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Physical and Sensory Properties of All-Barley and All-Oat Breads with Additional Hydroxypropyl Methylcellulose (HPMC) β-Glucan

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Hydroxypropyl methylcellulose (HPMC) is a substituted cellulose that reduces serum cholesterol at modest intake levels. HPMC has also been used for decades in gluten-free breads at a level to optimize loaf volume. Because consumers resist the consumption of whole wheat breads, the sensory and physical properties of all oat and barley breads incorporating HPMC were evaluated. Oat and barley also contain β-glucan, a glucose polymer similar to HPMC that also lowers cholesterol. The textural and sensory properties of the breads were determined by instrumental and chemical methods and sensory panels. HPMC increased the loaf volume of the breads by up to 2 times and decreased hardness immediately after baking and after up to 3 days of storage. Barley bread with HPMC was rated the highest in overall acceptability by sensory panelists compared to oat and wheat breads with or without HPMC.

KEYWORDS: Whole grain bread; barley bread; oat bread; HPMC; soluble fiber

INTRODUCTION

Consumers are becoming increasingly aware of the health benefits of whole grain cereal products and dietary fiber. However, Americans consume only one serving of whole grain per day and about half the recommended amounts (38 and 25 g, young men and women, respectively) of dietary fiber (*1*). Grain consumption is dominated by wheat, which makes up about 80% of all grain intakes but mostly in the form of debranned wheat flour. However, it is difficult to find bread and other cereal products that contain oat and barley flour as the primary ingredient. White wheat bread may be perceived as lower in healthful components since it has lower amounts of dietary fiber, protein, and antioxidants than whole grain bread. Moreover, white wheat bread has a high glycemic index, and this may contribute to the negative perception of white bread.

Oat and barley are incorporated into breads but typically at low levels (< 20% of the flour) because they reduce loaf volume and produce undesirable denser texture. The consumption of whole oat and barley can prevent heart disease because both oat and barley are high in the soluble dietary fiber β-glucan, which has been recognized by the U.S. FDA for its ability to reduce serum cholesterol and the risk of coronary heart disease (*2*). In addition to β-glucans, whole grains are generally higher in tocopherols, phytosterols, phenolic antioxidants, and other phytochemicals than white bread (*3*−*5*).

To produce a reasonable loaf volume, oat and barley flours are combined with wheat flour, which dilutes the β-glucan content to the extent that FDA health claims would not be allowed. High levels of wheat flour are necessary because yeast-leavened bread formulations containing significant amounts of nonwheat flours have been reported to result in a negative effect on loaf volume and poor crumb structure (*8*, *9*). However, some studies (*6*, *7*) have shown that when baking powder was used as a leavening agent, there were no significant differences in the loaf volume when up to 20−50% of the wheat flour was replaced with barley flour.

Hydroxypropyl methylcelluose (HPMC), at about 3% flour basis, has been used for over 30 years to produce rice breads for individuals with gluten intolerance (*10*). HPMC is a water-soluble viscous 1,4-glucose polymer that is produced by the addition of methyl and hydroxylpropyl groups to the cellulose backbone. This modification leads to a polymer with a high surface activity and unique hydration−dehydration solution dependent on temperature (*11*, *12*). HPMC has superior foam stabilization ability that is thought to be responsible for its gas-holding properties (*13*) which results in greater loaf volume and better crumb structure in gluten-free breads. The effect of HPMC on the quality of breads, especially in loaf volume, depends largely on the amount of HPMC added. Like other hydrocolloids such as xanthan, addition of 2−6% HPMC or 1% xanthan significantly increases volume, but higher levels result in reduced volume due to lower rates of gas incorporation (*14*, *15*). Numerous studies (*16*−*19*) have shown that the optimum level of HPMC is about 0.5% for texture improvement and antistaling properties of wheat breads. However, few studies have addressed the health effects of the addition of > 3% HPMC to wheat-free breads as a source of soluble dietary fiber (*20*). As a viscous soluble dietary fiber, HPMC lowers plasma cholesterol and postprandial blood glucose (*21*, *22*). HPMC and cereal

