Utilization of Diverse Hulless Barley Properties To Maximize Food Product Quality

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Although barley is not considered a staple food, or even a major food ingredient, in the average North American diet, it is consumed on a daily basis in other parts of the world. In Tibet, hulless barley has been utilized as a staple food for centuries and is still consumed in large quantities today (155 kg/person/year), providing rural Tibetans with 80% of their total calories and, in many cases, their only significant source of fiber (15).

Traditionally, preparation and consumption of barley in Tibet includes *tsampa*, a shelf-stable barley flour product made from ground, roasted barley. Utilization of barley as a food source has continued to evolve in Tibet, with large modern food factories producing a variety of barley-based foods, ranging from traditional products like *tsampa* to popular Asian noodles.

Barley products are also common in other parts of Asia. For example, barley tea, traditionally made from hulled barley, is widely consumed in Japan and Korea (10,14). Barley tea provides a protective effect against gastric stress ulcers and helps reduce blood pressure, which may reduce the risk of circulatory diseases related to lifestyle (14).

In traditional Tibetan medicine, roasted barley flour is thought to have the most *jue* (safety and nutrition). Studies have confirmed that barley has medicinal properties, which are most often linked to the presence of mixed-linked β-glucan. The role of mixed-linked β-glucan in human nutrition has been the subject of numerous clinical trials and literature reviews. Much of the scientific research has focused on the cholesterol-lowering effect of barley, but the attenuation of blood glucose levels, possible effects on colon cancer, and bioavailability of vitamins and minerals have also been documented (8). β-Glucan reduces postmeal blood glucose response and lowers cholesterol levels through increased viscosity in the small intestine (18).

In addition to β-glucan, barley also contains a number of antioxidants (12). Recent studies have reported that antioxidants can reduce the incidence of chronic diseases, including some heart diseases, cataracts, brain dysfunctions, allergies, and cancers (11,12,16). Duh and coworkers (6) also have found that hot water extracts from both unroasted and roasted barley exhibit antioxidant activity.

The diversity of barley food applications in Asia, as well as emerging scientific evidence supporting the health benefits of barley, are positive indicators of the potential to successfully develop and promote barley usage in new global markets.

Developing Barley-Based Products for the North American Market

In contrast to Asian markets, the majority of barley grown in North America is used for animal feed and malting, with very little marketed for human food products. Despite barley's excellent nutritional content, food applications generally are limited to pearled or pot barley, from which the outer portion of the kernel has been removed, and incorporation of barley-based ingredients in breakfast cereals and bakery products. Among the wide variety of barley cultivars and forms available, many have unique cooking, texture, color, and flavor characteristics. This diversity, which could be likened to that of rice or corn, has not been exploited by food processors or consumers in North America (3).

Benefits and Quality. With a growing trend toward foods and ingredients that offer specific health-promoting benefits, the nutritional properties of barley would likely be of interest to North American consumers. For barley producers to capitalize on a new consumer-driven food market for barley, they must grow cultivars that will serve the needs of the functional foods industry, such

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as cultivars with higher levels of total dietary fiber, β-glucan, and phenolic acids and lower amounts of simple starches (1,5).

The promise of health-promoting benefits alone will not ensure the utilization of barley in product formulations or warrant investment in product development or advertising by major food manufacturers, because taste and appearance still determine consumer acceptance. However, the nutritional profile of barley coupled with the diverse functional and sensory properties provided by specific barley cultivars could be used to develop unique barley end products that consumers will accept. The challenge lies in the successful application of cultivar-specific properties in the appropriate product.

