Pearling of Hull-less Barley: Product Composition and Gel Color of Pearled Barley Flours As Affected by the Degree of Pearling

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Barley grains from two hull-less varieties, Phoenix and Candle, were pearled to various degrees (10−80%). The composition (starch, protein, β-glucan, lipid, and ash) of pearled grain (PG) and pearling flour (PF) was determined. Effect of pearling on Hunter *L*, *a*, and *b* color parameters of uncooked and cooked (gel) barley flour (milled from PG) was investigated over a 3 day storage at 4 °C.

Keywords: *Barley; chemical composition; gel color; pearling*

INTRODUCTION

Pearling, an important primary process in food-barley utilization, refers to the gradual removal of grain tissues (by abrasive action) starting from the outer grain tissues/layers, bran (i.e., pericarp, testa, aleurone, and subaleurone layers), and germ. The removal of barley bran through pearling yields a bright white kernel that is ideal for various food applications. The removed grain layers are called pearling flour (PF), and the remainder is called pearled grain (PG). The PF is usually sold as feed. However, its use for producing various innovative food products such as high-fiber (β-glucan-rich) functional pasta (Marconi et al., 2000) has been studied. A pearler generally is composed of six to eight abrasive carborundum- or emery-coated disks, which revolve at a high speed (∼450 rpm) within a perforated cylinder or closed chamber (Leonard and Martin, 1963). The process of pearling is usually a batch process, which is designed to achieve uniform removal of the grain outer layers. The process involves grain cleaning, conditioning/tempering (to ∼15% moisture), pearling, screening/sifting, aspirating (to remove fine bran particles/specs), and cooling. The "degree of pearling", a term widely used in the industry, has different definitions in different regions of the globe. For instance, in North America, 30% pearled means that 30% of the weight is PF and 70% is PG. In Japan, where significant amounts of pearled barley are used in foods (for example, as rice extender and meso), 70% pearled means that 70% of the weight is PG and 30% is PF. In North America, depending on the degree of pearling, products range from dehulled barley to pot barley (up to 15% pearled) to pearled barely (>15% pearled).

In barley, the starch and most of the storage proteins are generally confined to the endosperm cells, but several other storage and functional proteins (i.e., enzymes) exist in aleurone, subaleurone, and germ tissues. The β-glucan is present mostly in the cell walls of endosperm, but small amounts exist in the cell walls of aleurone and subaleurone layers. β-Glucan in barley is more evenly distributed than in oat, where it is predominantly found in the subaleurone layers.

The type of component distribution pattern (uniform or gradient) in barley grain would influence the composition and functionality of the pearling products. Zheng et al. (2000) reported that the distribution of β-glucan within the grain of hull-less barley varies depending upon the variety. Gohl et al. (1977, 1978) studied the distribution of carbohydrates in barley grains harvested at early and late stages of maturity and reported that xylose, fructose, and glucitol were found mostly in the outer layers. A trace amount of myoinositol was detected in all fractions. Sucrose was found in all fractions except in the bran. Stachyose and raffinose were concentrated in the center of the kernel. Glucose was found in all layers in increasing amount toward the center of the kernel. The authors further reported that protein was concentrated in the intermediate layers for early-harvested barley grains and in 15−45% abrasion for late stage of maturity. Ash was found in the outer layer of the kernel. Also, the lipid content of PF reached its highest concentrations of 10−25 and 15% of the abraded barley grains in early-harvested and late-harvested barley, respectively. Klamczynski et al. (1998) reported a significant increase in starch and total β-glucan contents in pearled grain with progressive pearling. Bhatty (1997) demonstrated that the PF obtained by 30% pearling of barley grain constitutes the bran (pericap, testa, aleurone, and subaleurone layers). Most of the lipids, protein, and minerals (ash) are concentrated in the germ and bran. Bhatty and Rossnagel (1998) compared Canadian and Japanese barleys and reported that pearling to 55% decreased β-glucan, total dietary fiber, ash, and protein contents, but increased starch and soluble fiber contents. Klamczynski et al. (1998) reported that substantial amounts of barley grain protein and minerals (ash) are concentrated in PF.

