Effects of Oat Grain Hydrothermal Treatments on Wheat-Oat Flour Dough Properties and Breadbaking Quality

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ABSTRACT

Hydrothermal treatments, which are routine in oat processing, have profound effects on oat flour dough rheological properties. The influence of roasting and steam treatments of oat grain on dough mixing and breadbaking properties was investigated when hydrothermally treated oat flour was blended with wheat flour. Roasting of oat grain (105°C, 2 hr) resulted in oat flours that were highly detrimental to wheat flour dough mixing properties and breadbaking quality. Steaming (105°C, 20 min) or a combination of roasting and steaming of oat grain significantly improved the breadbaking potential of the oat flours. The addition of oat flours increased water absorption and mixing requirements of the wheat flour dough and also decreased bread loaf volume. However, at the 10% substitution level, steamed oat flours exhibited only a gluten dilution effect on bread loaf volume when wheat starch was used as a reference. Oat flour in the breadbaking system decreased the retrogradation rate of bread crumb starch. The results indicate that adequate hydrothermal treatments of oat grain are necessary for oat flour breadbaking applications. Steamed oat flours used at a 10% level retarded bread staling without adversely affecting the loaf volume.

The (1→3),(1→4)-β-D-glucans (β-glucans) found in whole oat flour or oat bran can have an important influence on human nutrition and health (Anderson et al 1984, Newman et al 1989). Soluble fiber (β-glucan) from foods such as oat bran, rolled oats, or whole oat flours, as part of a diet low in saturated fat and cholesterol, may reduce the risk of heart disease (Food and Drug Administration 1997). The proposed mechanism for the hypocholesterolemic effect of water-soluble oat fiber appears to be related to the viscous properties of the high molecular weight β-glucans. Increased gut viscosity caused by oat β-glucan may either impede the uptake of dietary cholesterol or inhibit bile salt reabsorption (Shinnick and Marlett 1993).

Oats have been used in baked products as rolled oats or oat flakes for topping or dusting to provide a whole-grain appearance, special flavor, and healthy images for the baked products (McKechnie 1983). Oat bran, oat protein concentrate, oat starch, and oat flours (without oat bran) have been evaluated for breadbaking properties (Hoseney et al 1971, D'Appolonia and Youngs 1978, Oomah 1983, Krishnan et al 1987). Oat products have generally performed poorly in breadbaking systems (D'Appolonia and Youngs 1978, Sosulski and Wu 1988). Few reports have been published on the application of oat groat flour in breadbaking.

An important step in oat processing is the hydrothermal treatment, which involves roasting (kilning) and steaming of oat grain (Ganssmann and Vorwerck 1995). The main purposes of these treatments are to inactivate lipid-degrading enzymes and to develop desirable flavors for the finished products. Hydrothermal treatments also affect the viscous properties of oat flour slurries and the oat β-glucan (Zhang et al 1997). The objective of this study was to determine how these treatments of oat grain affected the breadbaking properties of whole oat groat flours blended with wheat flours.

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MATERIALS AND METHODS

Materials

Oat (*Avena sativa* L.) cultivars (Marion and Robert) were grown at Fargo, ND, in the 1995 crop year and were obtained from Michael S. McMullen, Department of Plant Sciences, North Dakota State University, Fargo. Heat treatments were applied to grain before dehulling and milling. Grain (200-g samples) was steamed in a vegetable steamer (260 × 170 mm), fitted with a lid, by placing the grain in a metal basket suspended ≈10 cm above boiling water for 20 min. Roasting consisted of placing 200-g samples of oat grain in a glass dish (190 × 100 mm) in a convection oven at 105°C for 120 min. The heat-treated grain was exposed to atmosphere at room temperature for 24 hr to allow moisture equilibration. The samples were then dehulled with a laboratory oat huller (Codema, Eden Prairie, MN), and were hand-sorted to obtain hull-free groats. Oat groats were milled in a Resch ZM-1 centrifugal mill (Brinkmann Instruments, Westbury, NY), fitted with a 0.5-mm collar screen, unless otherwise specified. Screens with openings of 0.2 and 1.0 mm were also used to generate fine and coarse particle size oat flours for the study of particle size effects.

