Whole Grain Saltine Crackers: Formulation, Processing, and Quality Improvements

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Gary Hou
Wheat Marketing Center

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J. Li
Jiangnan University, Wuxi, Jiangsu, PRC, and Wheat Marketing Center, Inc., Portland, OR, U.S.A.

G. G. Hou[1]
Wheat Marketing Center, Inc.
Portland, OR, U.S.A.

Z. Chen
Jiangnan University
Wuxi, Jiangsu, PRC

In recent years, greater emphasis has been placed on the health benefits of whole grains. In 1999, AACC International (AACCI) adopted the following definition for whole grains (www.aaccnet.org/initiatives/definitions/Documents/WholeGrains/wgflyer.pdf): "Whole grains shall consist of the intact, ground, cracked or flaked caryopsis, whose principal anatomical components—the starchy endosperm, germ, and bran—are present in the same relative proportions as they exist in the intact caryopsis."

The strong appeal of whole grains is driven by the nutritional benefits they offer versus refined flours. Studies have shown that whole grains contain high concentrations of nutrients and phytochemicals and are rich in dietary fiber, resistant starches, oligosaccharides, vitamins, trace minerals, and antioxidants, including phytate, phytoestrogens, and phenolic compounds, with known health benefits (9). Compared with other cereal grains, barley contains relatively high levels of β-glucan (2), a soluble polysaccharide with health-promoting properties that include helping reduce the health risks associated with high cholesterol and high blood pressure (19,20).

Epidemiological studies have demonstrated that whole grain intake can reduce the risk of certain cancers, cardiovascular disease, type 2 diabetes, obesity, and stroke (10), as well as provide prebiotic benefits and lower the risk of gum disease, tooth loss, and asthma (5,16). The USDA *Dietary Guidelines for Americans, 2010* (18) recommends that at least 50% of all grains consumed should be whole grains. In May 2013, the AACCI Board of Directors approved the AACCI Whole Grains Working Group's characterization of whole grain products. The characterization asserts that a whole grain food product must contain 8 g or more of whole grain per 30 g of product (www.aaccnet.org/about/newsreleases/Pages/WholeGrainProductCharacterization.aspx).

Crackers, an important product line within the large-scale baking industry, can be divided into three broad categories: chemical, enzyme, and saltine (soda) (11). Saltine cracker production typically utilizes a sponge-and-dough (≈24 hr fermentation) preparation method. The prolonged sponge fermentation produces the unique flavor and crispy texture associated with saltine crackers (13). In contrast, chemical crackers typically require a leavening system that does not utilize sourdough starter and yeast. In addition to leavening agents, enzymes (proteinases) are incorporated into the formulation of enzyme crackers. Both chemical and enzyme crackers are relatively simple to handle and require less time to manufacture. However, they lack the unique flavor of saltine crackers imparted by the sourdough starter and yeast fermentation.

Although laboratory-scale methods for producing traditional saltine and chemical crackers have been developed (7, 12,14), there is no consensus method for producing whole grain crackers. In addition, the processing and quality characteristics of these products can be negatively affected by use of whole grain flour. The limited gluten strength and high water absorption of whole grain flour inhibit the formation of a gluten network, which results in reduced oven spring during baking (8).

There has been little research performed on the quality characteristics of whole grain saltine crackers. This article reports on the effects of whole grain flour on the quality attributes of saltine crackers and the use of functional ingredients to improve the end-product quality of whole grain crackers.

Whole Wheat Saltine Cracker Preparation

Whole wheat cracker flour samples were composited from blends of soft white whole wheat (SWWW; Ultragrain, ConAgra Flour Mills Inc.), soft red winter wheat (SRW; Golden Shield, enriched and unbleached, General Mills, Inc.), and hard

Table I. Composition (%) of whole wheat cracker flour blends[a]

	Sponge (65%)			Dough (35%)	
% SWWW	SWWW	SRW	HRW	SWWW	SRW
0	50	15		35	
25	25	25	15		35
50	50	15		35	
75	50	15	25	10	
100	65		35		

[a] SWWW: soft white whole wheat; SRW: soft red winter wheat; and HRW: hard red winter wheat.