Table I. Composition of several hulless barley genotypes and milling fractions

Genotype	Milling Fraction[a]	Protein (%)	β-Glucan (%)	Total Starch (%)	Dietary Fiber (%)
CDC Alamo	SGF	16.24	5.69	62.98	14.03
	DFFS	17.11	9.73	54.65	21.36
	DFFB	17.72	11.23	53.61	21.60
CDC Fibar	SGF	17.88	6.91	58.73	18.24
	DFFS	17.50	11.29	51.24	23.68
	DFFB	16.35	14.45	56.08	26.01
CDC Candle	SGF	16.06	3.87	66.28	12.98
	DFFS	17.58	7.77	58.33	19.21
	DFFB	15.29	9.65	62.33	22.17
HB 805	SGF	13.81	3.82	71.42	10.50
	DFFS	16.99	6.97	55.91	19.34
	DFFB	15.66	11.71	…	24.52
CDC Dawn	SGF	14.22	3.28	70.42	10.24
	DFFS	18.46	6.53	50.09	22.86
	DFFB	17.50	5.83	44.91	27.14
AC Hawkeye	SGF	12.34	3.15	74.20	9.38
	DFFS	15.82	5.78	60.20	19.73
	DFFB	16.26	5.85	51.66	24.65
Condor	SGF	13.88	3.18	71.26	11.93
	DFFS	17.93	7.81	57.03	20.37
	DFFB	19.13	8.44	51.79	24.02
Millhouse	SGF	13.36	3.04	71.52	9.68
	DFFS	16.98	6.21	55.80	19.33
	DFFB	15.98	7.17	53.26	23.52
CDC Freedom	SGF	12.00	3.44	72.07	9.65
	DFFS	13.84	6.82	56.72	19.63
	DFFB	16.68	7.35	56.32	23.12
SB 94893	SGF	20.18	6.58	52.23	19.16
	DFFS	18.42	10.57	54.43	23.43
	DFFB	17.79	12.23	52.30	25.27

[a] SGF = straight-grade flour; DFFS = flour obtained from passing the shorts fraction through a bran dusting machine; DFFB = flour obtained from passing the bran fraction through a bran dusting machine.

Analysis of Barley Characteristics. Prior to conducting application studies, the diverse functional and nutritional characteristics of several hulless barley genotypes grown in diverse environments in western Canada were evaluated. Flour fractions were prepared using a Buhler mill and subsequent dusting of shorts and bran fractions to separate adhering endosperm. The result was dusted flour from shorts (DFFS) and dusted flour from bran (DFFB). Large genotypic variation in the composition of barley flour fractions was observed (Table I).

Several genotypes had straight-grade flours with low levels of β-glucan (<4%) and total dietary fiber (<13%) and high levels of total starch (>66%). Conversely, two genotypes had straight-grade flours with >6% β-glucan and 18% total dietary fiber and low levels of total starch. For all genotypes, the DFFS and DFFB fractions contained higher concentrations of β-glucan and total dietary fiber, which would be of particular interest to food manufacturers interested in health claims. For most genotypes, these two fractions also had higher protein and lower total starch; however, this trend was not consistent across all genotypes, indicating variation in the distribution of nutritional components throughout the kernel and/or differences in the way the kernels fractionate during milling. Barley genotypes also varied significantly in phenolic acid and tocopherol content and antioxidant activity (data not shown). In addition, growing environment and genotype–environment interactions played a role in the variation in β-glucan content in barley flour fractions. This information can be used to

Table II. Sensory attributes of tortillas made from 15 barley genotypes[a]