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Table 1. General Composition of Whole Wheat, Barley, and Oat Flours Used for Breadmaking[a]

flour	% IDF	% SDF	% TDF	% ash	% protein	% fat
whole wheat	10.75 ± 0.4	1.84 ± 0.5	12.58 ± 0.3	1.81 ± 0.01	18.10 ± 0.13	2.33 ± 0.01
barley, pearled	9.46 ± 2.1	4.36 ± 0.4	13.82 ± 0.3	1.67 ± 0.01	12.90 ± 0.10	2.52 ± 0.01
oat, debranned	11.71 ± 0.8	1.42 ± 0.3	13.13 ± 0.4	1.23 ± 0.01	12.00 ± 0.18	6.80 ± 0.01

[a] IDF, insoluble dietary fiber; SDF, soluble dietary fiber; TDF, total dietary fiber.

β-glucans are both β-glucans, but the cereal β-glucans contain both 1,3- and 1,4-β-glycan linkages, whereas HPMC contains only 1,4-β-glycan linkages. The current study was conducted to develop leavened all-barley and -oat breads fortified with 5% HPMC. In addition, the sensory and physical properties of all-barley and -oat breads with or without HPMC were compared to those of whole wheat bread to determine their potential as suitable commercial products.

MATERIALS AND METHODS

Materials. Commercial barley (pearled, Giusto's Inc., San Francisco, CA), oat (debranned, General Mills Inc., Eugene, OR), and whole wheat flour (King Arthur Flour Co. Inc., Norwich, VT) were purchased from a local grocery store. For the additional soluble fiber used as a substitute for gluten, two different viscous types of HPMC (Dow-Wolff Cellulosics, Midland, MI) were used, L-HPMC (Methocel K4M) and H-HPMC (Methocel K15M). HPMC is characterized by its viscosity as 2% water solutions at 20 °C, and L- and H-HPMC had reported viscosities of 3475 and 18529 mPas by a Ubbelohde viscosity method (ASTM 2363) (*23*), respectively.

Preparation of Leavened Breads. All-barley, all-oat, and whole wheat breads were prepared by the addition of 5% HPMC (5%, w/w, flour basis) using a modified rice bread formulation (*10*). A typical bread formula consisted of 100 g of flour, 3 g of dry yeast, 6 g of vegetable oil, 2 g of salt, 7.5 g of sugar, 5 g of HPMC, and 75−120 g of water. The amount of water was determined on the basis of the subjective visual evaluation of acceptable loaf structures and uniform dough consistency. With the exception of yeast, all dry ingredients were combined and blended thoroughly using a stand mixer (Pro Line KSM5, KitchenAid Inc., St. Joseph, MI). Yeast, water, and vegetable oil were then added to the dry mixture, which was subsequently mixed for 5 min at a speed of 4. The wet dough was then transferred directly into the baking pan and proofed at 38 °C and 85% relative humidity for 30 min. The breads were then baked at 204 °C for 35 min, after which they were allowed to cool to room temperature for 1 h. The breads were then packed in polypropylene bags and stored at 4 °C until further analysis.

Chemical Analysis. The protein and fat of the flours were determined according to AOAC Method 990.03 (*24*) using a combustion nitrogen analyzer (Elementar Americas Inc., Vario Macro, Mt. Laurel, NJ) and a high-pressure solvent extractor (model AES200, Dionex Corp., Sunnyvale, CA), respectively. The ash content was determined according to AOAC Method 923.03 (*24*). The total dietary fiber was determined after hydrolysis of starch and protein using an assay kit (TDF-10, Sigma-Aldrich, St. Louis, MO) based on the enzymatic−gravimetric method, AOAC Method 45.4.09 (*24*). The β-glucan content was determined enzymatically using an assay kit (Megazyme, Wicklow, Ireland) following the method described by AOAC Method 995.16 (*24*).