Commercial breadbaking flour, Dakota Pride (12.7% protein content at 14.0% mb), from the North Dakota Mill and Elevator (Grand Forks, ND) was used as a base flour to evaluate the effect of oat groat flour breadbaking properties. Wheat starch (Midsol 50) from Midwest Grain Products Inc. (Atchison, KS) was used to compare the gluten dilution effect of oat groat flours.

Farinograph Measurements

Dough water absorption and mixing characteristics were evaluated using the farinograph (C.W. Brabender Instruments Inc., South Hakensack, NJ) following Approved Method 54-21 (AACC 1995). The 50-g mixing bowl was used, and the experiment was conducted in duplicate.

Breadbaking Test

The breadbaking test was based on Approved Method 10-09 (straight-dough, 3-hr fermentation) (AACC 1995). Wheat flour was replaced with 0, 10, or 20% of the various oat groat flours. Pup loaves (100-g) were baked using the formulation (baker's percentage): wheat flour, 100%; oat flour, 0, 10, or 20% wheat flour replacement; sugar, 5%; salt, 1%; instant dry yeast, 0.66%; shortening, 3%; yeast food, 0.5%; ascorbic acid, 50 ppm; calcium propionate, 0.2%; and optimum amount of water based on dough mixing characteristics. Bread loaf volume, loaf weight, and moisture content were determined 1 hr after baking. Bread was also evaluated on external appearance, crust color, grain texture, and crumb color by an experienced baker. Scores range from 0 to 10, with 10 being the best. Experiments were conducted in triplicate.

Differential Scanning Calorimetry

The effect of heat-treated oat flours used in bread formulation on the starch retrogradation of bread crumb was studied by using differential scanning calorimetry (DSC). Bread loaves containing oat flours were stored in plastic bags for 4 hr or 2, 4, 6, 8, or 10 days at 25°C. Crumb samples were taken from each treatment, frozen, and lyophilized. The dried bread crumb (with crust removed) was ground into fine particles using a mortar and pestle. Duplicate samples of 4.7 ± 0.1 mg of dry crumb in excess water (one part crumb to two parts water) were scanned (DSC-7, Perkin-Elmer Corp., Norwalk, CT) at 10°C/min, from 25 to 95°C. Indium was used to calibrate the calorimeter. The endothermic peak area was converted to enthalpy and was reported as ΔH in J/g of dry crumb. The reported enthalpy is essentially the energy required to melt the recrystallized starch. Enthalpy values were used as an index of the starch recrystallization that occurred during storage (Zeleznak and Hoseney 1987).

Statistical Analyses

Results were analyzed using a Statistical Analysis System computer program (SAS Institute, Cary, NC). Analysis of variance was performed by following the general linear model procedure of SAS. Duncan's new multiple range test ($\alpha = 0.05$) was used to differentiate treatment means determined to be significantly different.

RESULTS AND DISCUSSION

Genotype Effects

Two oat cultivars, Marion, 5.5% β-glucan, and Robert, 4.1% β-glucan, were used for all experiments. However, in no experiment did genotype significantly affect any of the results (not shown). Thus, data reported are pooled from both genotypes.

Dough Mixing Properties

The farinograph is the dough-testing instrument most commonly used in the breadbaking industry. A farinograph curve gives two important physical properties of flour: water absorption (the amount of water required for a dough to reach a defined consistency) and a general profile of the mixing behavior (mixing time, mixing stability) of the dough (D'Appolonia 1984).

Oat flours with different heat-treatment histories affected wheat flour dough mixing properties differently (Table I). Substituting oat flour for wheat flour increased dough water absorption as measured by the farinograph. Oat groat flour that was first roasted and then steamed resulted in the highest water absorption, longest mixing time, and greatest mixing stability. Oat flour from roasted grain greatly decreased dough-mixing time and had the least mixing stability. Oat flours with steaming or a combination of steaming and roasting treatments resulted in fairly good dough mixing properties. Only roasted oat flours had a significant detrimental effect on the mixing properties of the wheat flour dough system ($P < 0.05$). The roasting process was insufficient to inactivate all the endogenous oat enzymes (Zhang et al 1997). Thus, residual endogenous oat enzymes or other bioactive reducing agents may be involved in the dough-weakening effect observed.

