Physicochemical and Sensory Evaluation of Extruded High-Fiber Barley Cereals[1]

P. T. BERGLUND, C. E. FASTNAUGHT, and E. T. HOLM[2]

ABSTRACT

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Fourteen blends of four barley cultivars (ground) and rice or wheat flour were extruded into a ready-to-eat cereal using a corotating twin-screw extruder. The raw blends and subsequent cereals were analyzed for soluble and insoluble dietary fiber, β-glucan, alkaline viscosity, and other physical and chemical properties. Cereals produced from rice and five of the barley-rice blends were evaluated by a consumer sensory panel. Cereals produced by extrusion of 100% barley had limited expansion and high bulk densities. When blended with 50% rice, the bulk densities were reduced by 50%, and the appearance was similar to that of the 100% rice cereal. Extrusion resulted in increased alkaline viscosity and soluble fiber content of most cereals. Sensory panelists rated cereals extruded from four 50:50 barley-rice blends and a 65:35 Wanubet barley-rice blends higher than the 100% rice cereal for crispness and color and rated them similar to the rice cereal for flavor and overall acceptability. The total dietary fiber of the barley cereal ranged from 5.8-9.0%, with 2.0-4.7% soluble fiber. Barley is a suitable material for production of a ready-to-eat high-fiber cereal.

Recent interest in fiber, particularly soluble dietary fiber (SDF), has prompted research into the use of waxy hull-less barley for food (Newman and Newman 1991, Berglund et al 1992). Hull-less barley, especially cultivars with 100% amylopectin starch (waxy), has high total dietary fiber (TDF) and SDF contents. It also has a higher β-glucan level than do most covered barley and oat cultivars (Bhatty 1987, Åman and Graham 1987, Newman and Newman 1991). Marlett (1991) and Berglund et al (1992) also reported substantial amounts of SDF in barley.

Foods that are high in TDF and SDF have been related to decreased incidence of a wide spectrum of diseases. The cholesterol-lowering effect of SDF in specific foods has been documented in animal (Ranhotra et al 1987) and human clinical studies (Jenkins et al 1980, Behall et al 1984, Anderson and Tietyen-Clark 1986).

Most processed grain products, such as breakfast cereals, contain dietary fiber. Extrusion processing is suitable for the production of fiber-rich foods (Lue et al 1991). Limited work has been reported on the use of barley, especially waxy hull-less barley, in extruded human foods. Shin and Gray (1983) analyzed extruded barley, but did not evaluate fiber content. Østergard et al (1989) extruded Danish whole grain barley that had been ground in a hammer mill and found a significant increase in TDF, ranging from 5 to 16%, in the extruded products. The SDF was also significantly higher in the extruded products (3.3-3.8%) than it was in the raw barley flour (2.6%). Marlett (1991) found that the solubility of dietary fiber increased when waxy hull-less barley was used in a ready-to-eat (RTE) cereal prepared by a process similar to that used for production of oven-puffed crisp rice.

The objectives of this study were to evaluate the potential of several barley cultivars of differing starch composition and hull type for production of an extruded RTE cereal and to evaluate the change in fiber content after extrusion.

MATERIALS AND METHODS

Raw Material

Two hull-less, waxy barley cultivars, Wanubet and Apollo (Western Plant Breeders, Bozeman, MT), were supplied by Nu-Grain Technologies (Martin, ND) and Ross Seed (Fisher, MN), respectively. Tupper, a hull-less barley cultivar with normal starch, and Bowman, a covered-barley cultivar with normal starch, were supplied by Natural Way Mills (Middle River, MN). All barley cultivars were hammer-milled (1.5/64 mesh screen, 0.6-mm opening) into whole grain meals by Natural Way Mills. Rice flour, RL100, was supplied by Rivland Partnership (Houston, TX). Bakers Pride wheat flour (76% extraction) was obtained from North Dakota Mill and Elevator (Grand Forks, ND); non-gelatinized wheat starch, Atex P, was supplied by Ogilvie Mills (Minnetonka, MN).

Extrusion Treatments

Twenty-two kilograms each of fourteen blends (Table I) of barley and rice or wheat were extruded to produce RTE cereals. All blends contained 6% sugar and 1% salt and were mixed for 15 min in a 0.15-m^3 twin shell dry blender (Patterson Kelley, East Stroudsberg, PA) before extrusion.

