements of weight and volume of eight loaves, two from each of four doughs.
[b]Means with same letter are not significantly different, $P > 0.05$.
[c]Mean values of internal and external score of four bread loaves by five trained panelists.

retained slightly more moisture than control bread. All fiber ingredients caused a reduction in caloric content of bread. Percentage decrease in calories ranged from 7.6% for whole wheat flour to 20.7% for alpha-cellulose relative to the control. Percent change in protein content of breads was interesting. Wheat bran and oat bran increased the bread protein content, while all other fiber ingredients reduced it.

In most cases fiber ingredients in bread produced large decreases in both specific volume and loaf score when compared to values for high gluten flour bread (control) as shown in Table IV. Percentage loaf volume relative to control ranged from 92% for barley bran to 58% for corn bran. Bread scores ranged from 88 for barley bran to 46 for corn bran, with control bread assigned a score of 100. Among the fiber ingredients investigated, BBF retained the highest loaf volume and loaf score, while corn bran, soy bran, and alpha-cellulose caused the largest decrease in both values. Also, breads containing barley bran, oat bran, and wheat bran were preferred over corn bran, soy bran, alpha-cellulose, and whole wheat bread when judged by the panel for mouthfeel, taste, and aroma.

CONCLUSIONS

Significant changes in both composition and quality of bread were realized by 15% replacement of wheat flour by individual fiber ingredients. In general, fiber ingredients in bread decreased both specific volume and loaf score relative to control bread made with a strong (high gluten) bread flour. However, BBF caused the smallest decrease in both volume and loaf score. BBF along with oat bran and wheat bran produced acceptable breads on the basis of key attributes—volume, texture, and taste. While alpha-cellulose, corn bran, and soy bran contributed higher dietary fiber and lower calorie content to the breads, these breads were less than acceptable when scored for loaf volume texture and taste. Overall, BBF outperformed other fiber ingredients when used at 15% replacement level. It required increased mixing time, but produced a bread with substantially increased dietary fiber, reduced calories, and with minor loss in loaf volume, texture, flavor characteristics.

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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.

[1]Partly included in a final report to the Agricultural Development Fund, Regina, SK, Canada.

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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

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 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% (12*M*) 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	*L* Values 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]

Property/Component	Bran		Flour	
	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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Cholesterol-lowering effect of barley bran flour and oil

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ABSTRACT

Objective To compare the effects of adding barley bran flour and a barley oil extract to a fat-modified diet on serum lipids in persons with hypercholesterolemia.
Design The basic design of the study was a randomized, 30-day intervention trial. It included a neutral-fiber control group and a 1-week preintervention period for the collection of baseline data.
Subjects The subjects were 79 men and women with hypercholesterolemia. Subjects had a mean age of 48.2 years, and all completed the study.
Intervention All participants were instructed to follow the National Cholesterol Education Program (NCEP) step 1 diet and were randomly assigned to one of three treatment groups: 20 g added cellulose, 3 g added barley oil extract, or 30 g added barley bran flour.
Main outcome measures Total serum cholesterol, high-density lipoprotein cholesterol (HDL-C), low-density lipoprotein cholesterol (LDL-C), and very-low-density lipoprotein cholesterol were measured, along with serum triglycerides, before the intervention, at week 1, at week 3, and at the end of the intervention.
Statistical analyses performed Student's paired *t* test was used to detect significant changes within each treatment group from baseline to the end of the 30-day intervention. In addition, Pearson's correlation coefficients were used to detect significant correlations between the variables measured.
Results Addition of barley bran flour significantly (P=.0001) decreased total serum cholesterol (–0.60 mmol/L) as did addition of barley oil (–0.50 mmol/L; P=.002) after 30 days of intervention. Similarly, LDL-C decreased 6.5% with addition of barley bran flour (P=.036) and 9.2% with addition of barley oil (P=.003). Total serum cholesterol or LDL-C of the cellulose control group did not decrease significantly over the same period. HDL-C decreased significantly in the cellulose control group and the barley bran flour group (–0.15 mmol/L, P=.012, and –0.15 mmol/L, P=.006, respectively), but not in the barley oil group.
Conclusion We conclude that addition of barley bran flour or barley oil enhances the cholesterol-lowering effect of the NCEP step 1 diet in individuals with hypercholesterolemia. *J Am Diet Assoc. 1994; 94:65-70.*