Genotype[b]	Amylose (%)	Rollability	Breakability	Hardness	Ease of Compression	Chewiness	Moisture Absorption	Stickiness to Teeth
Whole-wheat reference[c]	…	9.8	3.7	7.4	10.2	8.9	6.6	4.9
CDC Alamo	0.00	11.1ab	2.1ef	8.2d–f	12.0a	9.3bc	5.5f	6.7a
Bacon	26.52	8.7c–e	3.1b–f	12.4a	7.1d	11.9a	6.4b–f	4.8ab
CDC Candle	5.10	12.2a	1.2f	6.9ef	11.8a	10.4a–c	5.6ef	5.6ab
H1632	25.87	8.3ef	3.8b–e	10.5a–d	7.1d	11.5ab	7.5a–e	5.4ab
H1653	25.95	8.5de	5.1b	11.7a	7.5cd	11.2a–c	8.0a–c	4.1b
Hawkeye	25.86	8.1ef	4.4b–d	11.1ab	8.0cd	10.9a–c	7.7a–d	5.0ab
Millhouse	25.78	8.1ef	4.7bc	10.6a–c	7.7cd	10.7a–c	8.2ab	5.0ab
HB803	3.68	10.3b–d	3.2b–f	9.3b–d	11.4ab	9.9a–c	6.2c–f	6.2ab
SB93977	4.44	12.1a	1.5f	6.9ef	12.2a	9.8a–c	5.0f	6.5ab
SB94893	40.36	6.5f	7.9a	9.0b–e	4.6e	9.0c	9.0a	5.2ab
SB94917	4.19	8.5de	4.6bc	10.6a–c	9.5bc	9.9a–c	6.7b–f	5.7ab
SB94966	6.26	11.3ab	2.4d–f	8.7c–f	11.7a	9.8a–c	5.7d–f	6.1ab
SH96082	4.33	10.6ab	2.7c–f	8.6c–f	11.7a	9.8a–c	5.6ef	7.0a
SH96085	6.07	10.4a–c	2.3ef	9.3b–d	11.2ab	9.9a–c	5.4f	5.5ab
SH99696	0.00	11.9ab	2.0ef	6.6f	11.9a	9.8a–c	5.1f	6.3ab

[a] Values represent average scores based on a 15-cm line scale, where 1 = low intensity of the given attribute and 15 = high intensity. Rollability = ability of sample to be rolled tightly; breakability = tendency of sample to break when rolled tightly; hardness = amount of force it takes to bite through sample; ease of compression = degree to which sample compresses; chewiness = number of chews required to break up sample before swallowing; moisture absorption = amount of moisture absorbed by sample after mastication; stickiness to teeth = amount of sample that sticks to all surfaces of the teeth.

[b] Genotype means followed by the same letter(s) are not significantly different ($P < 0.05$) based on Tukey's HSD.

[c] Sensory scores for a whole-wheat tortilla were predetermined by the sensory panelists during training and used throughout testing as a reference sample.

help breeders determine what measures to take to ensure that selection for high β-glucan content is effective.

In preliminary research in our laboratory, we observed unique functional properties of barley flours that were well suited to the production of tortillas and provided improved nutrition, flavor, and shelf stability. A study was done to determine which barley cultivars and milling fractions should be used to develop tortillas with desirable texture, appearance, and nutritional properties. Research was also performed to assess the potential of applying heat–moisture treatments to create whole-grain barley ingredients. The products identified in the study were a whole-grain, rapid-cook side dish and a crunchy snack. The final product considered in this report is a barley beverage prepared as a hot water extract of heat-treated and ground grain to obtain a drinkable serving of β-glucan and antioxidants.

Barley Tortillas

Consumption of tortillas made from barley flour, rather than traditional corn or wheat flour, is nutritionally beneficial due to the higher amounts of total dietary fiber and β-glucan found in barley. Despite the benefits of a higher nutritional content, to gain consumer acceptance barley tortillas must also roll well and be soft without being too chewy (*unpublished data*).

Previous experiments have demonstrated clear genotypic variation in the properties of barley flour; therefore, it was important to evaluate several genotypes for tortilla quality before and after freezing. Flour fractions from selected barley genotypes were blended to the equivalent of 60% extraction and made into tortillas using methods optimized in the laboratory. Genotype had a significant effect on tortilla production factors, including the amount of water required to produce optimum dough consistency and the ability to sheet the dough without sticking or tearing on the sheeting rolls. Overall, barley tortillas maintained their texture and nutritional content (data not shown) over at least 29 days of frozen storage.

A nine-member sensory panel trained to quantify several texture attributes was able to distinguish between cultivars (Table II). The panelists found that tortillas made from low-amylose ("waxy") barley genotypes had higher ease of rolling and compression and a lower degree of breakability.