Extrusion Conditions

RTE cereals were extruded by the Northern Crops Institute (Fargo, ND) on a Wenger TX 52 corotating twin-screw extruder (Wenger Mixers, Sabetha, KS) with a length-to-diameter ratio of 15:1, five jacketed heads, and a crisp rice die with 48 openings (0.8 mm wide × 3.8 mm high; 22.2 mm forming length). The raw mixes were fed at 1.3-1.4 kg/min, the screw speed was set at 410 rpm, the cooking zone temperature varied from 123-125°C, and extruder water was adjusted from 7.1-10.3% to optimize extruder operating conditions (Table I). Extruded cereals were toasted at 176°C for 15 min in a rotating-wheel, gas-fired oven (Middleby-Marshall, Chicago, IL).

Chemical Properties of Raw Materials and Cereals

Chemical analyses were performed on raw materials and unprocessed mixes without further grinding. Toasted extruded cereals were ground through a 0.5-mm screen using a Udy Cyclone

TABLE I
Extrusion Blends and Parameters for Ready-to-Eat Cereals

Extrusion Blend	Ingredient Density (g/cm^3)	Feed Rate (kg/min)	Cooking Zone Temperature (°C)	Extruder Water (%)
100% Rice	0.69	1.26	125	8.2
100% Wanubet	0.42	1.36	125	7.1
100% Apollo	0.41	1.35	123	7.1
100% Bowman	0.42	1.36	125	7.1
100% Tupper	0.42	1.36	125	7.1
80% Wanubet:20% rice	0.46	1.40	125	7.1
65% Wanubet:35% rice	0.51	1.32	125	7.1
50% Wanubet:50% rice	0.54	1.26	124	8.2
50% Apollo:50% rice	0.54	1.26	124	8.2
50% Bowman:50% rice	0.54	1.26	125	10.3
50% Tupper:50% rice	0.54	1.26	125	10.3
50% Wanubet:50% wheat	0.52	1.37	125	10.3
50% Wanubet:40% wheat: 10% wheat starch	0.52	1.37	125	10.3
50% Tupper:50% wheat	0.52	1.37	125	10.3

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[2] Assistant professor, food technologist, and associate professor, respectively, Department of Food and Nutrition, North Dakota State University.

sample mill (Udy, Fort Collins, CO) before analysis. Standard methods (AACC 1983) were used to determine: moisture by the one-stage, air-oven method; protein by Kjeldahl nitrogen (N × 6.25 for barley and rice, N × 5.7 for wheat); and crude fat by 16-hr extraction with petroleum ether. SDF and insoluble dietary fiber (IDF) were determined by the enzymatic-gravimetric method modified by using 0.2 ml (10 mg/ml) of amyloglucosidase (1202, *Aspergillus niger*, Boehringer Mannheim, Indianapolis, IN). TDF was calculated as the sum of SDF and IDF. β-Glucan content was determined according to the standard method, modified by using 13-mm × 100-mm screw cap tubes, 0.5 ml of 50% ethanol, 7.0 ml of sodium phosphate (20 m*M*, pH 6.5), and 10.0 ml of sodium acetate buffer (50 m*M*, pH 4.0). Alkaline viscosity was determined according to Ullrich et al (1981), using 0.5-g samples extracted with 10 ml of sodium carbonate-bicarbonate buffer (pH 4.0) and measured by a Wells-Brookfield LVT cone-plate viscometer (Brookfield Engineering Laboratories, Stoughton, MA). All analyses were conducted in duplicate, except fiber, which was conducted in quadruplicate, as required by the method.

Physical Characteristics of Cereals

Bulk density was calculated by weighing the quantity of toasted cereal required to fill a 167-cm^3 container and converted to kilograms per cubic meter. Hydration capacity was determined on whole cereal according to the standard method. Color was determined on whole cereal with a Gardner Tristimulus XL-23 colorimeter (Bethesda, MD) using the *L*, *a*, and *b* scale compared to a white standard (XL-23-246-D).

Sensory Evaluation

The rice and five of the barley-rice blend cereals were subjected to sensory evaluation. An untrained consumer panel consisted of 77 students, staff, and faculty volunteers from North Dakota State University who had responded to on-campus advertisements.

Sensory quality attributes were evaluated using a nine-point hedonic rating scale (1 = "dislike extremely", 9 = "like extremely"). A score of 5 was considered a neutral score, and scores >5 were in the "like" range.