Pasting Properties of Flours. The pasting properties of flours with or without HPMC during heating were determined by Rapid Visco Analyzer (New Port Scientific Pty, Ltd., Warriewood, NSW, Australia) using a constant paddle rotation speed of 160 rpm to monitor the viscosity during the gelatinization of flour suspensions. The flour suspension (3.5 g of flour/25 g of water) with or without HPMC was heated from 25 to 95 at 6 °C/min, after which it was maintained at 95 °C for 10 min and then cooled to 25 °C. The peak viscosity and initial pasting temperature were then determined.

Physical Characteristics of Breads. The loaf volume of breads was determined by rapeseed displacement method using a 400 mL wood reference. The color of the crumb and crust was measured using a Minolta Color Analyzer (Minolta CM-5080, Japan). Texture profiles of breads were evaluated using a SMS Texture Analyzer (TA-XT2, Stable Micro System, Godalming, Surrey, U.K.) with a 50 mm diameter cylinder aluminum probe. Three slices of bread (2.54 × 2.54 cm) were taken from the middle of the loaf and then compressed to 50% of the initial height at 1 mm/s. The hardness of breads was evaluated over 3 days on bread stored at room temperature.

Sensory Characteristics of Breads. Sensory tests were conducted by an untrained panel. Thirty-four untrained judges evaluated breads on a 7-point hedonic scale (1 = dislike very much; 7 = like very much). The sensory parameters rates included appearance, flavor, texture, aftertaste and overall acceptability. Sensory profiles of HPMC-enriched breads (whole wheat bread, barley and oat breads with HPMC) were assessed, and comparisons were made to whole wheat bread.

Statistical Analysis. Composition and color data were analyzed by the SPSS statistical package (SPSS ver 12.0) using *t* tests and Duncan's multiple-range test at the 5% significance level. Sensory data were analyzed by Minitab Release 14 (Minitab Inc., State College, PA) using one-way ANOVA (unstacked) and Tukey's multiple comparisons at the 5% significance level.

RESULTS AND DISCUSSION

Composition of the Whole Wheat, Barley, and Oat Flours. The compositions of the flours are shown in **Table 1**. Because commercially milled flours were used, the composition was compared to composition reported in the USDA's National Food Database (NFB) to gauge the degree of milling. The debranned oat flour had fat, TDF, and ash contents that were more similar to those of oat flour (NDB20038) than those of debranned oat (NDB20132). The pearled barley flour protein and fat levels were similar to those of whole barley flour based on comparisons to the composition data from NDB20005 and NDB20004, which correspond to pearled barley and barley, respectively.

Pasting Properties of Whole Wheat, Barley, and Oat Flours with HPMC. The pasting profiles of the flours used in this study are shown in **Figure 1**. All HPMC-added flour suspensions had a higher peak viscosity than suspensions of flour alone at about 95 °C. The peak viscosity of barley and oat flours, at about 12 min, increased from 2877 to 3649 mPas and from 3084 to 3912 mPas, respectively, when HPMC was added to the flour suspension at the maximum level tested. The increase in peak viscosity is partially attributed to a simple additive viscosity effect of HPMC, and the more viscous medium may also decrease the rate of breakdown of the gelatinized starch granules. A small transient peak occurred at about 9 min or 74−76 °C of the flour suspensions, and the viscosity of this early peak increased with increasing HPMC concentration. The viscosity of the 9 min peak increased from 610 to 1885 mPas and from 268 to 1319 mPas for barley and oat suspensions, respectively, as the amount of HPMC increased from 0.1 to 0.3 g. Rosell and Foegeding (*12*) have observed that HPMC forms hydrophobic associations with protein that produces a stable gel at around 75 °C. Although it is known that HPMC interacts with gluten (*25*), protein does not seem to be involved because the peak observed with starch occurs at about the same time as the main peak in waxy rice and before the main peak in nonwaxy rice. The presence of the transient peak in nonwaxy starch suggests that HPMC interacts with amylose and that some soluble amylose is released at about the time that amylopectin gelatinizes and absorbs water. The increased viscosity of the HPMC flour suspensions supports the idea that viscosity is necessary for gas entrapment. Nishita et al. (*10*) also observed