Relationships Between Composition and Instrumental and Sensory Texture Measurements. The fact that trained panelists are capable of distinguishing tortillas based on differences among cultivars and can match sensory properties of tortillas with texture attributes indicates that it should be possible to link sensory perception with instrumental analysis in a laboratory and, more importantly, with specific cultivar composition. Instrumental texture analysis discriminated between samples in a manner similar to trained panelists, allowing rapid accurate analysis and further comparison with chemical constituents, including β-glucan, total dietary fiber, insoluble fiber, starch, and amylose.

Significant correlations were found between selected instrumental measurements (TA-XT2i texture analyzer tortilla rig, Stable Micro Systems Ltd., Godalming, United Kingdom), such as gradient, and the sensory attributes of rollability ($r = -0.91$) and breakability ($r = 0.78$). The relationships between the instrumental texture measurements and the flour components are shown in the bi-plot created using principal component analysis (13) (Fig. 1). Parameters found in the same quadrant indicate positive correlations, and those in opposite quadrants indicate negative correlations. According to the results of the sensory panel and consumer focus groups (data not shown), consumers prefer tortillas with lower breakability, lower dryness, higher rollability, and greater ease of compression, which can be predicted with a lower gradient or "slope" of the instrumental force versus time texture curve. Tortillas with a preferred texture contained less amylose. Less chewy, softer tortillas were produced with flours containing higher amounts of β-glucan and total dietary fiber. Observed relationships indicate that tortillas formulated with barley flour containing less starch and amylose and more β-glucan would be easier to roll, less breakable, softer, and less dry and chewy. Based on these findings, barley milling fraction blends were optimized for production of tortillas with high ratings for consumer acceptability.

Consumer Acceptance. Desirable nutritional content, storage stability, and instrumental texture scores all contribute to a good tortilla, but the ultimate test of a product's success is whether consumers will buy it once it is available in grocery stores. A sensory panel made up of consumers in Manitoba, Canada, was asked to evaluate barley tortillas made with a CDC Candle flour blend (a low-amylose cultivar) compared with a commercially available wheat tortilla. At least 90% of the consumer panelists liked (i.e., scored "like slightly" or better) the barley tortillas overall, as well as texture and taste. A higher percentage of consumers liked the texture of the barley tortillas compared with the wheat tortillas, which may be due to the higher extensibility and lower gradient, peak force, and thickness of the barley tortillas (data not shown). Mean consumer scores for purchase intent for barley tortillas did not differ significantly from wheat tortillas. Purchase intent may have been influenced by the higher nutritional content of the barley tortillas—approximately 80% of consumers indicated that knowledge of the nutritional content of barley tortillas would affect their decision to purchase.

Table III. Effect of infrared heat treatments on milling yield, color, composition, and β-glucan extract viscosity of CDC Candle barley flour fractions

Milling Fraction[a]	Grain Moisture Prior to Infrared Treatment (%)	Milling Yield (%)[b]	Color			β-Glucan (%, db)	TDF[c] (%, db)	Total Starch (%, db)	Protein (%)	AEV[d] (mPa·sec)
			*L**	*a**	*b**					
SGF	Untreated	38	87.54	–0.75	6.87	4.19	9.32	69.88	12.86	1.32
	16	42	86.43	–0.49	8.08	4.65	10.96	66.57	13.63	3.58
	20	43	85.40	–0.30	8.67	4.98	11.44	65.74	13.82	7.05
	24	46	83.66	0.02	9.61	5.56	12.95	64.67	14.22	13.35
DFFB	Untreated	17	86.20	–0.29	8.00	8.47	19.08	58.88	14.56	15.12
	16	6	82.40	0.45	9.67	8.74	22.81	54.01	15.15	19.57
	20	4	81.91	0.50	9.77	8.71	22.15	54.54	15.53	27.25
	24	3	80.58	0.70	10.09	8.54	21.55	54.50	15.40	42.85
DFFS	Untreated	45	84.44	–0.04	8.97	8.76	21.05	54.75	15.12	16.55
	16	52	82.55	0.31	9.55	8.55	20.54	56.31	14.39	27.61
	20	53	81.76	0.42	9.51	8.23	19.72	56.70	14.04	32.21
	24	51	80.97	0.52	9.72	8.02	19.57	59.07	13.88	50.45

[a] SGF = straight-grade flour; DFFS = flour obtained from passing the shorts fraction through a bran dusting machine; DFFB = flour obtained from passing the bran fraction through a bran dusting machine.