Sensory evaluation was conducted in a single session from mid-morning 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.

Statistical Analysis

The data were analyzed using the Statistical Analysis System general linear models procedure (SAS 1982). 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. A one-way analysis of variance (completely randomized design) was used to test fiber differences between each raw mix-toasted cereal treatment.

RESULTS AND DISCUSSION

Analysis of Raw Materials

Results of proximate analysis of the raw materials used in the production of the extruded cereals is shown in Table II. Two of the barley cultivars, Wanubet and Apollo, contained 100% amylopectin (waxy). The other starting materials had normal distributions of amylose and amylopectin. The protein content of the barley and wheat ranged from 12.6 to 16.4%, whereas the rice had only 8.2% protein. The lipid content ranged from 0.89 to 2.82% and was highest for the barley samples. TDF was highest for all barley samples (12.37–17.86%); rice and wheat

TABLE II
Analysis of Raw Materials Used in Extruded Cereal Formulations

Raw Material	Protein[a]	Lipid[a]	Dietary Fiber[b] Total	Soluble	Insoluble	β-Glucan[a]	Alkaline Viscosity (cP)
Rice flour	8.2	1.33	1.68	0.00	1.68	0.07	0.8
Ground barley[c]							
Wanubet, *wx n*	12.9	2.82	14.48	6.06	8.42	6.39	22.7
Apollo, *wx n*	16.4	2.41	17.86	7.16	10.70	5.95	34.6
Bowman, *Wx N*	12.6	2.50	14.52	4.32	10.20	4.14	4.9
Tupper, *Wx n*	14.7	1.69	12.37	4.01	8.36	4.21	4.7
Wheat flour	14.2	0.89	1.21	0.31	0.90	0.14	2.1

[a] Percent of dry matter; $n = 2$.
[b] Percent of dry matter; $n = 4$.
[c] Barley genotypes: *wx* = waxy starch; *n* hull-less seed; *Wx* = normal starch; *N* = covered seed.

TABLE III
Physical Characteristics of Extruded Crisp Cereal

Extruded Cereal	Bulk Density[a] (kg/m^3)	Moisture[a] (%)	Hydration Capacity[a,b]	Colorimeter Values[c] *L*	*a*	*b*
Rice(R)	103.7 a	1.57 ab	7.37 a	71.14	5.98	18.68
Wanubet	331.6 j	4.13 d	3.02 h	58.67	6.43	17.97
Apollo	349.7 k	5.66 f	3.15 gh	59.50	6.74	18.43
Bowman	273.6 i	4.95 e	3.64 f–h	57.84	6.31	17.50
Tupper	259.9 h	5.00 c	3.94 ef	56.41	4.92	15.20
Wanubet-R 80:20	242.9 g	3.24 c	3.76 e–g	63.36	5.89	17.73
Wanubet-R 65:35	134.9 bc	1.47 ab	5.46 cd	65.66	6.97	18.83
Wanubet-R 50:50	138.7 cd	1.89 b	5.91 bc	65.15	7.26	19.19
Apollo-R 50:50	140.5 d	1.22 a	6.17 b	65.20	7.76	19.45
Bowman-R 50:50	132.4 b	1.70 ab	5.66 b–d	65.63	6.59	18.48
Tupper-R 50:50	131.3 b	1.56 ab	6.94 a	65.39	5.42	17.06
Wanubet-wheat (W) 50:50	257.2 h	5.57 f	4.04 ef	62.48	5.91	16.93
Wanubet-W-starch 50:40:10	231.9 f	5.65 f	4.38 e	64.14	5.28	16.11
Tupper-W 50:50	203.7 e	4.84 e	5.05 d	61.71	4.94	15.30

[a] Means within a column followed by different letters are significantly different according to Duncan's multiple range test ($P < 0.05$); $n = 2$.
[b] Grams of water per gram of cereal.
[c] Color scales: *L* = brightness (0 = black, 100 = white); +*a* = red, −*a* = green; +*b* = yellow, −*b* = blue; $n = 2$.

samples had less than 2% TDF, most of which was IDF. The SDF (4.01–7.16%) and β-glucan (4.14–6.39%) contents of all barley samples were considerably higher than those of rice and wheat. However, the waxy hull-less cultivars (Wanubet and Apollo) had higher SDF, β-glucan content, and alkaline viscosity than did the normal barley cultivars.