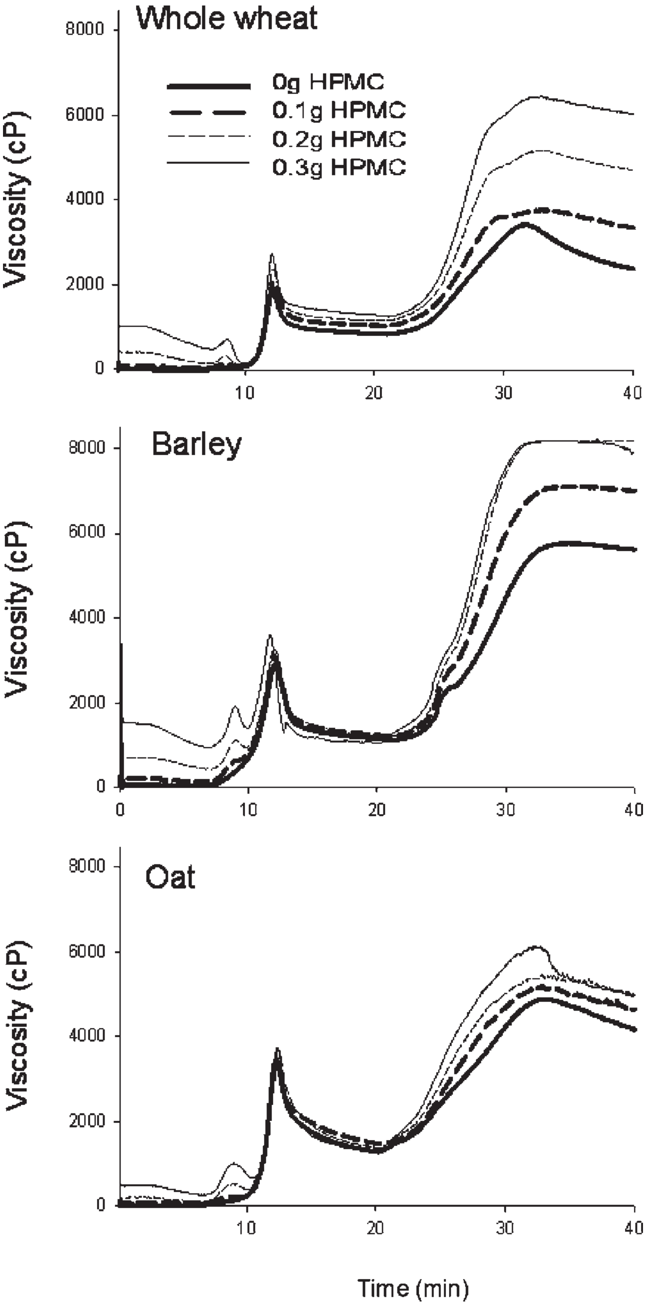

Figure 1. Pasting curves of whole wheat, barley, and oat flours with 0, 0.1, 0.2, and 0.3% HPMC using the Rapid Visco Analyzer.

that gum additives should be capable of providing doughs with sufficient viscosity to trap fermentation gases even while releasing enough water for starch gelatinization to occur in order to develop rice breads with rigid and porous cell structure and good loaf volume.