[b] The milling yields for the bran and shorts fractions were calculated prior to passing through the bran dusting machine and, therefore, represent the total yields of bran and shorts obtained from Buhler milling.

[c] Total dietary fiber.

[d] β-Glucan acid extract viscosity measured at a sheer rate of 2.651/sec.

Shelf-Stable Whole-Grain Barley Products

Given the potential health benefits and unique variability associated with specific barley genotypes, whole-grain barley products would provide consumers with a variety of high-fiber, low-calorie foods. However, whole-grain products and high-fiber milling fractions with desirable nutritional properties also contain the germ portion of the kernel, which can contribute to enzymatic rancidity. In addition, endogenous enzymes affect product color, especially in the presence of water, such as in dough systems. Infrared heat, which subjects food to electromagnetic radiation in the wavelength range of 1.8 to 3.4 μm, has been used in food applications to stabilize enzymes (7,17) and alter the cooking requirements of lentils (2).

In this study, a pilot-scale infrared heating machine was used to process barley grain tempered to various moisture levels (16–28%) to investigate the potential effects on nutritional and functional properties of different barley cultivars. The infrared heat-treated materials were evaluated as whole grain and after milling into various fractions.

Premilling Infrared Heat Treatments. Infrared heat treatments successfully inactivated the peroxidase enzyme in barley, which is commonly used as a marker for inactivation of several grain enzymes. Infrared heat treatment also affected how the barley fractionated during milling, as shown by changes in milling yields and composition of flour fractions, which resulted in improved β-glucan and total dietary fiber levels, particularly for the straight-grade flour from grain micronized at 24% moisture (Table III). Changes in flour color, starch damage, and β-glucan acid extract viscosity, as measured by Greenberg and Whitmore (9) and Bhatty and coworkers (4), were greater when grain was processed at higher moisture levels. When the treated flour was used in a tortilla end product, dough water requirements increased from 83% absorption (control) to 98–105% (infrared heat treated), but tortilla texture was not greatly affected. Tortilla dough made from unprocessed barley flour darkened rapidly over time and with cooking, a phenomenon that was greatly reduced by infrared heat treatment. These results showed that micronization can extend the use of barley flour in food products by stabilizing degradative enzymes, improving the nutritional quality of flour fractions, and helping to maintain good end-product color.

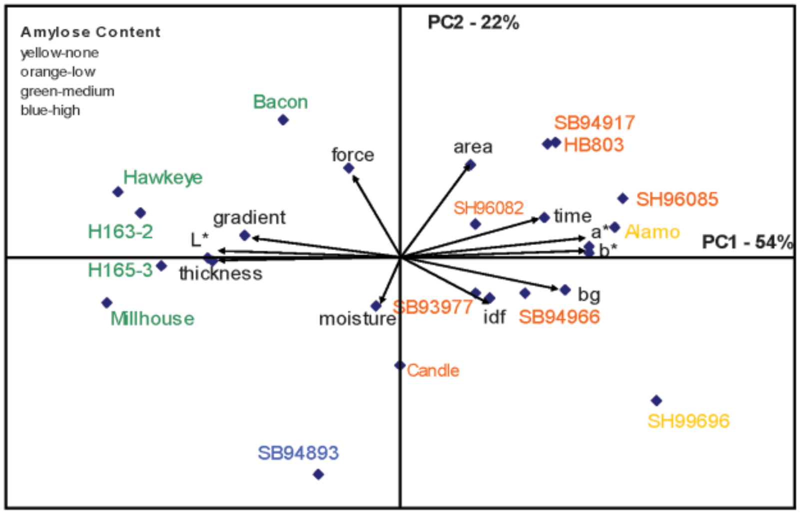

Fig. 1. Principal component analysis of relationships between instrumental texture and composition of barley tortillas made from 15 genotypes. Texture parameters measured were gradient (slope between onset of tortilla extension and breaking point [g/sec]), force (peak force required to break tortilla during extension), area (total work required to extend tortilla to breaking point), and time (length of time tortilla can be extended before breaking). Physical tortilla properties measured were thickness, moisture content, and *L**, *a**, *b** color. Barley components measured were bg (β-glucan) and idf (insoluble dietary fiber).