Because high serum cholesterol is an important, modifiable risk factor for coronary heart disease, factors thought to lower blood cholesterol have been the subject of intense investigation. Dietary fibers, for example, have been tested for their effect on serum lipids in a large number of clinical trials, which were critically reviewed by the Life Sciences Research Office in 1987 (1). Although some controversy remains (2), a 1991 review (3) updated the Life Sciences Research Office study and came to the same conclusion: consumption of foods containing soluble dietary fiber reduces serum cholesterol values. In contrast, cholesterol-lowering properties have not been shown for sources high in insoluble fiber, such as cellulose and wheat bran (3). Results of many studies, including those cited in the aforementioned reviews, have prompted most health professionals to recommend soluble fiber sources specifically to those individuals desiring to lower their serum cholesterol values.

Some evidence suggests, however, that certain insoluble fibers may also possess cholesterol-lowering properties (4,5). Barley, for example, is a fiber source commercially available in two distinctly different forms. Whole barley, like oat bran, is high in soluble fiber, particularly β-D glucans (6). Thus, it is not surprising that whole barley has been shown to lower serum cholesterol in animal studies (7,8) and in clinical trials (9-11). Brewers' grain, on the other hand, is the insoluble portion of malted barley, which has been extracted with hot water to remove soluble carbohydrate. It contains only 1% to 3% soluble fiber (12). Nevertheless, brewers' grain significantly lowered low-density lipoprotein cholesterol (LDL-C) levels in 10 patients who had had an ileostomy (13). Likewise, barley bran flour, which is made by drying and milling brewers' grain, had a hypocholesterolemic effect in chicks when provided at 20% by weight (14). Although these studies suggest that barley bran flour is hypocholesterolemic in individuals who have an intact gastrointestinal tract, confirmation requires testing in a clinical trial.

Therefore, we designed a study to test the potential cholesterol-lowering effects of barley bran flour. We further attempted to isolate the portion of the fiber source containing the hypocholesterolemic agent(s). Because the lipid fraction of barley survives the brewing process (12), and because some prelimi-

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Table 1
Demographic variables of the subjects at baseline

Variable	Group		
	Cellulose (control)	Barley bran flour	Barley oil
No. in group	27	26	26
No. of men	13	11	12
No. of women	14	15	14
Age (y)[a]	48 ± 11	48 ± 11	47 ± 11
Weight (kg)[a]	74.5 ± 16	71.4 ± 15	72.7 ± 13
% ideal body weight[a]	119 ± 15	118 ± 15	117 ± 15
Smokers	2	1	2

[a]Results are expressed as mean ± standard deviation.

nary evidence suggested that the hypocholesterolemic properties of barley are contained in this lipid fraction (15), we extracted the oil from the barley bran flour and provided it to one of our test groups. Finally, because barley bran flour is primarily insoluble fiber, we hypothesized that it would have a positive effect on colon physiology by increasing fecal bulk and/or accelerating gastrointestinal transit. The effects of barley bran flour on colon physiology are reported separately (16).

MATERIALS AND METHODS

Subject Recruitment and Selection

After obtaining approval from the Institutional Review Board of Texas A&M University, subjects were recruited by advertising in campus and community newspapers, television and radio interviews with the researchers in which they asked for volunteers, fliers distributed on campus, university memorandums, and personal contact with physicians. Of those individuals who responded to the recruitment efforts, 200 passed an initial telephone screening designed to eliminate subjects with cholesterol values less than 5.95 mmol/L[1] or those who would be unavailable during the dates of the intervention. These 200 individuals were tested for total serum cholesterol values and interviewed to determine their eligibility for the study. The criteria for selection were as follows: (a) men and women 20 to 64 years of age; (b) within 30% of ideal body weight; (c) no significant history of diabetes, hypothyroidism or hyperthyroidism, alcohol or drug abuse, liver or kidney disease, or use of cholesterol-lowering agents; and (d) total serum cholesterol value of 5.95 mmol/L or higher as measured on two occasions by an independent laboratory. Of the 200 individuals screened, 95 qualified; 79 of those who qualified were willing and able to participate in the study.