Optimum Formula and Breadmaking of All-Barley and All-Oat Leavened Breads. The development of the formulations of all-barley, all-oat, and whole wheat breads enriched with HPMC was accomplished by systematic changes in the amounts of HPMC and water. The viscosity of HPMC (H-HPMC and L-HPMC) and the type of oil (vegetable oil and shortening) were also systematically varied. The most important variables for proper leavening of HPMC breads were found to be the viscosity of the HPMC and the water to flour ratio. Barley and whole wheat flours improved loaf volume and texture with H-HPMC, whereas oat flour breads were improved by L-HPMC. Generally the required water levels for acceptable loaf structure and uniform dough consistency increased with increasing HPMC content, but they were also dependent on the type of flour used. Additional increments of water increased the elasticity of the dough and the proof height of the bread, but an optimum is reached and more water resulted in overexpansion and collapse during baking and large holes in the bread. The large holes may have been due to the lack of resistance to expanding gas bubbles that resulted in the merging of larger bubbles. Like most food gums, HPMC is capable of binding large amounts of water. Not surprisingly, we found that by systematically increasing the water/flour ratio the optimum amounts of water necessary when 5% HPMC was added to whole wheat, barley, and oat breads increased from 75 to 100 g, from 80 to 120 g, and from 80 to 110 g, respectively. The barley and oat doughs containing 5% HPMC were quite thick and pasty and could not be sheeted and molded like wheat dough; therefore, they were transferred to a baking pan using a spatula after the first proofing. This stickiness was most likely due to the hydrated β-glucan content of oat and barley.

Table 2. β-Glucan Content in Whole Wheat, Barley, and Oat Flours and Breads

type			β-glucan[a] (%)
whole wheat	flour		0.17 ± 0.08 b
	bread	without HPMC	0.56 ± 0.10 a
		with HPMC	0.24 ± 0.01 b
barley, pearled	flour		3.58 ± 0.11 a
	bread	without HPMC	3.43 ± 0.11 a
		with HPMC	4.09 ± 0.73 a
oat, debranned	flour		1.28 ± 0.18 a
	bread	without HPMC	0.68 ± 0.02 b
		with HPMC	0.99 ± 0.03 ab

[a] Different letters within the column indicate significantly different values by Duncan's multiple-range test ($p < 0.05$).

Dietary Fiber and β-Glucan Content in Breads. The insoluble dietary fiber (IDF), soluble dietary fiber (SDF), and total dietary fiber (TDF) contents of each of the flours are shown in **Table 1**. The commercial pearled barley flour had approximately twice the SDF as debranned oat and whole wheat flours. About 75% of the SDF of barley was β-glucan (**Table 2**), whereas approximately 50% of the SDF of oat was β-glucan. When the non-HPMC oat and barley breads were evaluated, the β-glucan content was found to be lower than that of the flour, but the β-glucan content increased in whole wheat breads. It is possible that the small amount of cellulose that is present in all 1,4-linked β-glucan was hydrolyzed during the breadmaking process, which resulted in a small increase in β-glucan content in the bread. There were no differences in β-glucan content of oat and barley breads containing HPMC compared to breads without HPMC (**Table 2**). The β-glucan was determined using an enzymatic method, and although HPMC is a 1,4-β-glucan, it is resistant to mammalian enzymes but perhaps not to microbial enzymes.

Physical Characteristics of Breads. The incorporation of 5% HPMC increased the loaf volume of all breads, including whole wheat bread (**Figure 2**). Because oat and barley contain no gluten, the loaf volume of these breads was minimal. The addition of HPMC increased the loaf volume by about 80 and 40% in the case of oat and barley breads, respectively. Oat bread that contained HPMC showed the greatest increase in loaf volume from 233 to 418 cm^3. Barley bread that contained HPMC showed an increase in loaf volume from 307 to 428 cm^3. Wheat bread had the highest loaf volumes with or without HPMC, 625 and 618 cm^3, respectively. These increases in loaf volume are in agreement with the results of other studies in which cellulose derivatives were