Barley lipid contains relatively high amounts of unsaturated fatty acids, oleic (18:1) and linoleic (18:2) acid (Morrison 1993), which are highly prone to autoxidation and subsequent rancid odor development. Therefore, the storage stability and overall quality of pearled barley are superior to those of unpearled barley. Another important benefit of pearling is the removal of a

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Table 1. Composition of Regular (Phoenix) and Waxy (Candle) Barley Grains and Their Pearling Products

degree of pearling (%)	pearling product	composition[a] (%, dry basis)				
		starch	protein	β-glucan	lipid	ash
			Phoenix			
whole		63.6 ± 1.2	13.5 ± 0.5	3.8 ± 0.2	2.1 ± 0.1	2.0 ± 0.1
10−12%[b]	PG	68.9 ± 0.2	12.8 ± 0.1	4.3 ± 0.1	1.5 ± 0.1	1.7 ± 0.1
	PF	11.3 ± 0.4	19.2 ± 0.6	1.7 ± 0.1	5.7 ± 0.2	5.3 ± 0.1
23−25%	PG	75.3 ± 0.1	10.9 ± 0.4	4.5 ± 0.2	1.1 ± 0.0	1.1 ± 0.1
	PF	28.9 ± 0.7	23.9 ± 0.5	1.9 ± 0.3	5.3 ± 0.1	4.4 ± 0.1
30−32%	PG	76.6 ± 0.4	10.4 ± 0.2	3.9 ± 0.1	1.1 ± 0.0	1.0 ± 0.1
	PF	32.7 ± 0.9	20.3 ± 0.5	3.6 ± 0.3	4.6 ± 0.2	4.3 ± 0.1
48−50%	PG	79.2 ± 0.7	10.1 ± 0.1	3.8 ± 0.3	0.9 ± 0.1	0.7 ± 0.1
	PF	48.7 ± 0.6	16.2 ± 0.4	3.9 ± 0.1	3.2 ± 0.2	3.3 ± 0.2
60−63%	PG	80.5 ± 0.6	9.3 ± 0.2	3.7 ± 0.2	1.2 ± 0.0	0.6 ± 0.1
	PF	50.7 ± 0.5	14.9 ± 0.7	3.8 ± 0.2	2.9 ± 0.1	2.6 ± 0.1
78−80%	PG	81.2 ± 0.7	8.9 ± 0.2	3.7 ± 0.2	1.1 ± 0.1	0.6 ± 0.1
	PF	59.1 ± 0.3	14.1 ± 0.5	4.0 ± 0.2	2.3 ± 0.2	2.4 ± 0.1
			Candle			
whole		58.5 ± 0.7	12.4 ± 0.2	5.9 ± 0.1	2.4 ± 0.1	2.1 ± 0.1
10−12%	PG	64.1 ± 1.1	11.9 ± 0.5	6.3 ± 0.2	1.9 ± 0.1	1.6 ± 0.1
	PF	8.9 ± 0.5	20.4 ± 0.7	1.9 ± 0.1	6.2 ± 0.2	6.7 ± 0.2
23−25%	PG	71.6 ± 1.0	10.1 ± 0.1	6.4 ± 0.1	1.3 ± 0.1	1.3 ± 0.1
	PF	22.7 ± 0.2	22.7 ± 0.6	4.6 ± 0.1	5.8 ± 0.2	4.8 ± 0.2
30−32%	PG	73.7 ± 0.4	10.2 ± 0.6	6.5 ± 0.2	1.2 ± 0.1	1.2 ± 0.1
	PF	24.2 ± 0.8	17.7 ± 0.4	4.7 ± 0.1	5.6 ± 0.1	4.4 ± 0.1
48−50%	PG	75.1 ± 1.1	9.0 ± 0.2	6.8 ± 0.2	0.9 ± 0.1	0.9 ± 0.1
	PF	41.7 ± 0.7	16.1 ± 0.8	5.0 ± 0.1	4.1 ± 0.1	3.3 ± 0.2
60−63%	PG	77.9 ± 0.7	7.0 ± 0.7	7.0 ± 0.2	0.8 ± 0.1	0.7 ± 0.1
	PF	47.1 ± 0.9	15.3 ± 0.5	5.3 ± 0.1	3.4 ± 0.2	3.2 ± 0.2
78−80%	PG	79.5 ± 0.8	5.9 ± 0.2	7.3 ± 0.2	0.7 ± 0.0	0.7 ± 0.1
	PF	53.6 ± 0.6	14.0 ± 0.6	5.5 ± 0.2	2.8 ± 0.1	2.4 ± 0.2