The increase in water absorption in wheat-oat flour mixtures was probably due to the high β-glucan content from the oat flours. The β-glucan content may also increase the dough-mixing requirement (Table I). Lee et al (1995) also reported that adding 1% barley β-glucan into a wheat flour dough system significantly increased farinograph water absorption and dough mixing requirements.

Breadbaking Properties

The effects of various heat treatments of oat grain, gluten dilution by oat flours, and oat flour particle sizes on breadbaking properties were investigated. Four types of heat treatments were applied to the oat grain, and the resulting oat flour's breadbaking properties were compared (Table II). Breads containing roasted oat flours had significantly lower loaf specific volume and poorer bread quality scores than breads containing roasted-steamed, steamed, or steamed-roasted oat flours ($P < 0.05$). Flours from roasted oat grain caused a reduction in dough mixing stability and decreased loaf volume when mixed with wheat flour. The unidentified detrimental factor in roasted oat flour was inactivated by the steaming treatment of oat grain. As discussed above, this detrimental factor may be either enzyme activity or a bioactive reducing agent.

Gluten Dilution Effect

Because oat flours do not contain gluten proteins, adding oat flours into a breadbaking formulation dilutes the wheat gluten protein and thus decreases dough strength and bread volume. To distinguish between the real detrimental effect and the simple gluten dilution effect of oat flours in a breadbaking system, substitution of steamed oat flour was compared with substitution of wheat starch at 10 and 20% substitution levels. Loaf volumes from these different formulations were compared.

At a 10% wheat flour replacement level, breads containing oat flours had a loaf specific volume similar to that of the breads containing the same level of wheat starch (Table III). Breads containing oat flour also had significantly higher external appearance scores ($P < 0.05$). These results indicated that, at the 10% substitution level, steamed oat flours had no specific detrimental effects on bread dough structure and bread volume beyond simple gluten dilution. Because the wheat starch did not contain bran and had a much smaller particle size, breads containing wheat starch had better crumb color, grain, and texture. However, at a 20% substitution level, oat flours had detrimental effects on loaf specific volume and external appearance. Breads containing wheat starch had better loaf volume and bread characteristics than breads containing oat flour, especially in terms of specific volume, external appearance,

TABLE I
Effect of Heat Treatments of Oat Grain on Wheat Flour Dough Farinograph Parameters[a]

Sample[b]	Water Absorption (%)	Mixing Time (min)	Mixing Stability (min)
Wheat flour	64.45d	6.00c	8.85a
R/S oat flour	66.65a	7.88a	8.88a
S oat flour	66.38ab	7.00b	7.38b
S/R oat flour	66.10bc	7.00b	6.38c
R oat flour	65.95c	4.25d	3.13d

[a] Marion and Robert oat flours incorporated at 20% wheat flour substitution level. Values ($n = 4$) within a column followed by the same letter are not significantly different ($P > 0.05$).
[b] R/S = roasted first, then steamed; S = steamed only; S/R = steamed first, then roasted; R = roasted only.

TABLE II
Effect of Heat Treatment of Oat Grain on Oat Flour Breadbaking Properties[a]

Oat Flour Sample[b]	Specific Vol. (cm^3/g)	External Appearance[c]	Grain Texture[c]	Crumb Color[c]
Control	6.73	9.60	8.24	8.59
R/S	5.68a	7.48a	6.26a	6.70a
Steamed	5.78a	6.90a	6.46a	6.67a
S/R	5.67a	7.08a	6.30a	6.63a
Roasted	4.68b	4.70b	5.24b	5.89b

[a] Marion and Robert oat flours used at 10 and 20% substitution levels. Values ($n = 24$) within a column followed by the same letter are not significantly different ($P > 0.05$).
[b] R/S = roasted first, then steamed; S/R = steamed first, then roasted.
[c] Scores range from 0 to 10, with 10 being the best.

grain texture, and crumb color. Because of the high water retention capacity of oat β-glucan, breads containing oat flour had significantly higher moisture content than breads containing wheat starch at both substitution levels ($P < 0.05$).