Extruded Cereal Properties

The bulk densities, moistures, hydration capacity, and colorimeter values of the extruded cereals are compared in Table III. The lowest bulk density of the extruded RTE cereals was for the one prepared from 100% rice. Cereals made from 100% barley and the 50:50 blend of Wanubet barley and wheat had the greatest bulk density, which was a result of limited expansion during the extrusion process. Camire et al (1990) discussed the limited expansion of fiber-enriched extrudates and their higher bulk densities. The high fiber content of barleys used in this study probably inhibits expansion during extrusion, resulting in the increased bulk densities. Bulk densities of the other barley-rice cereals and barley-wheat cereals were intermediate. Bulk density did not increase linearly with percentage of barley in the blend. Increasing the barley from 50 to 65% did not increase the bulk density, but increasing the barley to 80% nearly doubled the bulk density.

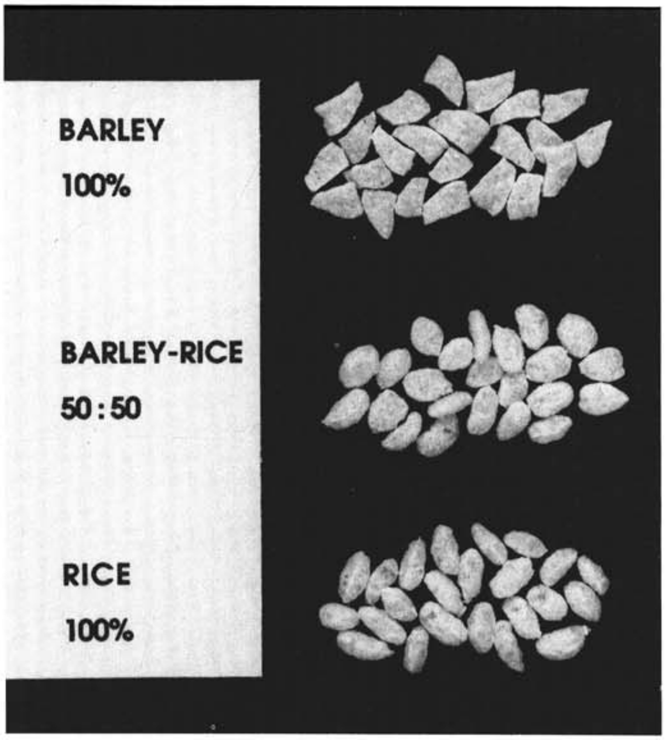

Fig. 1. Cereal samples extruded from 100% barley, 50:50 barley-rice blend, and 100% rice.

Higher bulk densities could be economically advantageous because packages of cereals are sold by weight. However, the limited expansion of the 100% barley mixes resulted in the formation of a uniquely shaped cereal product, quite different from the usual shape of crisped-rice cereal (Fig. 1). The barley-rice cereals were more similar in shape to the crisped-rice cereal.

Although the cereals were all toasted under the same conditions, moisture content varied from 1.22–5.57% (Table III). The normal moisture content for finished cereals is 1–3% (Fast and Caldwell 1990). Thus, several of the 100% barley and barley-wheat blend cereals that had the highest moisture contents may have reduced shelf life. These cereals also had the lowest hydration capacities.

Generally, as the moisture of the cereal increased, the bulk density increased ($r = 0.84$, $P < 0.001$). The hydration capacity decreased with increasing moisture ($r = -0.80$, $P < 0.001$) and bulk density ($r = -0.95$, $P < 0.0001$). Camire et al (1991) also found that higher moisture contents were associated with less expanded extrudates, and that increased water content of the material (cornmeal and glandless cottonseed flour) before extrusion was related to decreased hydration capacity of the extruded product.

The *L* value was highest for the rice cereal, lowest for the 100% barley cereals, and intermediate for the blends. The high *L* value indicates that rice was the lightest sample in color, whereas the 100% barley cereals were the darkest. There was no trend evident for *a* and *b* colorimeter values (higher numbers indicating a greater degree of redness and yellowness, respectively).