Assignment of Subjects to Treatment

After a 1-week collection of baseline data, the 79 participants were randomly placed into three groups that were then stratified according to sex, age, ideal body weight, and whether the subject smoked. The amount of fiber supplemented was based on the recommendation of the National Cancer Institute to increase fiber intake to 30 g/day. The initial dietary intake of 9 to 11 g plus the supplement of 20 g fiber, equaled the 30-g recommendation. The control group added 20 g cellulose fiber (Avicel PH101, FMC Corp, Philadelphia, Pa) to the daily intake. A second group added 30 g barley bran flour (patent No. 4,541,805, provided by Miller Brewing, Milwaukee, Wis). The different weights of supplements were necessary to equalize intakes of dietary fiber, because barley bran flour is only 70% fiber (12) compared with 100% fiber cellulose supplement. The third group added 3 g barley oil to daily intake. The barley oil was extracted from the brewers' grain by hexane and then degummed, alkali refined, bleached with clay, and deodorized by vacuum. The 3 g barley oil represents the approximate amount one would obtain from extracting 30 g barley bran flour.

Each day's fiber supplement was provided in two equal amounts in preweighed packets. We decided to provide the supplements in pure form rather than incorporated into products to minimize the effects of processing or interaction with other ingredients. Subjects were instructed to mix the contents of one packet into the beverage of their choice and to ingest one packet at breakfast and one at dinner. Barley oil was taken in capsule form in two daily doses of three capsules each. In addition to taking the daily supplements, the entire cohort followed the National Cholesterol Education (NCEP) step 1 diet (17). Individuals were instructed weekly about adherence to this diet. Fiber supplements and oil capsules were distributed weekly at dietary instruction meetings.

Study Design and Data Collected

The basic design of the study was a randomized, 30-day intervention trial. It included a neutral-fiber control group and a 1-week preintervention period for the collection of baseline data.

Serum lipid and apoprotein analyses Subjects had their blood drawn by trained phlebotomists at baseline, at week 1, at week 3, and at the conclusion of the intervention. All blood was drawn in the morning after a 12-hour fast, and samples were analyzed enzymatically for total serum cholesterol (18) and triglycerides (19). Lipoproteins were separated by selective precipitation (20) and the cholesterol in the high-density lipoprotein fraction was measured directly. LDL-C was calculated (21). Very-low-density lipoprotein cholesterol was considered as the remaining portion of the total cholesterol after LDL-C and high-density lipoprotein cholesterol (HDL-C) were determined and subtracted from total cholesterol. Apoprotein A-1 and apoprotein B-100 were measured using the Turbiquant Apolipoprotein Kit with the Behring Turbitimer (Behring Diagnostics, Inc, Somerville, NJ) (22).

Blood pressure measurements Body weights and blood pressure were recorded each time blood was drawn. Blood pressure was measured using a standard cuff and sphygmomanometer on the left arm after the subject rested in a seated position for 5 minutes. Systolic blood pressure was recorded with the appearance of the first Korotkoff sound, and diastolic blood pressure was measured with the disappearance of the fifth Korotkoff sound.

Dietary intake assessment and additional analyses All subjects attended an orientation meeting and four lessons on diet given throughout the study. Subjects were provided with formatted data collection forms for keeping 3-day dietary records and were instructed as to their use. Food models helped with estimates of portion sizes. Each 3-day record included 2 weekdays and 1 weekend day. The records were completed and turned in at baseline, at week 2, and at the end of the intervention. All records were analyzed by computer using the Nutripractor food analysis program and database (Nutripractor 6000 nutrient analysis system, 1987, Practocare, San Diego, Calif). Diets were analyzed for total energy, cholesterol, and fat (total, saturated, monounsaturated, and polyunsaturated).

[1]To convert mmol/L cholesterol to mg/dL, multiply mmol/L by 38.7. To convert mg/dL cholesterol to mmol/L, multiply mg/dL by 0.026. Cholesterol of 5.00 mmol/L=193 mg/dL.