Table II. Analysis of components (%) of whole wheat cracker flour blends

% SWWW[a]	Moisture	Protein (14% mb)	Ash (14% mb)	Wet Gluten (14% mb)	Gluten Index	Starch Damage (14% mb)
0	13.2	8.43	0.442	24.5	60.9	3.1
25	12.5	8.92	0.734	24.4	44.1	3.1
50	11.7	9.35	1.015	28.6	26.2	3.4
75	11.0	9.92	1.241	26.0	8.4	3.4
100	10.3	9.77	1.522	22.2	6.6	3.3

[a] SWWW: soft white whole wheat.

[1] Corresponding author. E-mail: ghou@wmcinc.org; Tel: +1.503.295.0823; Fax: +1.503.295.2735.

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red winter wheat (HRW; Harvest King winter wheat, enriched and unbleached, General Mills, Inc.) flours. Preliminary trials determined that the optimum blend level of HRW flour was 15% based on the breaking strength of the end-products (at HRW ≥ 20%, end-product texture was harder and less crispy). HRW flour was added at the same level in each group, except for the 100% SWWW group (Table I). Whole wheat cracker flour blends were analyzed for protein, moisture, ash, starch damage, wet gluten, and gluten index according to AACCI Approved Methods (Table II) (1).

The whole wheat saltine cracker formulations used are detailed in Table III. Baking soda, mineral yeast food, vegetable shortening, and instant dry yeast were purchased from a local supermarket. All ingredients were scaled on a 500 g flour weight basis. The original sourdough starter was supplied by Oregon State University and maintained by adding old starter (50 g), HRW flour (100 g), and distilled water (50 g) daily during the course of the study. Water was added at the minimum level of cracker flour absorption, rather than the maximum level, to develop a dough wet enough to sheet, yet dry enough to avoid the formation of an elastic dough. More water was required in the preparation of sponge dough that contained higher levels of SWWW flour to achieve proper dough handling and processing characteristics. Any excess water must be removed through baking, which results in a longer baking time (15). Total titratable acidity (TTA) tests were used as indicators of the fermentation process. The amount of baking soda to be added was determined based on the TTA of the sponge after 18 hr of fermentation and the pH of the end-products (≈7.0–8.0). The amount of baking soda required based on sponge TTA is listed in Table IV.

Table III. Formula (flour weight basis) used for whole grain saltine crackers

Ingredient	Sponge (%)	Dough (%)
Cracker flour blends[a]	65	35
Starter	4.0	
Instant yeast[b]	0.3	
Mineral yeast food[b]	0.03	
Vegetable shortening		14.0
Salt[b]		0.8
Baking soda		0.8–1.5
Water[c]	27–34	1.0

[a] Cracker flour blend compositions are the same as those listed in Table I.
[b] Instant yeast, mineral yeast food, and salt were predissolved in water.
[c] Water was added at 27, 29, 30, 32, and 34% to 0, 25, 50, 75, and 100% whole wheat saltine cracker flour blends, respectively.

A laboratory-scale, whole grain saltine cracker-making process is illustrated in a schematic diagram (Fig. 1). The sponge ingredients were combined in a mixer (Hobart A-200 mixer and McDuffy mixing bowl, National Manufacturing, Co.). The sponge was fermented at 28°C and 85% RH in a fermentation cabinet for 18 hr. After 18 hr of fermentation, the remaining flour, water, shortening, and dry ingredients (Table III) were combined with the fermented sponge. The dough was mixed and placed in the fermentation cabinet to proof for another 2 hr. After the dough was proofed, 500 g of cracker dough was placed in a plastic container to shape into a rectangular dough block (15 × 13.5 × 2.5 cm). The shaped dough block was laminated into a thin sheet (SSO-615 Seewer reversible lamination machine, Rondo Inc.). Dough lamination settings are provided in Table V. The final height, width, and length of the dough sheet were 1.5 mm, 22.5 cm, and 40.0 cm, respectively. The dough sheet was transferred to a specially designed cutter-docker (14), and the dough sheet was perforated using a rolling pin. The dough sheet was sprinkled with salt and rested under a covered couche for 1 min. The cracker dough sheet was then transferred to a specially designed wire mesh belt (CB5 Baking Band, Ashworth) on a rectangular-shaped rack that was preheated in a deck oven (PICCOLOI-3, Wachtel Company) for 30 min. The top-level baking temperature was 220°C, and the bottom-level baking temperature was 215°C. The baking time was ≈6–7 min. After the cracker dough was properly baked, the cracker sheet was removed from the oven, and vegetable oil was sprayed on the surface. After cooling, the cracker sheet was broken into individual pieces along the perforated lines and sealed in plastic bags at room temperature until analyzed.