Fiber Content of Extruded Cereals

The dietary fiber content of the raw mixes and related cereals is shown in Table IV. Extrusion generally increased the SDF content of most of the cereals. The increase in SDF was statistically significant for half of the cereals and ranged from 5–64%, depending on the starting material. This concurs with Marlett (1991), who also found that processing of barley into a RTE cereal increased the solubility of dietary fiber. IDF decreased in all of the cereals, with the exception of the 100% Apollo sample. It appears that the increase in SDF was at the expense of the IDF, because the change in TDF was generally small. Additionally, the decrease in TDF was significant in only four of the cereals, and those decreases were only 6–10%.

β-Glucan Content of Raw Mix and Cereals

β-Glucan content of several of the cereals (Table V) increased significantly over that of the raw mixes (100% Tupper, 50:50

TABLE IV
Dietary Fiber Content (%)[a] of 14 Ready-to-Eat Cereals

	Soluble Dietary Fiber			Insoluble Dietary Fiber			Total Dietary Fiber		
Treatment	Raw Mix	Cereal	Diff[b,c]	Raw Mix	Cereal	Diff[b,c]	Raw Mix	Cereal	Diff[b,c]
Rice(R)	0.0	0.41	0.41^{**}	1.25	0.95	−0.30	1.25	1.35	0.10
Wanubet	6.18	5.87	-0.31^{*}	7.33	6.89	-0.44^{*}	13.51	12.76	-0.75^{**}
Apollo	6.37	6.04	−0.33	10.03	10.22	0.19	16.40	16.26	−0.14
Bowman	3.26	3.90	0.64^{**}	9.31	7.99	-1.32^{**}	12.57	11.89	−0.68
Tupper	4.25	4.93	0.68^{*}	8.08	6.17	-1.91^{**}	12.22	11.04	-1.18^{**}
Wanubet-R 80:20	5.24	5.48	0.24^{*}	6.79	5.35	-1.44^{***}	11.96	10.84	-1.12^{***}
Wanubet-R 65:35	3.61	4.72	1.11^{**}	4.83	4.20	-0.63^{**}	8.44	8.99	0.55
Wanubet-R 50:50	2.45	2.78	0.33	3.61	3.04	-0.57^{*}	6.01	5.82	−0.19
Apollo-R 50:50	2.55	2.72	0.17	5.96	5.33	-0.63^{*}	8.51	8.06	−0.45
Bowman-R 50:50	1.36	2.06	0.70^{***}	4.26	4.01	−0.25	5.62	6.07	0.45
Tupper-R 50:50	2.69	2.73	0.04	3.46	3.18	−0.28	6.20	5.96	−0.24
Wanubet-wheat (W) 50:50	3.62	4.37	0.75^{***}	4.60	4.01	-0.59^{**}	8.22	8.38	0.16
Wanubet-W-starch 50:40:10	3.80	4.08	0.28	5.11	3.95	-1.16^{**}	8.91	8.03	-0.88^{*}
Tupper-W 50:50	2.24	3.68	1.44^{*}	5.17	3.83	-1.34^{***}	7.42	7.52	0.10

[a] Percent of dry matter; $n = 4$.
[b] Difference = cereal − raw mix.
[c] *, **, *** = $P \leq 0.05, 0.01, 0.001$, respectively.

Tupper-wheat, 65:35 Wanubet-rice, 50:50 Wanubet-rice, 50:50 Apollo-rice, and 50:50 Bowman-rice). The β-glucan content of the 100% Apollo and the Wanubet-wheat 50:50 blends was significantly lower in the cereal than in the raw mix. We are unclear as to the reason for the increase or decrease in β-glucan content from the raw mix to the extruded product. Marlett (1991) found that total β-glucan in the SDF fraction increased in barley samples after processing, and that processing increased the proportion of fiber that behaved analytically like SDF. However, this does not explain any decrease in β-glucan.

Alkaline Viscosities of Raw Mix and Cereals

Alkaline viscosity of all the RTE cereals was significantly greater than the viscosity of the raw mixes from which the cereals were extruded (Table VI). The raw mixes containing the two 100% waxy hull-less cultivars (Wanubet and Apollo) had the highest alkaline viscosity. The blends from those two cultivars also had higher viscosities than other raw mix treatments. Additionally, the cereals from the waxy cultivars had the highest alkaline viscosities. One difficulty that resulted during the determination of alkaline viscosity of the cereals was the formation of two layers after the centrifugation step with cereals extruded from both Wanubet and Apollo. Only the viscosity of the upper layer is reported here. The lower layer had a viscosity similar to that of rice and wheat. The viscosity of several of the blends with Wanubet were particularly high. This was partly a result of the layer formation, but an interaction between the Wanubet and the rice or wheat is apparent.