Table 2
Mean (±standard deviation) effect of intervention on body weight, blood pressure, and serum lipids[a]

Variable	Cellulose (n=27)				Barley bran flour (n=26)				Barley oil (n=26)			
	Before	After	Change	*P*	Before	After	Change	*P*	Before	After	Change	*P*
Body weight (kg)	74.5±16	75.0±16	0.5	.630	71.4±15	71.4±14	0	.984	72.7±13	72.7±12	0	.765
Systolic blood pressure (mm Hg)	117±11	119±9	2	.161	120±12	122±13	2	.3841	119±15	123±12	4	.245
Diastolic blood pressure (mm Hg)	77±8	70±9	−7	.004	80±8	69±9	−11	.0001	76±11	70±8	−6	.019
Total serum cholesterol (mmol/L)[a]	6.80±0.65	6.55±0.85	−0.25	.109	7.25±0.55	6.65±0.55	−0.60	.0001	6.85±0.70	6.35±0.80	−0.50	.002
LDL-C[b] (mmol/L)	4.30±0.70	4.20±0.90	−0.10	.618	4.70±0.85	4.40±0.65	−0.30	.036	4.60±0.90	4.15±0.95	−0.45	.003
HDL-C[b] (mmol/L)	1.55±0.45	1.40±0.45	−0.15	.012	1.65±0.40	1.50±0.35	−0.15	.006	1.55±0.40	1.55±0.40	0	.461
Triglycerides (mmol/L)[c]	1.92±1.02	1.98±1.08	0.06	.601	1.80±1.20	1.70±0.80	−0.10	.447	1.42±0.80	1.48±0.70	0.06	.554
Apoprotein A-1 (g/L)	1.38±0.25	1.33±0.19	−0.05	.208	1.42±0.32	1.28±0.22	−0.14	.014	1.31±0.2	1.25±0.25	−0.06	.181
Apoprotein B-100 (g/L)	1.39±0.31	1.37±0.34	−0.02	.689	1.47±0.35	1.32±0.26	−0.15	.004	1.42±0.27	1.29±0.30	−0.13	.052

[a]To convert mmol/L cholesterol to mg/dL, multiply mmol/L by 38.7. To convert mg/dL cholesterol to mmol/L, multiply mg/dL by 0.026. Cholesterol of 5.00 mmol/L = 193 mg/dL. [b]LDL-C = low-density lipoprotein cholesterol. HDL-C = high-density lipoprotein cholesterol. [c]To convert mmol/L triglyceride to mg/dL, multiply mmol/L by 88.6. To convert mg/dL triglyceride to mmol/L, multiply mg/dL by 0.0113. Triglyceride of 1.80 mmol/L = 159 mg/dL.

At the time of this experiment, the database for dietary fiber was incomplete. Therefore, we developed a fiber index to estimate daily fiber consumption. We found that neutral detergent fiber values for cereals and grains were adequate in the database, but values for fruits and vegetables were lacking; therefore, we analyzed the number of fruit and vegetable servings per person and arbitrarily assigned a value of 1 g fiber per serving. The fiber index was the sum of neutral detergent fiber plus fruit and vegetable servings. The resultant values were within the range of reported values for Americans (23).

Finally, intakes of four key index nutrients (vitamins A and B-6, calcium, and iron) were calculated to predict the overall adequacy of the diet (24).

Data Analysis

One-way analysis of variance was used initially to stratify individuals into the three treatment groups to ensure that no statistically significant differences in the variables of interest existed between the three groups. Student's paired *t* test was used to detect significant changes within each treatment group from baseline to the end of the 30-day intervention. In addition, Pearson's correlation coefficients were used to detect significant correlations between the variables measured. All statistics were obtained by means of the Statistical Analysis System (1976, SAS Institute, Cary, NC) (25); a *P* value ≤.05 was considered statistically significant.

RESULTS

Demographics of the Intervention Groups

All 79 people who committed to the study completed it. Each received $50 as an incentive. Demographics of the control and test groups are shown in Table 1. The total cohort comprised 36 men (46%) and 43 (54%) women. Mean age of the entire cohort was 48.2 years. The average person was 118.2% of ideal body weight. No significant differences were found among groups in any of the variables listed in Table 1.