Whole-Grain Products. The effects of infrared heat processing on whole barley kernels were also investigated. The heat–moisture treatments resulted in unique physical, texture, and water absorption characteristics that depended largely on the barley genotype used. All infrared heat-treated barley showed higher paste viscosity at 25°C (as measured by a Rapid Visco Analyser [Newport Scientific, Warriewood, Australia) compared with the untreated control, which is typical of pregelatinized samples. In addition, the bran layer of selected genotypes became physically disrupted under certain processing conditions, leading to reduced bulk density, increased water uptake, and altered cooking times. For example, the low-amylose genotype CDC Candle puffed consistently during the infrared heat treatment, resulting in a product with a texture similar to the instant rice reference sample when cooked for only 5 min (Fig. 2).

These physical modifications are useful in the development of a rapid-cooking, whole-grain barley product for applications that traditionally use instant rice or couscous, such as side dishes. Such products would provide consumers with the benefits of barley's high fiber and β-glucan contents without having to compromise convenience.

In contrast, other barley genotypes with normal starch contents, such as CDC Dawn and McGwire, did not undergo the same degree of physical disruption during infrared heat processing. Instead, their kernels underwent only slight cracking of the bran layer, which required less force to break than undisrupted kernels, giving them a desirable, crunchy texture when eaten as is, with no cooking required. Lower tempering levels within the range tested and longer tempering times prior to infrared processing were also important in further optimizing the crunchy kernel texture. The unique texture properties exhibited by these genotypes are suitable for utilization in ready-to-eat snacks and as a replacement for nuts in sweet confections. A savory flavored snack and confectionary chocolate cluster made with optimally processed whole-grain barley both received favorable acceptance ratings (9-point hedonic scale) in consumer trials. In addition to desirable sensory characteristics, the nutritional content and fact that these crunchy products contained no nuts were important to consumers.

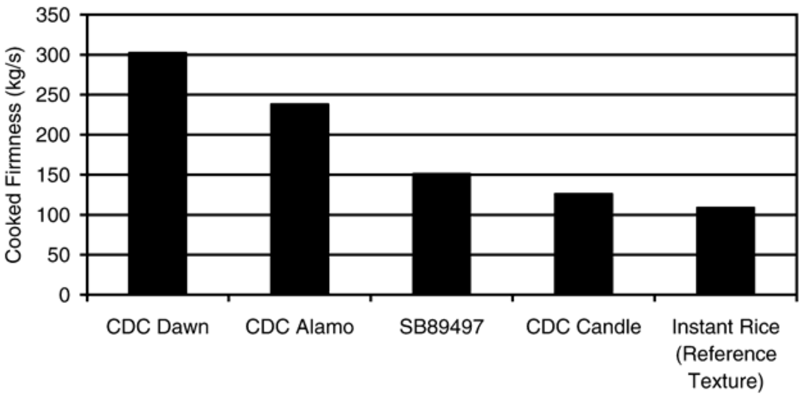

Fig. 2. Effect of genotype on the texture of infrared heat-treated whole-grain barley cooked for 5 min.

Novel Barley Beverages

More and more consumers are recognizing beverages as a source of health-promoting nutrients (19), which presents an opportunity for the introduction of novel products such as healthy grain-based beverages. For example, consumers searching for ways to increase their daily fiber consumption would benefit greatly from a hot barley tea product that releases β-glucan directly into the beverage.