Table IV. Total titratable acidity (TTA) of sponge fermented for 18 hr and amount of baking soda added in dough

TTA (mL)	Baking Soda (g)
7–8	3.0
9–11	4.0
12–13	5.0
14–16	6.0
17–18	7.0
18–19	7.5
20–21	8.0

End-product Evaluation

The stack height, stack weight, specific volume, and breaking strength of the whole wheat saltine crackers were determined. The data shown in Table VI indicate that cracker characteristics were affected by the composition of the whole wheat flour blend used. Stack weight, stack height, specific volume, and breaking strength of crackers decreased as the

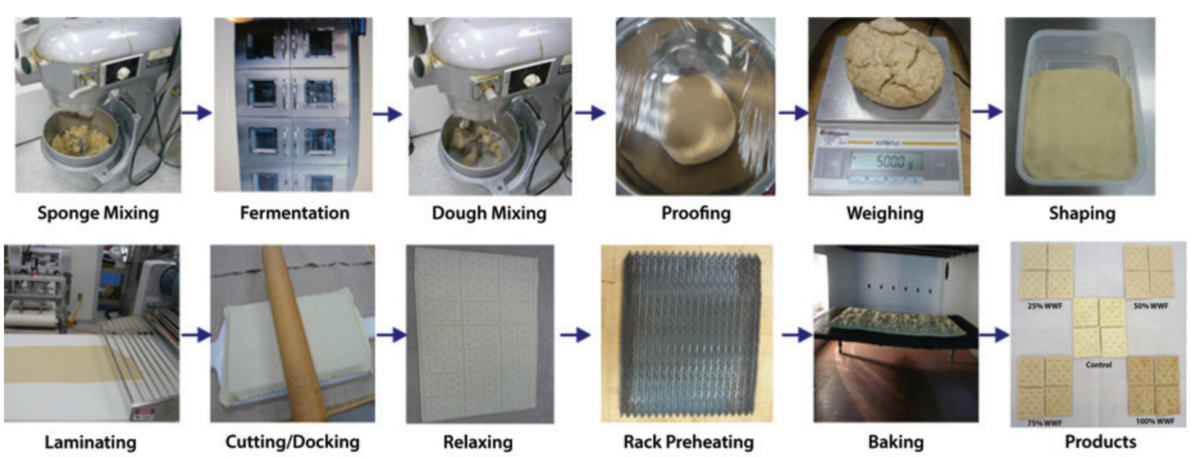

Fig. 1. Schematic diagram of laboratory-scale, whole grain saltine cracker production. WWF: whole wheat flour.

addition level of SWWW flour increased. Higher amounts of whole wheat flour tended to yield an uneven internal texture with less puffiness. Crackers with higher levels of SWWW flour were also more fragile (less breaking force). As expected, the color of the end-products became browner and darker with increasing amounts of whole wheat flour in the blend (Fig. 2).

End-product Quality Improvement

A cracker is a low-moisture product. The high water-absorbing capacity of whole wheat flour requires the addition of extra water during the preparation of whole wheat cracker dough. Any excess water added to the formulation must then be removed during baking, which increases the baking time and energy consumption of cracker production. Another difficulty encountered in the production of whole wheat crackers is the limited gluten strength caused by the shearing and dilution of wheat bran. The resulting weak gluten network reduces the gas retention capacity of the wheat dough and the oven spring of the baked product (8).

Several functional ingredients can be used to improve the quality of whole grain crackers. For example, endoxylanases can be used to decrease the water-holding capacity of wheat bran (water-unextractable arabinoxylans) and redistribute water in the dough system (4). They can also be used to increase the extensibility of dough and softness of bread and other leavened products and to improve dough handling and machinability (15). Gum arabic is a natural gum exudate with a highly branched, compact arabinogalactan structure that produces a low-viscosity solution and a central protein fraction that provides good emulsification properties. It is a multifunctional ingredient with properties that enable its use as a texturizing agent, film former, emulsifier, and stabilizer (17). Gum arabic offers many benefits for bakery products in terms of processing, texture, and shelf life due to its moisture regulation and film-forming properties. Vital wheat gluten traditionally has been used to improve dough strength and film formation, mixing and fermentation tolerances, gas retention and product volume, structure in whole grain products, and flavor, as well as to reduce breakage in snack products (6). Using the low-field nuclear magnetic resonance technique, we found that the addition of endoxylanases, gum arabic, or vital wheat gluten increases water mobility from the arabinoxylan matrix to gluten, which aids in the formation of the gluten network and improves the oven spring of whole wheat saltine crackers (Li et al., unpublished data).