Body Weight and Blood Pressure

Body weight stayed remarkably constant throughout the 4-week intervention (Table 2). Systolic blood pressure also did not change during the intervention. There was, however, a significant drop in diastolic blood pressure with all treatments (−9.12% with cellulose; *P*=.004; −14.53% with barley bran flour; *P*=.0001; −8.10% with barley oil; *P*=.019).

Serum Lipids and Apoproteins

Total serum cholesterol At baseline, the total serum cholesterol value for the entire cohort was 6.95 mmol/L (Table 2), which put the cohort at high risk for coronary heart disease—defined as values greater than 6.20 mmol/L (17). After 30 days of intervention, with all three treatment groups following the NCEP step 1 diet and taking supplements daily, total serum cholesterol was lowered by a mean of 0.45 mmol/L (6.3%) for the entire cohort. The control group, which consumed 20 g cellulose fiber daily, had a mean drop of 0.25 mmol/L (3.9%), which was not statistically significant (*P*=.109). The barley bran flour group (30 g/day) had a mean reduction of 0.60 mmol/L (7.7%), which was highly significant (*P*=.0001) (Table 2). The barley oil group (3 g/day) had a mean decrease of 0.50 mmol/L (7.1%), which was also statistically significant (*P*=.002).

LDL-C Changes in LDL-C were very similar to changes in total serum cholesterol. Initially, the total cohort had a mean LDL-C value of 4.55 mmol/L (high risk for LDL-C is >4.15 mmol/L) (17).

Table 3
Mean (±standard deviation) effect of intervention on energy, fat, and cholesterol intake[a]

Intake variables	Cellulose (n=27)				Barley bran flour (n=26)				Barley oil (n=26)			
	Before	After	Change	*P*	Before	After	Change	*P*	Before	After	Change	*P*
Energy (kcal)	1,694 ± 436	1,572 ± 450	−122	.146	1,891 ± 438	1,596 ± 359	−295	.007	1,751 ± 326	1,420 ± 478	−331	.006
Cholesterol (mg/day)	195 ± 98	175 ± 109	−20	.399	235 ± 101	161 ± 97	−74	.0003	202 ± 90	154 ± 85	−48	.013
Total fat (g/day)	58.1 ± 21	48.5 ± 22	−9.6	.018	67.0 ± 25	48.4 ± 20	−18.6	.001	64.4 ± 18	40.2 ± 17	−24.2	.0001
Saturated fat (g/day)	14.7 ± 7	12.6 ± 7	−2.1	.245	17.9 ± 9	11.6 ± 5	−6.3	.001	17.9 ± 7	9.6 ± 4	−8.3	.001
Monounsaturated fat (g/day)	13.7 ± 7	12.3 ± 6	−1.4	.372	16.1 ± 8	11.5 ± 5	−4.6	.009	15.4 ± 7	9.3 ± 5	−6.1	.0004
Polyunsaturated fat (g/day)	4.8 ± 3	4.4 ± 4	−0.4	.574	6.1 ± 3	4.4 ± 3	−1.7	.04	6.1 ± 4	3.4 ± 3	−2.7	.0026
Fiber estimate[b] (g/day)	9.9 ± 2	10.3 ± 2	0.4	.598	10.3 ± 2	11.6 ± 2	1.3	.670	9.7 ± 2	9.6 ± 2	−0.1	.544
Vitamin A (RE/day)	910 ± 619	864 ± 481	−46	.730	951 ± 551	797 ± 520	−154	.253	886 ± 508	706 ± 595	−180	.101
Vitamin B-6 (mg/day)	1.5 ± 0.8	1.3 ± 0.5	−0.2	.321	1.7 ± 0.8	1.6 ± 0.8	−0.1	.919	1.6 ± 0.8	1.5 ± 0.7	−0.1	.617
Iron (mg/day)	13.7 ± 6	12.0 ± 4	−1.7	.233	14.4 ± 4	12.5 ± 5	−1.9	.014	13.7 ± 4	12.9 ± 10	−0.8	.728
Calcium (mg/day)	652 ± 353	698 ± 427	46	.296	687 ± 223	567 ± 157	−20	.020	687 ± 275	582 ± 313	−105	.096

[a]These values do not include the contribution of the fiber or oil supplements.
[b]Fiber intake was estimated as described in the Materials and Methods section.