[a] Values are means of three determinations ± standard deviation. [b] Percent outer grain layers stripped and removed as PF leaving 88−90% of grain as PG.

variety of barley phenolic compounds and enzymes, such as polyphenol oxidase and peroxidase, along with the outer grain layers. This virtually eliminates the enzyme-driven darkening of barley products. However, in terms of the nutritional quality of pearled barley, the loss of tocols (vitamin E, a fat-soluble component), protein, and valuable minerals along with the bran and germ is a negative effect brought about by pearling. Research showed that 20% PF contains high amounts of total tocols, α-tocopherol, and α-tocotrienol (Wang et al., 1993; Peterson, 1994).

The objectives of the present study are (a) to understand the distribution of major components (i.e., starch, protein, lipid, β-glucan, and ash) in a waxy (Candle) and in a regular (Phoenix) hull-less barley grain by a gradual layer-by-layer pearling of up to 80% (w/w) of the grain tissues and compositional analysis of pearling products, namely PG and PF, and (b) to study the effect of various degrees of grain pearling on the color characteristics of uncooked and cooked (gel) flour milled from PG.

MATERIALS AND METHODS

Materials. Waxy barley grains (CDC Candle) were obtained from Jim Gray, Agricore, Calgary, AB. Regular barley grains (Phoenix) were obtained from Dr. Jim Helm, Alberta Agricultural, Food and Rural Development, Lacombe, AB. The analytical kits for starch and β-glucan determination were purchased from Megazyme International Ireland Ltd., Wicklow, Ireland.

Pearling and Milling. Barley grains were pearled at the University of Saskatchewan (Saskatoon, Canada) using a "Satake" testing mill (model TM05, Satake, Tokyo, Japan) (fitted with an abrasive roller and 1 mm screen) at low speed. Grains (200 g) were pearled to various degrees (10−80%, wet basis) (pearling time ranged from 13 to 56 min). At each degree of pearling, the PF and PG were collected. The PG was ground to flour in an Udy mill.

Compositional Analysis. The protein, fat, and ash contents of samples were determined according to AOAC (1990) Methods 979.09, 920.39, and 923.03, respectively.

Gel Preparation. Ten grams of flour (milled from PG) was mixed with 100 mL of water and then heated for 30 min in a water bath set at 96−100 °C. The resulting gel was transferred into a Petri dish and stored for 1 and 72 h, at 4 °C.

Color Measurements. A HunterLab Color Difference meter (model D52-2, Hunter Associates Laboratory, Fairfax, VA) was used to measure the Hunter *L*, *a*, and *b* values of the flours and gels.

RESULTS AND DISCUSSION

The compositions of whole barley grain and pearling products, namely, PG and PF, are given in Table 1 and Figure 1.

Whole Grain. The starch content of regular (Phoenix) barley was ∼5% higher than that of waxy (Candle) barley. The β-glucan content of Candle barley was ∼2% higher than that of Phoenix. The differences in the contents of protein, fat, and ash between the barley varieties were small (ranging from 0.1 to 1.2%).