In this study, different addition levels of endoxylanases (0.01, 0.02, 0.03, and 0.04%), gum arabic (0.5, 1, 2, and 3%), or vital wheat gluten (1.0, 2.0, 3.0, and 4.0%) (flour weight basis) were blended into SWWW flour to prepare 100% whole wheat saltine crackers according to the methods described previously. The control flour was 100% SWWW flour with no added ingredients. The quality attributes of 100% whole wheat saltine crackers with these additions were determined.

The stack height and specific volume of end-products increased with increasing levels of endoxylanases, while stack weight and breaking strength decreased (Table VII). As increasing amounts of endoxylanases were added, cracker dough became much softer (decrease in resistance to extension) and more extensible (increase in extensibility), which improved cracker oven spring during baking. The stack height and specific volume of end-products also increased with increasing levels of gum arabic, while breaking

Table V. Saltine cracker dough lamination procedures

	Roller Gap (mm)			
Step	1st Lamination	2nd Lamination	3rd Lamination	4th Lamination
1	12	12	10	10
2	9	10	8	8
3	6	8	6	6
4	Double folding, into middle, and turn 90°	–	Turn 90°	Turn 90°
5	–	6	4	4
6	–	4	3	3
7	–	Triple folding	Triple folding	–
8	–	–	–	2
9	–	–	–	1.5

Table VI. Evaluation of quality of whole wheat saltine crackers[a]

% SWWW[b]	Stack Weight[c] (g, db)	Stack Height[c] (mm)	Specific Volume (mL/g)	Breaking Strength (g)
0	27.2 ± 0.2 a	34.8 ± 0.4 a	1.27 ± 0.06 a	1,236.3 ± 70.1 a
25	27.0 ± 0.2 a	32.7 ± 0.3 b	1.25 ± 0.02 a	1,052.7 ± 82.6 b
50	26.5 ± 0.3 b	29.8 ± 0.4 c	1.14 ± 0.04 b	829.8 ± 25.6 c
75	25.1 ± 0.3 c	28.9 ± 0.3 c	1.02 ± 0.03 c	732.0 ± 23.0 c
100	24.9 ± 0.4 d	26.8 ± 0.6 d	1.00 ± 0.02 c	700.6 ± 16.6 c

[a] Values are means ± SD (based on at least 10 replicate measurements). Values in the same column followed by the same letters are not significantly different ($P < 0.05$).
[b] SWWW: soft white whole wheat.
[c] Stack of seven crackers.

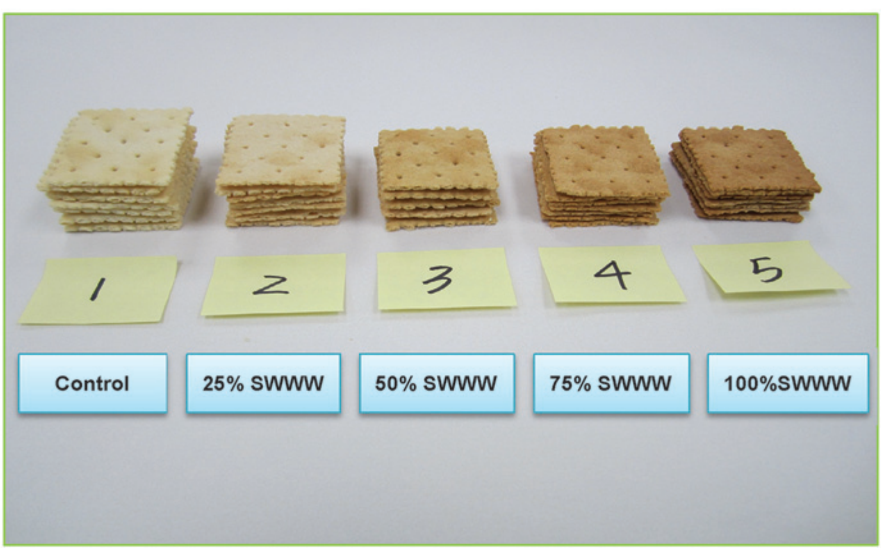

Fig. 2. Whole wheat saltine crackers made from blends of five levels of soft white whole wheat (SWWW) flour.