Oat Flour Particle Size

Oat flour particle size is an important parameter that affects β-glucan extraction and oat flour slurry viscosity (Wood et al 1978, Zhang et al 1997). Three particle sizes of oat flours were obtained by grinding steamed oat groats to pass 1.0-, 0.5- and 0.2-mm collar screens. The oat flours were designated as coarse, medium, and fine oat flours, respectively.

Breads containing fine particle size oat flours had significantly ($P < 0.05$) lower loaf specific volume and poorer bread crumb color than breads containing coarse particle size oat flours (Table IV). The darker crumb color of bread containing fine particle size oat flour can be explained as the result of a greater number of dark-colored bran particles being distributed throughout the bread crumb. A possible explanation for the low specific volume of these breads could be reduced gas retention in the dough due to the large amount of fine oat bran particles present in the flour. It has been reported that wheat bran of fine particle size resulted in lower bread specific loaf volume and darker bread crumb color when the bran was used in a breadbaking formulation (Pomeranz et al 1977, Zhang and Moore 1997). At the same substitution level, fine particle size bran provided more particles, which resulted in more gas escape sites than were provided by the coarse bran.

Bread Crumb Starch Retrogradation

Broadly speaking, bread staling refers to all changes that occur in bread after baking. Although research has been conducted for many years, we still have not completely answered all of the questions associated with this phenomenon. However, there is general agreement that starch retrogradation is one of the most important factors involved in bread staling.

The effect of oat flour on bread crumb starch retrogradation was measured by DSC over a 10-day storage period. The addition of steamed oat flour into the breadbaking formulation decreased the bread crumb starch retrogradation rate, and the decrease seemed to be related to the amount of oat flour used (Fig. 1A). Breads containing 10% steamed oat flour had less starch retrogradation than the control (wheat flour bread), and breads containing 20% oat flour had the lowest starch retrogradation (Fig. 1A). Replacement of 10 or 20% of the wheat flour with wheat starch increased the bread crumb starch retrogradation rate (Fig. 1B).

It has been reported that oat starch gels have greater storage stability than unmodified wheat or corn starches (Paton 1986). Oat starch has also been reported to retrograde more slowly than starches from other sources (Paton 1987, White et al 1989, Sowa and White 1992). Paton (1987) observed that, after 10 days of storage, oat starch had retrograded only 50% compared to wheat and waxy maize starches, which had retrograded 70–75%.

The mechanism by which oat flour reduced the bread crumb starch retrogradation rate could consist of a simple dilution effect. Substitution of oat flour for wheat flour decreased the concentration of wheat starch, which may lower the relative rate of wheat starch retrogradation. Another factor that could also affect starch retrogradation is the increased bread crumb moisture content due to addition of oat flours (Table III). It has been reported that increased moisture content in bread enhances bread softness and retards firming (Bechtel et al 1953, Clusky et al 1959, D'Appolonia and Morad 1981). Increased bread crumb moisture may slow the amylopectin crystal growth and thus reduce the rate of starch retrogradation as measured by DSC.

CONCLUSIONS

The high β-glucan content of oat flour may be responsible for the increased water absorption and mixing requirements of the wheat-oat flour doughs when compared to wheat flour doughs alone. Bread moisture content also increased with oat flour addition,

TABLE III
Comparison of Steamed Oat Flour and Wheat Starch on Wheat Flour Breadbaking Quality[a]

Sample	Specific Vol. (cm^3/g)	External Appearance[b]	Grain Texture[b]	Crumb Color[b]	Moisture (%)
Control	6.84	10.00	8.32	8.54	33.9
10% substitution					
Wheat starch	6.33a	8.67b	8.08a	8.17a	33.1c
Oat flour	6.45a	9.83a	7.25b	7.33b	34.5b
20% substitution					
Wheat starch	6.06b	8.33b	8.00a	8.58a	31.8d
Oat flour	5.62c	7.67c	6.50c	6.25c	35.6a

[a] Steamed Robert and Marion oat flours were used, and the experiment was conducted in triplicate. Values (n = 12) within a column followed by the same letter are not significantly different ($P > 0.05$).
[b] Scores range from 0 to 10, with 10 being the best.