PG Composition. Regardless of the degree of pearling, PG from both Phoenix and Candle had high starch contents (∼69−81 and ∼64−79% for Phoenix and Candle, respectively) compared to relatively low starch contents in the corresponding whole grains (∼64 and ∼58% for Phoenix and Candle, respectively; Table 1 and Figure 1a). The starch content in PG from both varieties increased rapidly as the degree of pearling increased from 10 to 25% and gradually reached a plateau thereafter. This suggests that the tissue layers stripped initially due to pearling were composed mainly of nonstarch materials and that starch is confined to the

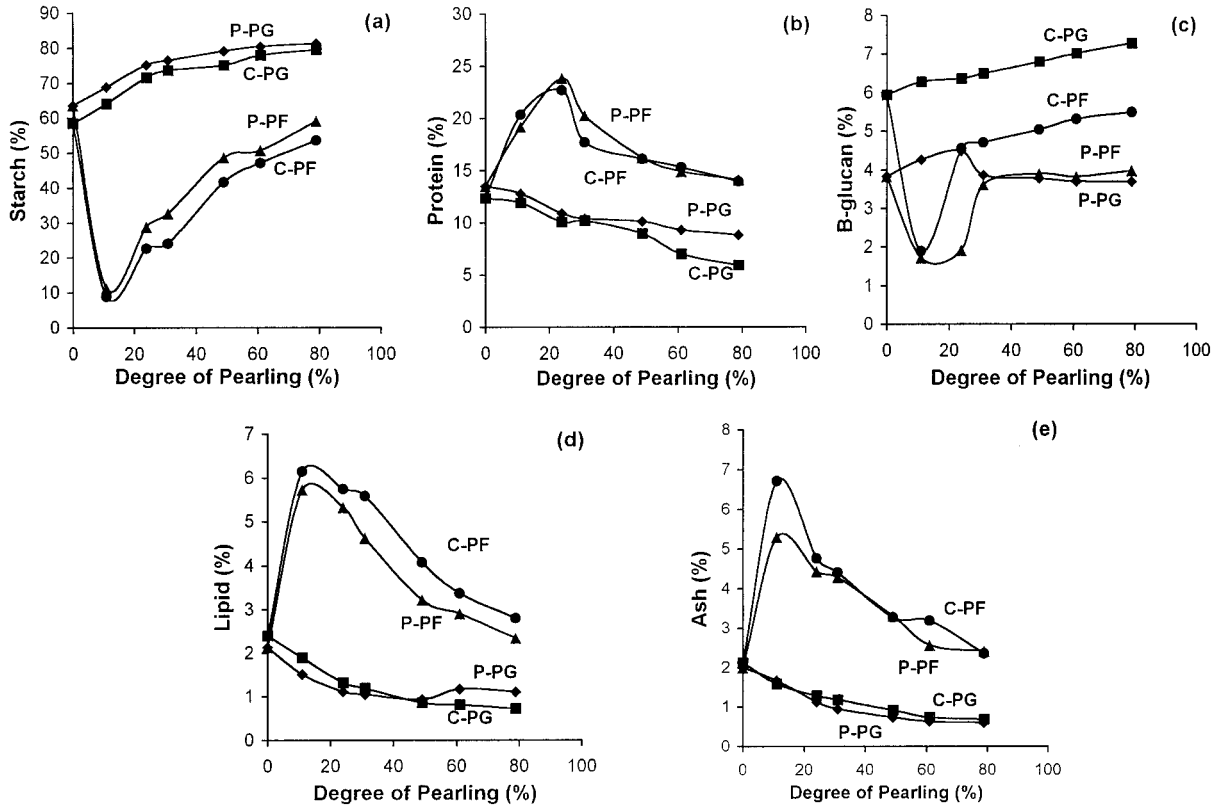

Figure 1. Starch, protein, β-glucan, lipid, and ash contents of the pearling products from Candle (C) and Phoenix (P) barley grains as affected by various degrees of pearling. Note: The whole grain component percent values are considered for 0% degree of pearling.

inner core of the grains. Furthermore, as the degree of pearling increases, a gradual decrease in the protein reserves of the grains was evident for both Phoenix and Candle (Table 1 and Figure 1b). This was indicative of a decreasing concentration gradient (from outer to inner tissue layers) for proteins across the grain.