strength decreased. The stack weight of the end-products had no significant correlation with the level of gum arabic added (Table VII). Whole wheat cracker dough was softened by the addition of gum arabic, which was expected to improve the oven spring and crispy texture of the end-products.

As levels of vital wheat gluten increased, stack weight, stack height, specific volume, and breaking strength of end-products increased (Table VII). The original SWWW flour had limited gluten strength, resulting in breakage of the cracker dough sheet during lamination. Gluten strength and the gluten network were enhanced by added vital wheat gluten, resulting in the development of a gluten network in the whole wheat cracker dough that was strong enough to retain gas, improve oven spring, and entrap more bubbles. However, excessive addition of vital wheat gluten would greatly increase the toughness of the cracker dough and restrict the puffiness of end-products.

Whole Barley-Fortified Saltine Cracker Preparation and Quality Improvement

Whole barley flour (10.5% protein, 11.0% moisture, and 1.25% ash) was purchased from Giusto's Specialty Foods Company. The high fiber content (both soluble and insoluble fiber) of whole barley flour is associated with a high water-absorption capacity. Gum arabic, guar gum, and xanthan gum are hydrocolloids that are widely used in the baking industry to modify gluten and its hydration properties (3). Gum arabic (Pre-Hydrated Gum Arabic FT), pre-hydrated guar gum, and xanthan gum (Ticaxan Xanthan 200EC) were provided by TIC gums, Inc. Two addition levels (1.0 and 2.0%) of each gum (wt/wt, cracker flour weight basis) and four levels (0, 25, 50, and 75%) of whole barley flour were blended. Whole barley-fortified cracker flour blends are presented in Table VIII. The control flour was a whole barley-fortified blend without added gums. The formulas and procedures used to produce whole barley-fortified saltine crackers were developed according to the methods described for the preparation of whole wheat saltine crackers, except that different gum addition levels were used and slightly more water (1–2%) was added.

The stack weight, stack height, specific volume, and breaking strength of whole barley-fortified saltine crackers were measured according to the evaluation methods described previously (Table IX). Stack

Table VII. Evaluation of quality of 100% whole wheat saltine crackers prepared with different levels of added endoxylanases, gum arabic, and vital wheat gluten[a]

Ingredient	Addition Level (%)	Stack Weight[b] (g, db)	Stack Height[b] (mm)	Specific Volume (mL/g)	Breaking Strength (g)
Control	0	25.0 ± 0.1 a	26.2 ± 0.6 a	1.01 ± 0.08 a	708.4 ± 68.5 a
Endoxylanases	0.01	24.9 ± 0.1 a	26.7 ± 0.6 ab	1.05 ± 0.09 a	701.2 ± 58.5 a
	0.02	24.5 ± 0.1 b	27.4 ± 0.4 b	1.09 ± 0.10 a	654.5 ± 55.7 a
	0.03	23.9 ± 0.1 c	28.8 ± 0.3 c	1.15 ± 0.05 a	512.0 ± 45.9 b
	0.04	23.4 ± 0.1 d	29.9 ± 0.2 d	1.26 ± 0.05 b	502.2 ± 38.4 b
Gum arabic	0.5	25.9 ± 0.1 b	33.7 ± 0.3 b	1.10 ± 0.02 a	651.9 ± 30.8 a
	1.0	25.9 ± 0.1 b	38.5 ± 0.2 c	1.16 ± 0.03 b	583.9 ± 23.5 b
	2.0	26.6 ± 0.2 c	41.9 ± 0.4 d	1.21 ± 0.02 b	530.6 ± 19.8 c
	3.0	25.9 ± 0.1 b	42.2 ± 0.2 d	1.27 ± 0.03 c	527.4 ± 20.1 c
Vital wheat gluten	1.0	24.9 ± 0.1 a	27.9 ± 0.6 b	1.10 ± 0.09 ab	736.3 ± 29.8 ab
	2.0	25.1 ± 0.1 a	28.3 ± 0.2 b	1.19 ± 0.04 b	800.4 ± 27.6 b
	3.0	24.4 ± 0.1 b	30.0 ± 0.5 c	1.20 ± 0.07 b	858.4 ± 28.0 c
	4.0	25.5 ± 0.1 c	37.2 ± 0.6 d	1.40 ± 0.06 c	861.5 ± 48.1 c