The cellulose fiber group had a mean decrease in LDL-C of 0.10 mmol/L, which was not statistically significant (*P*=.618). The barley bran flour group had a mean reduction of 0.30 mmol/L (6.5%), which was significant at *P*=.036. The barley oil group had the most substantial change with a mean reduction of 0.45 mmol/L (9.2%) (*P*=.003).

HDL-C A difference was seen in the changes in HDL-C compared with the changes in total serum cholesterol and LDL-C. The cellulose fiber group had a mean reduction of 0.15 mmol/L (7.4%); the barley bran flour group had a mean reduction of 0.15 mmol/L (7.8%). These were both statistically significant reductions with *P* values of 0.012 and 0.006, respectively. In contrast, the HDL-C level was preserved in the barley oil group (no change; *P*=.461).

Serum triglycerides Mean triglyceride levels did not change with treatment in any group. The cellulose and barley oil groups had minor increases (0.06 and 0.06 mmol/L, respectively), and the barley bran flour group had a slight decrease of 0.10 mmol/L. None of these changes was statistically significant.

Apoproteins A-1 and B-100 At baseline, the mean apoprotein A-1 value for the total cohort was 1.37 g/L, which is within the acceptable range of 0.73 to 1.69 g/L (26). After 30 days of intervention, apoprotein A-1 showed a mean reduction of 0.05 g/L (4.0%) in the cellulose group, 0.14 g/L (10.1%) in the barley bran flour group, and 0.06 g/L (4.8%) in the barley oil group. Of these reductions, only the 10% reduction in the barley bran flour group was statistically significant (*P*=.014). No significant correlation was found between changes in apoprotein A-1 and HDL-C (*r*=.14; *P*=.21).

The mean value for apoprotein B-100, which occurs in the low-density lipoprotein fraction, was significantly elevated for the total cohort at baseline (1.43 g/L); the normal range is 0.58 to 1.38 g/L (26). This elevation is not surprising because LDL-C values were also elevated in the total cohort at baseline. Apoprotein B-100 values were reduced after the intervention by 0.02 g/L (1.4%) in the cellulose group, 0.15 g/L (10.1%) in the barley bran flour group, and 0.13 g/L (9.3%) in the barley oil group. The reductions in the barley bran flour and barley oil groups were statistically significant (*P*=.004 and *P*=.052, respectively), but the reduction in the cellulose fiber group was not (*P*=.689). In contrast to the lack of correlation between apoprotein A-1 and HDL-C, there was a significant positive correlation between the changes in LDL-C and apoprotein B-100 levels (*r*=0.44; *P*=0.0001).

Dietary Changes

Energy, fat, and cholesterol Analyses of preintervention and postintervention dietary records showed a significant reduction of 295 kcal in the barley bran flour group (*P*=.007) and 331 kcal in the barley oil group (*P*=.006), but not in the cellulose control group (−122 kcal; *P*=.146) (Table 3). A similar pattern was found for dietary cholesterol, with a significant reduction of 74 mg with barley bran flour (*P*=.0003) and 48 mg with barley oil (*P*=.013) but not with cellulose (−20 mg; *P*=.399). In contrast, all three groups significantly reduced the total amount of fat consumed per day (Table 3). The barley oil and barley flour groups significantly decreased consumption of each type of fat (saturated, monounsaturated, and polyunsaturated). In contrast, even though the cellulose-supplemented group reduced total fat intake, no one type of fat was significantly reduced (Table 3).

Fiber Fiber intake was estimated from intake of neutral detergent fiber plus fruit and vegetable exchanges. These values do not include the fiber supplements. No differences in fiber intake were found between preintervention and postintervention for any group (Table 3).

Index nutrients Preintervention and postintervention values for the four index nutrients are also shown in Table 3. No significant changes were found in consumption of vitamins A or B-6 as a result of the intervention. In regard to iron and calcium consumption, there was no significant effect of cellulose or barley oil supplementation, but individuals who consumed barley bran flour significantly reduced their intake of these two nutrients.