The content of β-glucan in whole Candle grains was ~2% higher than that of the whole Phoenix grains, and this difference contributed heavily to the variety-dependent differences in the β-glucan contents in PG (Table 1 and Figure 1c). The β-glucan content in pearled Phoenix grains (P-PG) ranged from ~3.7 to 4.5%, whereas that of the pearled Candle grains (C-PG) ranged from ~6.3 to 7.3%. A sharp increase in the β-glucan content in P-PG up to a 25% of pearling followed by a gradual decrease suggests a concentration of β-glucan in the tissue layers immediately beneath the grain surface, perhaps in the aleurone and subaleurone tissues. In contrast, there existed a gradual increase of the β-glucan content in C-PG, indicating a positive concentration gradient toward the grain core. Zheng et al. (2000) also reported a similar trend for β-glucan in "low-β-glucan hull-less barley" (regular starch barleys), and they concluded that the bulk of β-glucan was concentrated in the subaleurone layer and the endosperm located immediately beneath it. β-Glucan in "high-β-glucan hull-less barley" (waxy starch barleys) was reported to be localized at the inner endosperm.

There were no clear-cut differences between the lipid contents in whole Phoenix and Candle grains. This resulted in similar lipid contents in PG of both varieties at the same degree of pearling. For both varieties, a continuous decrease in lipid fraction in PG as the degree of pearling increased suggests the existence of a negative concentration gradient toward the grain core (Table 1 and Figure 1d). Similar trends were observed for ash contents in PG from both barley varieties (Table 1 and Figure 1e). These findings are in agreement with those reported by Summer et al. (1985), Bhatty and Rossnagal (1998), Klamczynski (1998), and Marconi et al. (2000).

PF Composition. For both varieties starch and β-glucan contents of PF initially decreased with pearling of up to 10−12% (degree of pearling) and then increased through pearling of up to 78−80% (Table 1 and Figure 1a,c). This was due to the confinement of starch and β-glucan in the inner tissues of barley grain (i.e., endosperm). Increase in the starch content of the PF after 10−12% of pearling was not gradual (Figure 1a). The increase occurred at two distinct stages, perhaps due to the nonuniform distribution of starch in the endosperm. However, the pattern of increase in β-glucan content (Figure 1c) after 10−12% of pearling was found to be variety dependent. In Candle, a rapid increase up to 25% pearling and a gradual increase thereafter were observed. For Phoenix, a small increase existed up to 23% pearling, followed by a rapid increase to 32% and a gradual, but little, increase thereafter. This clearly indicates a nonuniform distribution of β-glucan across the endosperm and the possible concentration of β-glucan in the grain layers, which were removed between 23−32 and 12−23% of pearling for Phoenix and Candle, respectively.

For both barleys, the protein content (Figure 1b) initially increased up to 25% of pearling and decreased thereafter, suggesting high protein concentration in those layers. After 25% of pearling, the gradual decrease of protein content in Phoenix suggests that the protein distribution is uniform across the endosperm. However, in Candle, a sudden drop in protein content up to the