TABLE IV
Effect of Oat Flour Particle Size on Oat Flour Breadbaking Properties[a]

Sample[b]	Specific Vol. (cm^3/g)	External Appearance[c]	Grain Texture[c]	Crumb Color[c]
Coarse	5.59a	5.17a	5.08a	5.91a
Medium	5.67a	5.83a	5.25a	5.83ab
Fine	5.16b	5.33a	5.08a	5.41b

[a] Steamed Robert and Marion oat flours were used at 20% substitution level. Values (n = 12) within a column followed by the same letter are not significantly different ($P > 0.05$).
[b] Coarse, medium, and fine particle size oat flours were generated by grinding the oat groats through 1.0-, 0.5-, and 0.2-mm collar screens, respectively.
[c] Scores range from 0 to 10, with 10 being the best.

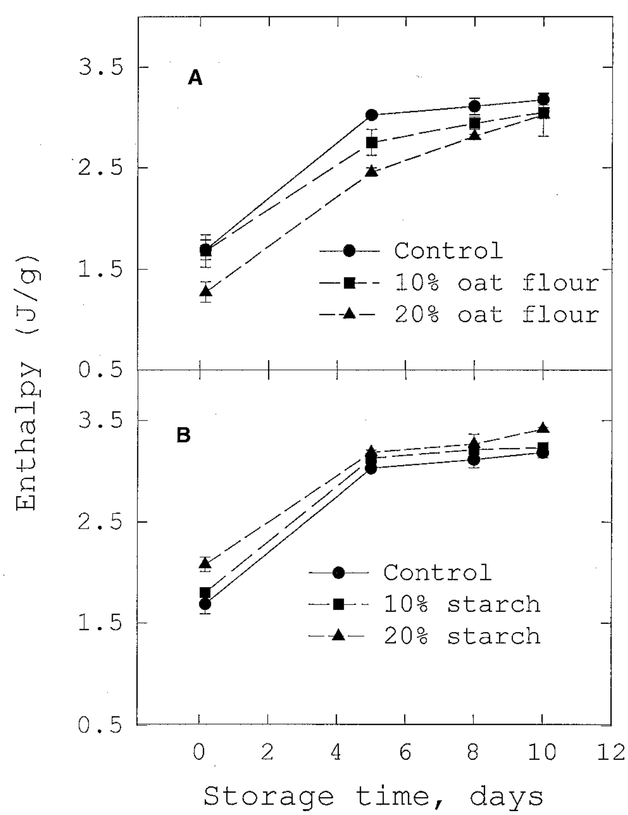

Fig. 1. Effect of oat groat flour from steamed oat grain (**A**) and wheat starch (**B**) at 10 and 20% wheat flour substitution level on bread crumb starch retrogradation rate.

which may have slowed the bread staling process. Roasting of oat grain resulted in oat flours that were highly detrimental to wheat flour dough mixing properties and breadbaking quality. This detrimental factor in roasted oat grain was sensitive to steaming and may consist of enzyme activity or a bioactive reducing agent. Oat flour milled from steamed grain had more favorable breadbaking properties.

At the 10% level of wheat flour replacement, oat flours from steamed oat grain exhibited only a gluten-dilution effect on bread loaf volume. Oat flour in the bread system resulted in more moisture retention and significantly reduced the bread crumb starch retrogradation rate. Reduced bread crumb starch retrogradation rate may be caused by increased bread crumb moisture in the wheat-oat flour breads, or by a slower retrogradation rate in oat starch compared to that in wheat starch.

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