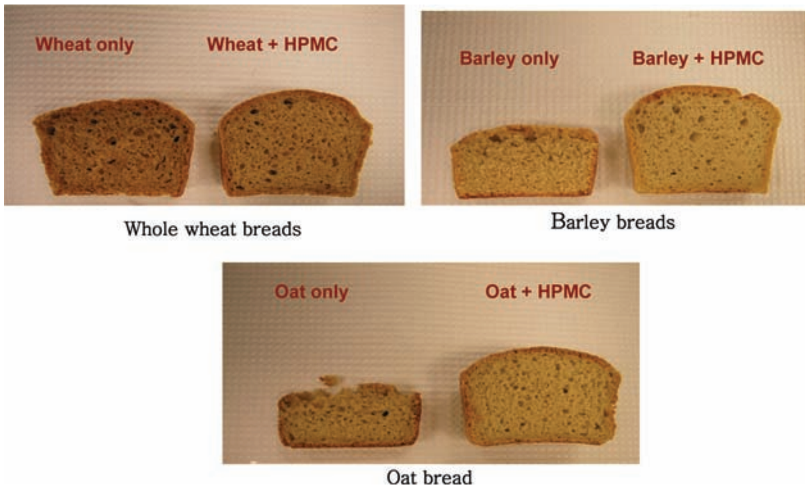

Figure 2. Photographs of whole wheat, barley, and oat breads with 5% HPMC or without HPMC showing relative expansion, cell structure, and color.

Table 3. Color of Crust and Crumb of Whole Wheat, Barley, and Oat Breads[a]

	crust			crumb		
bread type	*L*	*a*	*b*	*L*	*a*	*b*
WW	47.7 ± 0.4 a	13.1 ± 0.5 a	26.3 ± 0.2 a	54.1 ± 1.5 a	5.2 ± 0.3 a	20.1 ± 0.3 a
WWH	46.2 ± 2.2 a	13.4 ± 0.3 a	25.4 ± 0.9 a	58.3 ± 1.3 b	4.9 ± 0.3 a	19.9 ± 0.7 a
B	47.9 ± 3.9 a	16.0 ± 1.5 a	32.6 ± 2.7 a	62.7 ± 0.8 a	2.2 ± 0.3 a	21.8 ± 1.1 a
BH	42.7 ± 1.2 b	15.6 ± 0.2 a	26.9 ± 0.8 b	64.3 ± 0.4 b	1.2 ± 0.1 b	19.8 ± 0.5 b
O	55.9 ± 0.8 a	10.0 ± 0.3 a	33.6 ± 0.8 a	54.0 ± 3.6 a	1.1 ± 0.5 a	19.2 ± 0.4 a
OH	43.0 ± 0.4 b	14.7 ± 0.3 b	26.1 ± 0.5 b	66.9 ± 0.4 b	0.8 ± 0.2 a	21.4 ± 0.2 b

[a] *L* = 100*L* (white) to 0*L* (black); *a* = +*a* (red) to −*a* (green); *b* = +*b* (yellow) to −*b* (blue); WW, whole wheat bread; WWH, whole wheat bread with 5% HPMC; B, barley bread; BH, barley bread with 5% HPMC; O, oat bread; OH, oat bread with 5% HPMC. Different letters within a column are significantly different by *t* test($p < 0.05$).