[a] Values are means ± SD (based on at least 10 replicate measurements). Values for each ingredient (for the four levels) were compared to the control value. Values for each ingredient within the same column followed by the same letters are not significantly different ($P < 0.05$).
[b] Stack of seven crackers.

Table VIII. Composition (wt/wt) of whole barley-fortified cracker flour blends[a]

	Sponge (65%)			Dough (35%)	
% WB	WB	SRW	HRW	WB	SRW
0		50	15		35
25	25	25	15		35
50	50		15		35
75	50		15	25	10

[a] WB: whole barley flour; SRW: soft red winter wheat flour; and HRW: hard red winter wheat flour.

Table IX. Evaluation of quality of whole barley fortified saltine crackers containing different levels of added gum[a]

WB (%) + Gum[b]	Stack Weight (g, db)	Stack Height[c] (mm)	Specific Volume (mL/g)	Breaking Strength (g)
25 (Control)	25.2 ± 0.1 a	38.5 ± 0.5 h	1.20 ± 0.06 fgh	538.4 ± 52.4 abcd
25 + 1% Gum arabic	25.2 ± 0.1 a	42.5 ± 0.4 k	1.41 ± 0.03 ij	587.5 ± 56.1 abcde
25 + 2% Gum arabic	25.9 ± 0.1 b	43.9 ± 0.7 l	1.58 ± 0.04 k	553.0 ± 43.4 abcd
50 (Control)	25.9 ± 0.1 b	35.3 ± 0.4 e	1.19 ± 0.06 efgh	672.9 ± 38.2 ef
50 + 1% Gum arabic	26.6 ± 0.1 c	39.5 ± 0.5 hi	1.37 ± 0.01 i	594.1 ± 27.8 cd
50 + 2% Gum arabic	27.3 ± 0.1 d	41.5 ± 0.3 j	1.48 ± 0.06 jk	561.7 ± 41.3 abcd
75 (Control)	26.6 ± 0.1 c	32.1 ± 0.6 c	1.08 ± 0.05 de	705.3 ± 34.4 fg
75 + 1% Gum arabic	27.3 ± 0.1 d	36.7 ± 0.5 f	1.11 ± 0.06 def	576.9 ± 26.1 bcd
75 + 2% Gum arabic	28.7 ± 0.1 f	39.6 ± 0.4 i	1.23 ± 0.07 fgh	518.7 ± 30.0 a
25 + 1% Guar gum	25.9 ± 0.1 b	41.5 ± 0.3 j	1.27 ± 0.03 h	516.4 ± 47.4 ab
25 + 2% Guar gum	26.6 ± 0.1 c	35.2 ± 0.2 e	1.25 ± 0.04 gh	605.0 ± 19.6 d
50 + 1% Guar gum	27.3 ± 0.1 d	40.5 ± 0.5 i	0.94 ± 0.07 bc	543.2 ± 38.6 abc
50 + 2% Guar gum	28.0 ± 0.2 e	36.5 ± 0.5 f	0.80 ± 0.06 a	759.4 ± 59.8 fghi
75 + 1% Guar gum	28.0 ± 0.1 e	36.8 ± 0.2 f	1.10 ± 0.03 e	585.8 ± 43.8 abcd
75 + 2% Guar gum	28.7 ± 0.1 f	33.5 ± 0.3 d	0.90 ± 0.02 b	1,043.1 ± 45.3 kl
25 + 1% Xanthan gum	27.3 ± 0.1 d	38.8 ± 0.3 h	1.16 ± 0.05 efg	715.1 ± 47.4 fg
25 + 2% Xanthan gum	28.0 ± 0.1 e	37.5 ± 0.2 g	1.02 ± 0.03 cd	754.3 ± 35.5 gh
50 + 1% Xanthan gum	28.7 ± 0.2 f	33.3 ± 0.3 d	1.13 ± 0.02 ef	786.5 ± 22.7 hi
50 + 2% Xanthan gum	29.4 ± 0.1 g	29.5 ± 0.5 ab	0.94 ± 0.05 bc	848.1 ± 43.1 ij
75 + 1% Xanthan gum	29.4 ± 0.2 g	29.5 ± 0.4 b	0.98 ± 0.02 c	896.7 ± 44.2 j
75 + 2% Xanthan gum	30.1 ± 0.2 h	28.5 ± 0.5 a	0.82 ± 0.03 a	1,102.6 ± 39.1 l