The potential for utilizing barley genotypes and milling fractions that are high in β-glucan and antioxidants for beverage applications was investigated. Four barley genotypes (CDC Candle, CDC Rattan, SR93139, and Millhouse) and two milling and sieving techniques (hammer and roller milling) were used to provide fractions that had a range of β-glucan contents (5–12%) and antioxidant activities (2,500–5,000 µmol TE/100 mL). Interactions were observed among genotype, milling fraction, and infrared heat treatment regarding the amount of β-glucan extracted into the hot water and the viscosity of the extract. Although genotypes varied with respect to whole-grain and milled-fraction β-glucan content, high values were not necessarily indicative of high β-glucan extractability into hot water. Furthermore, extractability of β-glucan into hot water was lower for the roller-milled fractions than for the hammer-milled fractions.

These results indicate that selection of genotypes for high-quality barley extract beverages cannot be accomplished by measuring grain composition alone; extractability is also influenced by milling technique and particle size. For CDC Candle, SR93139, and CDC Rattan, increased infrared heat processing time prior to milling resulted in increased hot water extractability of β-glucan (Table IV). The best extraction of β-glucan was achieved using a tea press method. Further investigation into additional filter materials and different membrane technologies to improve the extraction of β-glucan using a filter bag system is ongoing.

Conclusions

The results demonstrate that barley can be successfully utilized in the production of nutritious, high-quality food products. It is evident that selection of an appropriate barley genotype is crucial for food manufacturers to take full advantage of the nutritional and functional properties of barley in the development of products that are acceptable to consumers. Infrared heat pretreatments had varying effects on whole-grain and milled barley, depending on genotype, level and duration of grain tempering, and time and intensity of infrared heat. Based on the results, infrared heat processing can extend the use of barley in food products by stabilizing degradative enzymes, improving nutritional quality (increased fiber content, as well as β-glucan viscosity and extractability), maintaining end-product color, reducing cooking time, and modifying grain texture and fractionation. New food applications present opportunities to offer consumers a wide variety of health-promoting foods and expand the markets available to barley producers beyond animal feed and malt.

Evaluation of the potential marketability of new products, including consumer sensory trials, shows that barley tortilla and whole-grain products have a potential place in the market. Information gained from consumer trials confirms that the nutritional benefits provided by barley products are recognized by consumers and would be a contributing factor to the potential success of new products in the marketplace. To launch new barley products into markets where their benefits can be realized by consumers, manufacturers must align the grain handling, milling, and production segments of the supply chain.

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Table IV. Effect of barley genotype, milling fraction, and infrared heat treatment on extraction of β-glucan into water at 95°C

		No Infrared Heat Treatment		Infrared Heat Treatment (70 sec)	
Genotype	**Milling Fraction**	**β-Glucan (mg/100 mL)**	**Extractability (%)**	**β-Glucan (mg/100 mL)**	**Extractability (%)**
CDC Candle	Fine	18.03 ± 0.43	34.0	31.23 ± 0.61	47.6
	Coarse	1.66 ± 0.09	1.9	2.16 ± 0.04	3.0
	Wholemeal	8.47 ± 0.01	11.6	18.22 ± 0.84	26.9
SR93139	Fine	19.37 ± 0.30	25.9	33.09 ± 0.08	40.3
	Coarse	2.07 ± 0.04	1.9	5.04 ± 0.01	4.9
	Wholemeal	13.32 ± 0.08	14.3	16.44 ± 0.13	18.3
Millhouse	Fine	17.60 ± 0.01	45.3	13.25 ± 0.06	30.6
	Coarse	1.89 ± 0.10	3.4	1.54 ± 0.05	3.08
	Wholemeal	10.64 ± 0.40	23.1	6.05 ± 0.02	13.3
CDC Rattan	Fine	16.72 ± 0.54	29.2	34.49 ± 0.74	48.0
	Coarse	3.05 ± 0.13	3.2	4.66 ± 0.01	5.8
	Wholemeal	10.85 ± 0.09	13.9	20.97 ± 0.05	28.2

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