found to improve wheat bread volume (*16*−*18*). HPMC has great water-holding ability but forms a gel when heated with a simultaneous release of water. HPMC gelation is believed to form stronger hydrophobic bonds with other HPMC chains and may result in the production of a strong gel network at higher temperature (*12*), but that is temporal because the gel dissolves upon cooling (*26*). This gel network strengthens the walls of the expanding gas cells in the dough during baking, which reduces gas loss and improves bread volume (*18*). Although the volume of all barley and oat breads was increased by HPMC addition, these nonwheat breads still had lower loaf volumes than whole wheat bread. However, incorporation of wheat flour with other cereal flours also reduces loaf volume. Trogh et al. (*9*) reported that the replacement of 30% of the wheat flour by barley flour decreased the loaf volume by 32%. This was likely due to the dilution of gluten, but may also be the result of higher levels of dietary fiber and barley proteins that disrupted the formation of a viscoelastic gluten network. In the case of rice breads, Kim et al. (*27*) reported no decrease when 71% of the wheat flour was replaced with rice flour. The specific volumes of 100% wheat bread and wheat−rice bread (24:71) were 4.96 and 4.95 mL/g, respectively. In contrast, 100% rice breads amended with 3 or 5% HPMC showed reduced specific volumes of 3.85 and 3.83 mL/g, respectively. In this study cell structures (**Figure 2**) of both barley and oat flours with HPMC breads were acceptable with good crumb structure, whereas all-barley and all-oat breads that did not contain HPMC were dense with poor cell structure.

Table 3 shows that the color of the crust and crumb of breads were affected by HPMC addition. HPMC resulted in breads with darker and less yellow crust when compared to breads made without HPMC. Oat bread showed the greatest change in *L* value of the crust, followed by barley bread. However, HPMC resulted in whiter crumbs compared to non-HPMC breads. All breads showed a significant HPMC-induced change in the *L* value of the crumb ($p < 0.05$). The darker crust color may be advantageous in products because darker breads are usually associated with whole grains and wholesomeness.

Hardness of Breads during Storage. The textural profiles of the freshly baked and 1-, 2-, and 3-day-old breads were evaluated instrumentally at 20 °C. The hardness increased during storage for all types of bread (**Figure 3**), including HPMC-added breads. These increases were greater for all barley and oat breads than whole wheat breads. The oat and barley breads that did not contain HPMC were 3 times harder than the reference whole wheat bread. In addition, breads that did not contain HPMC became much harder during the first and second days after baking when compared to breads that contained HPMC. The hardness of breads containing HPMC also increased over storage time, but at a slower rate than breads without HPMC. These results suggest that HPMC could have a positive effect on shelf life by decreasing the initial hardness and slowing the rate of hardening. The incorporation of 5% HPMC significantly improved the hardness of all breads, especially barley and oat breads ($p < 0.05$). These textural changes are in agreement with the results of a study conducted by Bárcenas and Rosell (*18*), who reported that the presence of HPMC decreased the hardening rate of bread crumbs and the retrogradation of amylopectin. Davidou et al. (*28*) has also suggested that the softer crumbs may have been formed by interference with the interactions among starch polymers and between the proteins and starch by the HPMC chains. The peak observed at 9 min of pasting is also indicative of starch−HPMC interactions because this peak is not seen when HPMC is not present. If soluble amylose is interacting with HPMC, this peak may be useful as an indicator of the amount of soluble amylose released.

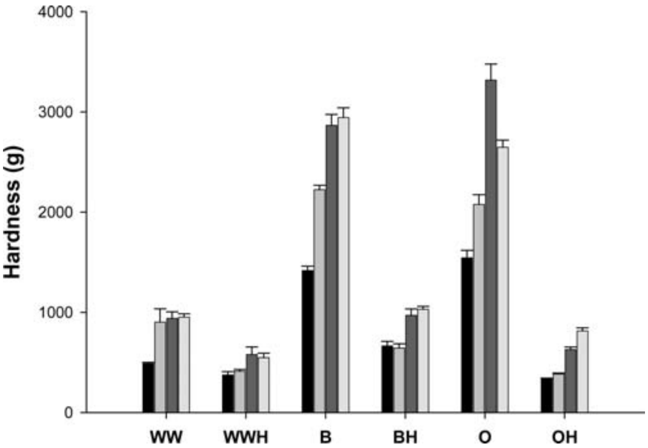

Figure 3. Hardness of whole wheat, barley, and oat breads after baking or after storage from 1 to 3 days at 20 °C: black bars, fresh bread; medium gray bars, bread stored for 1 day; dark gray bars, bread stored for 2 days; light gray bars, bread stored for 3 days. WW, whole wheat bread; WWH, whole wheat bread with 5% HPMC; B, barley bread; BH, barley bread with 5% HPMC; O, oat bread; OH, oat bread with 5% HPMC.