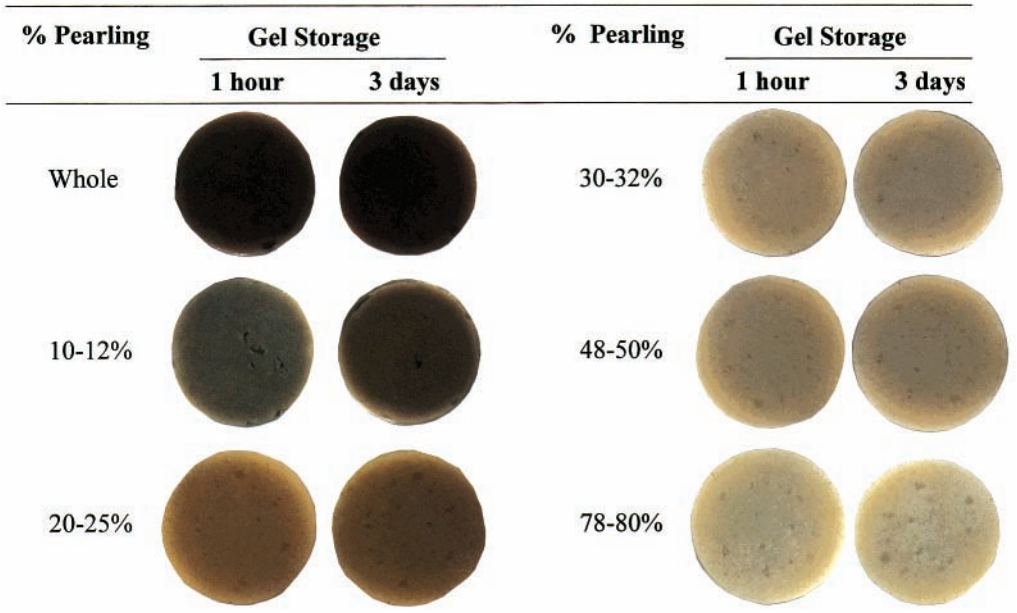

Figure 2. Color features of gels prepared with barley flours milled from whole and PG.

degree of pearling 32% and a gradual decrease thereafter were observed. This suggests that the loss of protein along with the grain layers removed during 25−32% pearling was minimal.

Both lipid and ash contents of barley PF investigated increased up to 10−12% pearling and decreased thereafter, suggesting the concentration of these components in the outer layer stripped by 23−25% pearling. It is noteworthy to indicate the existence of a gradual but a two-stage decrease in ash content after 12% pearling.

Gel Color. The gels were prepared from PG flour from both varieties and photographed after refrigerated (4 °C) storage for 1 h as well as 3 days. However, only the photographs for those of Candle gels are presented in Figure 2, because only a small difference in gel color between barley varieties was observed subjectively. The color of the gels prepared with flour from whole grain was darker (dark black/brown) than that of the flour milled from PG. The brightness of the PG gels increased as the degree of pearling increased up to 32% and reached a plateau thereafter. Furthermore, it was evident that the stability of gel color was influenced by the degree of pearling. The intensity of the dark black/brown color of the gels prepared from whole grain flour increased (subjective evaluation) during the 3 day storage. Similar trends in the color intensities were observed for gels prepared with flour from 10−12% and 23−25% PG. However, the gel color stability was observed to be high at a degree of 30−32% pearling and higher.

The color characteristics (Hunter *L*, *a*, and *b*) of the flours and gels are given in Table 2. Hunter *L*, *a*, and *b* values of samples represent their brightness, redness, and yellowness, respectively. The flours from both barley varieties had little differences in their color values. For a given variety, PG flours had higher *L* and lower *a* and *b* values than those of the whole grain flours. However, a substantial difference existed between the color of flour and that of the gel. The *L* values of flours were higher and the *a* and *b* values were lower than those of corresponding gels. The brightness of the PG gels increased as the degree of pearling increased, whereas a small change was observed in *a* and *b* values.

Table 2. Effect of Pearling on the Hunter Color Values[a] of Barley Flour and Gel

pearling (%)	flour[b]			gel[c] 1 h[d]			gel[c] 3 days[d]		
	L[e]	*a*[e]	*b*[e]	*L*	*a*	*b*	*L*	*a*	*b*
Phoenix									
whole	87.7	1.4	10.4	55.9	2.7	13.1	55.0	2.3	11.0
10−12%	89.1	1.0	9.1	57.3	2.6	13.0	56.0	2.3	10.8
23−25%	90.9	0.7	6.9	59.2	2.6	12.6	58.1	2.2	10.1
30−32%	91.5	0.5	6.1	66.4	2.0	10.7	66.3	2.0	9.8
48−50%	92.9	0.4	5.4	66.8	2.0	10.7	66.5	2.0	9.7
78−80%	93.7	0.4	5.0	67.1	2.0	10.2	66.8	1.9	9.7
Candle									
whole	87.0	1.3	10.5	50.0	2.7	11.8	46.7	4.0	11.2
10−12%	89.8	1.1	9.0	54.7	2.5	11.5	49.8	3.8	11.0
23−25%	91.6	0.6	6.7	58.9	2.1	10.8	55.3	3.3	10.4
30−32%	92.2	0.4	5.1	66.2	1.8	10.6	66.0	2.2	10.0
48−50%	93.0	0.4	4.6	66.5	1.8	10.6	66.0	1.9	9.9
78−80%	93.5	0.4	4.2	66.5	1.7	10.5	66.5	1.7	9.9

[a] Values are means of three determinations. Standard deviations are <3%. [b] Barley flour is produced by grinding of PG in an Udy mill. [c] Aqueous slurry of flour (10%, w/v) cooked at 100 °C for 0.5 h. [d] Storage period at 4 °C. [e] Hunter *L*, *a*, and *b* values of samples represent the brightness, redness, and yellowness respectively.