[a] Values are means ± SD (based on at least 10 replicate measurements). Values in the same column followed by the same letters are not significantly different ($P < 0.05$). Values within each column were compared across all samples.
[b] Control: whole barley-fortified cracker flour blends without added gum; WB: whole barley flour.
[c] Stack of seven crackers.

weight and breaking strength of end-products increased and stack height and specific volume generally decreased as increasing amounts of whole barley flour were added. With increasing levels of added gum arabic, stack weight, stack height, and specific volume of end-products increased, while breaking strength generally decreased. Guar and xanthan gums had a similar effect on the quality of whole barley-fortified saltine crackers. Stack height and specific volume of barley-fortified saltine cracker decreased and breaking strength increased with increasing levels of added guar and xanthan gums. However, xanthan gum exhibited greater effects on the stack weight and breaking strength of whole barley-fortified saltine crackers than did gum arabic or guar gum, which suggests that xanthan gum was more effective in modifying the internal structure of the end-products.

Conclusions

Although the whole grain saltine crackers tested in this study possessed a unique flavor, crispy texture, and significant nutritional and health benefits, some difficulties were experienced during production due to the high water-absorption capacity and limited gluten strength of the whole grain flour used. Both the processing characteristics and end-product quality attributes, especially oven spring, were negatively influenced by the use of whole grain flour. However, the addition of functional ingredients can be used to improve the quality characteristics of whole wheat saltine crackers.

Results showed that the stack height and specific volume of whole wheat saltine crackers were increased by the use of endoxylanases, gum arabic, and vital wheat gluten. Because water tends to migrate from high water-absorbing components (such as arabinoxylans or β-glucan) to gluten in the presence of endoxylanases, gum arabic, and vital wheat gluten, greater gluten network formation is achieved in whole grain dough when these ingredients are added, and the oven spring of whole grain saltine crackers is improved. For the whole barley-fortified saltine crackers, three types of gums (gum arabic, guar gum, and xanthan gum) were compared for their impact on end-product quality. Results showed that gum arabic was more effective than guar or xanthan gum for improving the stack height and specific volume of whole barley-fortified saltine crackers.

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Juan Li is a Ph.D. candidate at the National Engineering Laboratory for Cereal Fermentation Technology, Jiangnan University, Wuxi, China. Her major is in food science, with research in the area of cereal chemistry and engineering. Her Ph.D. research program focuses on the development of whole grain products and quality improvement. In 2012, Juan completed a research project on the development of whole grain saltine crackers as a visiting scholar at the Wheat Marketing Center, Portland, OR. Juan is a member of AACC International and can be reached at lijuanjuan2010@gmail.com.

Gary G. Hou is the technical director and wheat foods specialist at the Wheat Marketing Center, Portland, OR. He has been very active in conducting numerous research projects on wheat-based foods and ingredient functionality. One of Gary's current research areas is the development of whole grain products, including Asian noodles, breads, crackers, pastas, and steamed breads. He also conducts a number of technical training courses on Asian noodles, artisan breads, biscuits and crackers, frozen dough technology, flat breads and flour tortillas, whole grain products, etc. Gary is a professional member of AACC International and the Institute of Food Technologists. He can be reached at ghou@wmcinc.org.

Zhengxing Chen is a professor, Ph.D. student supervisor, and executive deputy director of the National Engineering Laboratory for Cereal Fermentation Technology, Jiangnan University, Wuxi, China. In recent years, Zhengxing and his group have engaged in research on deep processing of grains, development of cereal products, and comprehensive utilization of grains, cereal chemistry, and functional ingredients. Zhengxing can be reached at zxchen2007@126.com.