Table 4. Sensory Evaluation Scores for Various Types of Breads[a]

type	appearance	flavor	texture	aftertaste	acceptability
WW	4.61 ± 1.1 a	4.52 ± 1.4 a	4.42 ± 1.5 a	3.91 ± 1.4 a	4.27 ± 1.4 a
WWH	4.64 ± 1.4 a	4.30 ± 1.6 a	4.70 ± 1.4 a	4.03 ± 1.3 a	4.15 ± 1.2 a
BH	4.97 ± 1.3 a	5.06 ± 1.1 a	4.97 ± 1.5 a	5.00 ± 1.4 b	5.21 ± 1.2 b
OH	5.15 ± 1.33 a	4.76 ± 1.5 a	4.76 ± 1.8 a	4.33 ± 1.3 ab	4.73 ± 1.7 ab

[a] Means within the same column with the same letter are not significantly different at $p < 0.05$. 1 = dislike very much; 2 = dislike moderately; 3 = dislike slightly; 4 = neither like nor dislike; 5 = like slightly; 6 = like moderately; 7 = like very much. WW, whole wheat bread (control); WWH, whole wheat bread with 5% HPMC; BH, barley bread with 5% HPMC; OH, oat bread with 5% HPMC.

Sensory Characteristics of Breads. The sensory characteristics of breads were scored for appearance, flavor, texture, aftertaste, and acceptability (**Table 4**). The oat and barley breads with HPMC had darker crusts and lighter crumbs but had slightly higher appearance scores than both wheat breads. The lighter crumb color may be due to the higher water activity that might also decrease the reactions necessary for typical bread flavors. However, this did not occur possibly because there was sufficient flavor in the oat and barley flours to compensate for the decrease in flavor reactions (browning reaction). Panelists scored barley and oat breads containing HPMC higher in flavor than wheat breads with or without HPMC; however, these differences were not significant. Although the oat and barley breads containing HPMC were denser, the panelists scored their texture the same as whole wheat breads with or without HPMC. HPMC is known to impart products with an undesirable filmy mouthfeel. However, in this study, the breads containing HPMC were not down-rated for aftertaste, which indicates that any filmy residue that was present was not significant and may support the idea of HPMC–starch interactions. In fact, the barley bread containing HPMC was rated significantly higher than the wheat breads for aftertaste, but similar to the oat bread containing HPMC. The panelists also expressed a significant preference (acceptability) for all grain oat and barley breads. Additionally, the overall acceptability of barley bread that contained HPMC was significantly higher than that of the whole wheat breads and similar to the oat bread containing HPMC. The panelists perceived breads with all-grain flours to have a "grainy" or "branny" flavor character, indicating that the sensory characteristics of HPMC-fortified all-grain breads were generally different from those of wheat bread. The sensory results of all-grain breads containing 5% HPMC supported this additive level for acceptable mouthfeel. Overall, the breads in this study were found to be acceptable for flavor and appearance, but higher preference for oat and barley breads might occur if knowledge of the health benefits were also included (*29*).

In summary, all-barley and all-oat breads formulated with 5% soluble fiber (HPMC), substitution of HPMC for gluten, resulted in all-grain breads with lower but reasonable loaf volumes, a darker crust, lighter crumb color, and acceptable textures. The overall acceptability of the oat bread was similar to that of whole wheat and barley, but the barley bread was rated significantly higher than the whole wheat breads with or without HPMC. We believe that a market exists for all-grain breads that have superior nutritional properties, good flavor quality, and acceptable appearance.

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