Comparison of Predicted vs Actual Changes in Serum Cholesterol Values

Because of the differences in intakes of energy, cholesterol, and saturated and polyunsaturated fat among the three treatments, we decided to apply the formula of Keys et al (27) to the data to differentiate lipid responses to changes in dietary fat and fiber. The results of these analyses are shown in Table 4. In each case, fiber or oil supplementation resulted in a greater cholesterol-lowering effect than predicted by changes in fat or cholesterol intake alone. The difference between actual and predicted values was greatest for barley bran flour (predicted=–5.84 mg/dL, actual=–22mg/dL, difference=–16.16 mg/dL). Barley oil resulted in the second greatest cholesterol-lowering effect that was not due to changes in lipid intake (predicted=–6.79 mg/dL, actual=–18 mg/dL, difference=–11.21 mg/dL). When the formula was applied to the cellulose-supplemented group data, the predicted value was –1.55 mg/dL and the observed value was –10 mg/dL. By this reasoning, cellulose alone resulted in a cholesterol-lowering effect of 8.45 mg/dL.

Table 4
Predicted changes in serum cholesterol values because of changes in intake of saturated fat, polyunsaturated fat, and cholesterol compared with actual values

Supplement	Predicted change according to equation of Keys et al[a]	Actual change	Change not due to intake of saturated fat, polyunsaturated fat, or cholesterol
Cellulose	– 1.55 mg/dL	– 10 mg/dL	– 8.45 mg/dL
Barley bran flour	– 5.84 mg/dL	– 22 mg/dL	– 16.16 mg/dL
Barley oil	– 6.79 mg/dL	– 18 mg/dL	– 11.21 mg/dL

[a]Predicted change in serum cholesterol calculated using the equation of Keys et al (27): Δcholesterol = $1.2\,(2\Delta S - \Delta P) - 1.5\Delta Z$.
Δcholesterol = difference in initial vs final total cholesterol in mg/dL.
S = % of total energy provided by glycerides of saturated fatty acids.
P = % of total energy provided by glycerides of polyunsaturated fatty acids.
Z^2 = milligrams of dietary cholesterol/1,000 kcal.

DISCUSSION

Our hypothesis was that an insoluble fiber source (barley bran flour) would have hypocholesterolemic properties and that these properties would be contained in the lipid portion of the barley bran flour. This hypothesis was based on animal studies in which barley oil significantly decreased serum cholesterol in female pigs (28) and in chicks (29). To our knowledge, our study provides the first evidence of a similar response among human beings. Barley bran flour significantly lowered both total serum cholesterol and LDL-C. These same cholesterol-lowering properties were also seen with barley oil, which had the added benefit of not lowering HDL-C. In contrast, the cellulose-supplemented control group did not experience a significant reduction in either total cholesterol or LDL-C.

The amount of cholesterol reduction attributable to barley bran flour or oil alone is not known, because there are multiple variables in a free-living population consuming self-selected diets. However, the purpose of the cellulose-supplemented group was to provide data on individuals who differed from the two barley intervention groups solely by their consumption of a different supplement. Obviously, we could not obtain identical populations; but by selecting those variables most known to affect serum cholesterol and ensuring that they were the same across groups, we at least helped to minimize differences. Stratification at baseline resulted in the three groups being similar with respect to numbers of men and women, age, weight, percentage of ideal body weight, and numbers of smokers and nonsmokers. Our next consideration was to minimize the number of variables introduced by consuming a fiber supplement. For this reason, we decided to provide the supplements in a pure form rather than incorporated into products that would contain additional ingredients. To control for the ingestion of a fiber supplement itself, we used a parallel cellulose-supplemented group rather than a group that received no intervention, because we assumed that the actual process of consuming a fiber supplement twice a day could affect behavior.

Therefore, if we compare the values from the barley bran flour and oil groups to those from the cellulose-supplemented group, the differences should be attributable to the particular supplement alone. For example, reductions in total serum cholesterol were 7.7% for barley bran flour, 7.1% for barley oil, and 3.9% for cellulose. These data could be interpreted to mean that the effect of barley bran flour alone was 3.8% (7.7%–3.9%) and 3.2% for barley oil. Applying the same reasoning to the LDL-C values, reductions were 6.4% for barley bran flour, 9.2% for barley oil, and 1.8% for cellulose, resulting in an effect of barley bran flour alone on LDL-C of 4.6% and an effect of barley oil of 7.4%. These values are similar to those observed by adding 56 to 60 g oat bran or oatmeal to a low-fat diet (30,31).