Extract viscosity of barley and its associated β-glucan content relate both to functional quality in food products and to health effects. Recently, Gallaher and coworkers (1992) reported that both in vitro and ex vivo (intestinal contents) viscosities were inversely correlated to plasma cholesterol in a log-linear fashion over a wide range of viscosities.

Sensory Evaluation of Selected Cereals

The six cereals presented to the consumer sensory panel (Table VII) were selected because they were most similar to crisped-rice cereal, a successful cereal familiar to the consumer. Panelists liked the color of the barley-rice cereals from Wanubet, Apollo, and Bowman better than they liked the rice and Tupper-rice cereals. There was no difference in the flavor and overall acceptability of any of the cereals. The tenderness of the rice cereal was most liked, followed by several of the barley-rice cereals. The crispness of the 50:50 barley-rice cereals was liked more than that of the rice cereal. The 50:50 barley-rice cereals received crispness scores equivalent to "like slightly" to "like moderately". Thus, sensory scores for the cereals indicate that, in general, the RTE cereals extruded from 50:50 barley-rice blends were liked better than the 100% rice cereal for color and crispness and liked similarly to the 100% rice cereal for flavor and overall acceptability.

TABLE V

β-Glucan Content (%)[a] of Raw Mixes and Extruded Cereals

Treatment	Raw Mix	Cereal	Difference[b,c]
Rice(R)	0.02	0.07	0.05
Wanubet	6.15	6.25	0.10
Apollo	6.09	5.60	−0.49*
Bowman	3.68	3.82	0.14
Tupper	3.91	4.25	0.34**
Wanubet-R 80:20	5.19	4.93	−0.26
Wanubet-R 65:35	3.45	4.06	0.61**
Wanubet-R 50:50	2.48	3.78	1.30**
Apollo-R 50:50	2.50	3.30	0.80**
Bowman-R 50:50	1.75	2.23	0.48**
Tupper-R 50:50	1.98	2.12	0.14
Wanubet-wheat (W) 50:50	3.69	2.96	−0.73***
Wanubet-W-starch 50:40:10	3.50	3.10	−0.40*
Tupper-W 50:50	1.84	2.33	0.49**

[a] Dry basis, $n = 2$.

[b] Difference = cereal − raw mix.

[c] *, **, *** = $P \leq 0.05$, < 0.01, and < 0.001, respectively.

When the sensory color scores (Table VII) were correlated with the color scores from the Gardner colorimeter (Table III), the correlation coefficient for the colorimeter *a* values and the sensory scores was $r = 0.90$ ($P < 0.05$). In other words, those cereals that received higher sensory scores for color also had higher *a* values (redness) as tested by the colorimeter.

Chemical Analysis of Selected RTE Cereals

The fiber, protein, and lipid content of the six extruded cereals that were evaluated by sensory analysis are shown in Table VIII. The 100% rice cereal had the lowest TDF, SDF, IDF, and β-glucan contents of the cereals evaluated. The 65:35 Wanubet-rice cereal had the highest TDF (8.99%) and SDF (4.72%) contents of all the cereals. The 100% rice cereal had a TDF of 1.35% and an SDF of 0.41%. The Apollo-rice cereal had the next highest TDF (8.06%). The cereals extruded from 50:50 blends of rice and the hull-less cultivars (Wanubet, Apollo, and Tupper) all had similar SDF of 2.7%. SDF comprised 34–53% of the TDF in the cereals extruded from barley blends. The IDF of the Apollo-rice cereal was the highest, followed by the 65:35 Wanubet-rice cereal and the 50:50 Bowman-rice cereal. All the barley-rice blends had a higher β-glucan content than did the rice cereal. The cereals extruded from Wanubet and Apollo had the highest β-glucan contents (3.30–4.06%).