The *L* value of the gels prepared with flour from whole and PG (10−12 and 23−25%) decreased during the 3 day storage. A very little change in the *L* value of gels prepared with flour from PG (pearled to 30−32% or more) was observed.

Conclusions. Although the barley grain components, such as starch, protein, β-glucan, lipids, and ash, are distributed in various tissues (i.e., aleurone, germ, and endosperm) of the grain, the patterns of distribution of these components within a tissue differ widely depending upon the barley variety. Understanding this pattern of distribution through a gradual layer-by-layer grain pearling process will be useful in order to strategically select flour (PF) characteristics for industrial pearling operations. This may enable the production of barley flours rich in a particular grain component and also the optimization of flour functionality for different food/industrial applications. The morphological features

(photographs) and Hunter color values of barley flour gels indicated that pearling of barley at least to a degree of 32% is required to ensure the bright color and its stability in barley-based foods.

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LITERATURE CITED

AOAC. *Official Methods of Analysis*, 15th ed.; Association of Official Analytical Chemists: Washington, DC, 1990; Methods 979.09, 920.39, and 923.03.

Bhatty, R. S. Milling of regular and waxy starch hull-less barleys for the production of bran and flour. *Cereal Chem*. **1997**, *74*, 693−699.

Bhatty, R. S.; Rossnagel, B. G. Comparison of pearled and unpearled Canadian and Japanese barleys. *Cereal Chem*. **1998**, *75*, 15−21.

Gohl, B.; Larsson, K.; Nilsson, M.; Theander, O.; Thomke, S. Distribution of carbohydrates in early harvested barley grain. *Cereal Chem*. **1977**, *54*, 690−698.

Gohl, B.; Nilsson, M.; Thomke, S. Distribution of soluble carbohydrates in barley grain at late stage of maturity and relation to viscosity. *Cereal Chem*. **1978**, *55*, 341−347.

Klamczynski, A.; Baik, B. K.; Czuchajowska, Z. Composition, microstructure, water imbibition, and thermal properties of abraded barley. *Cereal Chem*. **1998**, *75*, 677−685.

Leonard, W. H.; Martin, J. H. Barley. In *Cereal Crops*; Macmillan: New York, 1963; pp 478−543.

Marconi, E.; Graziano, M.; Cubadda, R. Composition and utilization of barley pearling by-products for making functional pastas rich in dietary fiber and β-glucans. *Cereal Chem*. **2000**, *77*, 133−139.

Morrison, W. R. Cereal starch granule development and composition. In *Seed Storage Compounds: Biosynthesis, Interactions and Manipulation*; Shewry, P. R., Stobart, A. K., Eds.; Oxford University Press: Oxford, U.K., 1993; pp 175−190.

Peterson, D. M. Barley Tocols: Effects of Milling, Malting and Mashing. *Cereal Chem*. **1994**, *71*, 42−44.

Summer, A. K.; Gebre-Egziabher, A.; Tyler, R. T.; Rossnagel, B. G. Composition and properties of pearled and fines fractions from hulled and hull-less barley. *Cereal Chem*. **1985**, *62*, 112−116.

Wang, L.; Xue, Q.; Newman, R. K.; Newman, C. W. Enrichment of tocopherols, tocotrienols and oil in barley fractions by milling and pearling. *Cereal Chem*. **1993**, *70*, 499−501.

Zheng, G. H.; Rossnagel, B. G.; Tyler, R. T.; Bhatty, R. S. Distribution of β-glucan in the grain of hull-less barley. *Cereal Chem*. **2000**, *77*, 140−144.

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