Other factors that can independently affect total serum cholesterol and LDL-C values are body weight and intake of fiber, cholesterol, and fat, particularly saturated fat. No change in weight occurred in any group, which was surprising given the decrease in energy intake. However, it is likely that food intake was underreported, because energy values are lower than would be predicted for a population of this weight. In addition, weight changes may have occurred if the intervention had continued. There were also no changes in fiber intake across diets (independent of the supplements). All groups experienced significant reductions in total fat; however, only the barley bran flour and oil groups significantly reduced their intake of cholesterol and saturated fat.

Why the groups differed with respect to their intakes of saturated fat and cholesterol is not clear, because they all received the same dietary instructions and were treated identically. However, because dietary cholesterol and saturated fat have been shown to affect serum cholesterol values, and because the two barley groups but not the cellulose group reduced their intake of these two constituents, we made a decision to apply the formula of Keys et al (27) to the three groups to further establish how much of the change was likely attributable to fat reduction. This formula does not include a fiber factor, so if the observed response is greater than the predicted response, the effect of the fiber intervention can be better assessed. Applying the formula results in similar conclusions as to the benefits of fiber or oil supplementation alone compared with reductions in lipid intake. For example, nonlipid modification accounted for 16.16 of the 22 mg/dL drop in cholesterol with barley bran flour supplementation, or 73%. This would mean that the cholesterol-lowering effect of barley bran flour alone was 73% of 7.7%, or 5.6%; 62% of 7.1%, or 4.4%, for barley oil; and 84% of 3.9%, or 3.3%, for cellulose. These percentages are slightly higher than those obtained by subtracting the cellulose control, because cellulose itself had a small but nonsignificant cholesterol-lowering effect. For a critical review of the methodology related to dietary fiber and lipid response, see reference 32.

To monitor changes in nutrient intake during the study, we analyzed 3-day dietary records before and after the intervention. Four index nutrients were used to predict the overall nutritional status of the participants. Individuals who consumed barley bran flour significantly reduced their intakes of iron and calcium. The initial values for calcium were below the Recommended Dietary Allowances (33) for men and women and those for iron were below the Recommended Dietary Allowance for women, so perhaps emphasis should be placed on foods high in these nutrients when people are reducing fat in their diets. Alternatively, greater individualization of the NCEP step 1 diet and/or more frequent and intensive intervention for those consuming the step 1 diet may have resulted in an improvement in the status of these and other nutrients as reported by others.

Although not a major focus of this study, the finding that all treatments resulted in significant decreases in diastolic blood pressure is of interest, particularly because a review article (34) on diet and blood pressure concluded that no studies to date show a clear link between modification of diet and reduction in blood pressure, except when weight loss is involved. Weight loss was not a factor in our study. In an attempt to understand the factor or factors related to this decrease in blood pressure, we tested for any potential correlations. The only significant correlation with the decrease in diastolic blood pressure was the decrease in apoprotein B-100 (r=.260; P=.021). The potential relationship between apoprotein B-100 levels and diastolic blood pressure requires further investigation.

Another secondary finding of our study was the relationship, or lack of it, between apoprotein A-1 and HDL-C and apoprotein B-100 and LDL-C. Although there was a significant correlation between changes in apoprotein B-100 and LDL-C, no such correlation existed between apoprotein A-1 and HDL-C. This suggests that decreases in LDL-C were attributable to decreases in numbers of LDL-C particles, whereas decreases in HDL-C were attributable to less cholesterol carried per particle. Confirmation of this hypothesis requires detailed analyses of the lipoprotein particles, which we did not do.

APPLICATIONS

Our study suggests that foods containing barley bran flour have the potential benefit of lowering serum cholesterol. Because the hypocholesterolemic effect is in the lipid fraction, care should be taken to avoid defatting the barley bran flour. An additional benefit of barley bran flour is that it is a source of insoluble fiber. In general, insoluble fibers accelerate colonic transit and increase fecal bulk, two factors thought to be protective against colon cancer.

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