Protein content of the barley cereals ranged from 9.0 to 11.5%. The barley-rice blends were lower in protein than were the original barleys, due to the dilution effect from the addition of the lower protein rice flour. The lipid content of the cereals ranged from 0.93 to 2.56% and was highest for the barley-rice blends. The lipid content could have negative implications for long-term stor-

TABLE VI

Alkaline Viscosity (cP) of Raw Mixes and Extruded Cereals

Treatment	Raw Mix	Cereal	Difference[a,b]
Rice(R)	1.0	4.6	3.6**
Wanubet	24.7	100.2	75.5**
Apollo	33.7	101.0	67.3**
Bowman	4.4	12.9	8.5*
Tupper	4.3	13.2	8.9*
Wanubet-R 80:20	11.0	121.2	110.1*
Wanubet-R 65:35	7.0	98.0	91.0***
Wanubet-R 50:50	4.3	142.6	138.3*
Apollo-R 50:50	5.3	52.4	47.1**
Bowman-R 50:50	1.8	3.9	2.1*
Tupper-R 50:50	1.8	5.3	3.5*
Wanubet-wheat (W) 50:50	5.7	168.9	163.2*
Wanubet-W-starch 50:40:10	5.7	96.3	90.6**
Tupper-W 50:50	2.4	7.0	3.6**

[a] Difference = cereal − raw mix.

[b] *, **, *** = $P \leq 0.05$, < 0.01, and < 0.001, respectively.

TABLE VII

Sensory Characteristics of Extruded Crisp Cereals[a,b]

Cereal	Color	Flavor	Tenderness	Crispness	Overall Acceptability
Rice(R)	5.6 b	5.8 a	6.5 a	6.4 b	6.3 a
Wanubet-R 65:35	6.3 a	5.9 a	5.5 c	6.6 ab	6.0 a
Wanubet-R 50:50	6.3 a	5.8 a	5.9 bc	6.8 a	6.2 a
Apollo-R 50:50	6.6 a	6.1 a	6.0 b	7.0 a	6.4 a
Bowman-R 50:50	6.4 a	5.9 a	6.1 ab	6.8 a	6.1 a
Tupper-R 50:50	5.7 b	5.7 a	5.9 b	6.9 a	6.1 a

[a] Hedonic rating: 1 = "dislike extremely"; 9 = "like extremely."

[b] Means within a column followed by different letters are significantly different according to Duncan's multiple range test ($P < 0.05$); $n = 77$.

TABLE VIII
Fiber, Protein, and Lipid Content of Extruded Crisp Cereals[a]

Cereal	Dietary Fiber[b] Total	Soluble	Insoluble	β-Glucan[c]	Protein[c]	Lipid[c]
Rice(R)	1.35 d	0.41 d	0.95 d	0.07 e	8.2 e	0.66 d
Wanubet-R 65:35	8.99 a	4.72 a	4.20 b	4.06 a	10.6 b	2.56 a
Wanubet-R 50:50	5.82 c	2.78 b	3.04 c	3.78 b	9.6 cd	1.69 ab
Apollo-R 50:50	8.06 b	2.72 b	5.33 a	3.30 b	11.5 a	1.05 cd
Bowman-R 50:50	6.07 c	2.06 c	4.01 b	2.23 c	9.0 d	0.93 cd
Tupper-R 50:50	5.96 c	2.73 b	3.18 c	2.12 d	9.8 c	1.36 b–d

[a] Means within a column followed by different letters are significantly different according to Duncan's multiple range test ($P < 0.05$).
[b] Percent of dry matter; $n = 4$.
[c] Percent of dry matter; $n = 2$.

age, although informal observations in our laboratory have not indicated development of off-flavors during storage over one year.

CONCLUSION

Barley is an excellent raw material for a high-fiber RTE cereal because it has higher levels of TDF, SDF, and β-glucan than do rice or wheat. Extrusion of 100% barley (four cultivars), under the conditions used in this study, resulted in limited expansion and cereals with high bulk densities. However, when the four barley cultivars were blended 50:50 with rice, the bulk densities decreased by 50%, and the appearance was similar to that of the 100% rice cereal. Increasing the proportion of Wanubet to 65% did not change the bulk density, but it did increase the SDF content significantly. For cereals extruded from 50:50 blends of all four cultivars and the 65:35 blend with Wanubet, the consumer sensory panel rating was higher than that for the 100% rice cereal for crispness and color, and similar to that of the rice cereal for flavor and overall acceptability. The TDF of the extruded barley blend cereals evaluated by the sensory panel ranged from 5.82 to 8.99%, with approximately 34–53% of the TDF being SDF. Most extruded cereals had higher alkaline viscosity and SDF content than did the related unprocessed raw mix. The physiological significance of this increase in fiber and fiber-related viscosity should be examined.

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