Application of Oat Oil in Breadbaking

Sofía V. Erazo-Castrejón,[1] Douglas C. Doehlert,[2,3] Bert L. D'Appolonia[1]

ABSTRACT

Cereal Chem. 78(3):243–248

Lipids, especially polar lipids, can improve loaf volume, grain and texture, and delay staling in bread. Oats (*Avena sativa* L.) are rich in total and polar lipids. We have investigated the effect of oat lipids in a bread formulation on loaf volume, appearance, and bread staling. Oat oil was fractionated into polar and nonpolar fractions by water-degumming. Crude oat oil and shortening (at 3%) increased loaf volume by ≈11% over the zero lipid formulation. The polar lipid fraction increased loaf volume by nearly the same amount when added at only a 0.5% level. The addition of 3% crude oat oil or 0.7% oat oil polar fraction significantly delayed bread firming and starch retrogradation; the difference between oat lipids and shortening was more evident at the end of a four-day storage period. Oat lipids had a stronger relative effect on bread from a weak flour (10% protein) than from a strong flour (14% protein). The effects of oat oil in the bread formulation could be related to the amphipathic character of polar lipids in oats that enables them to interact with starch, proteins, and other bread components.

Bakery goods are the major cereal products available to consumers. Among them, bread has been the principle food in over half of the countries around the world. Compared with other types of baked goods, breads require small amounts of fats (2–4%). Lard has been the fat predominantly used in bread production for years. However, trends in the baking industry have been to replace animal fats or hydrogenated shortenings with vegetable oils and surfactants (Chung and Pomeranz 1983). This trend is due to several reasons, including health, nutrition, availability, handling, and storage, as well as religious considerations of certain consumer groups. Currently, another trend can be identified. The presence of *trans*-fatty acids in vegetable shortenings due to the hydrogenation of double bonds in unsaturated fatty acids has raised health concerns. Recent findings on a possible relationship between *trans*-fatty acid intake and coronary heart disease (Allison et al 1995) is pushing food producers to reformulate products with low or no *trans*-fatty acids (Juttelstad 1998). For this reason, new options to substitute vegetable shortenings have to be explored.

Lipids are one of the most important components in food. They perform many desirable sensory, physical, nutritional, and biological functions. The sensory attributes of lipids in foods include their contribution to flavor, color, texture, mouthfeel, and overall sensory satisfaction and satiety effects (Kinsella 1988). Lipids contribute to tenderness of various baked products. In bread, the basic ingredients are flour, water, salt, and yeast. Fat and sugar are added to improve texture and flavor. The proper amount of fat or shortening in bread dough improves the volume, grain, texture, crust tenderness, and keeping quality of the bread and makes the dough more elastic (Sultan 1980). All these attributes determine bread quality and, even though high loaf volume is the first characteristic to look for, there must be a balance with the other appearance properties such as symmetry, grain and texture, and crumb color.

The functional effect of lipids in breadmaking depends on the type of lipid used and the interactions with other dough components. Hoseney et al (1969) indicated that lipids in the bound state in flour were less important in baking than the free lipid group. Bound lipids are extractable only with polar solvents such as chloroform or water-saturated butanol, whereas free lipids can be extracted with nonpolar solvents such as diethyl ether or petroleum ether. With respect to free lipid, Daftary et al (1968) determined that polar lipid, and in particular glycolipid, was beneficial in baking, whereas nonpolar lipid was detrimental. MacRitchie (1973, 1977) found that the effects of polar lipids were twofold: high levels were beneficial and low levels were detrimental. Additional studies conducted by Lin et al (1974) and Chung et al (1984) showed that among glycolipids, digalactosyldiglyceride (DGDG) had the strongest influence on bread attributes.

Oat groats usually have a lipid concentration of 5.0–9.0%, which is the highest among the cereal grains. Oat oil contains free and esterified sterols, triglycerides, free and esterified fatty acids, glycolipids, and phospholipds. The most abundant glycolipid is DGDG (Sahasrabudhe 1979; Youngs 1986). Jayasinghe et al (1991) indicated that the addition of 2% polar oat lipid increased bread volume by 40%. However, their results were sparse and their baking protocols did not include a shortening control to determine whether the volume increase was beyond that which could be achieved by shortening. The objective of this study was to determine the effect of crude oat oil and its fractions on bread loaf volume, loaf appearance, and starch retrogradation.

MATERIALS AND METHODS

Flour

A hard red spring (HRS) wheat flour cultivar, Grandin, and a hard red winter (HRW) wheat flour (Bay State Milling, Winona, MN) were used for the baking tests. The moisture content of the flours was determined by the air-oven method (Approved Method 44-15A, AACC 2000). Protein content of the flours was determined using the combustion method as described in AACC Approved Method 46-30, with a nitrogen analyzer (Leco FP428, St. Joseph, MI). Rheological properties of the flour doughs were determined with a farinograph according to AACC Approved Method 54-21. A 50-g sample bowl was used and optimum consistency was reached by adjusting the water absorption to 500 BU ± 20.

Fractionation and Characterization of Oat Oil

Oat oil, prepared by hexane extraction, was kindly provided by ConAgra (Omaha, NE). Digalactosyldiacylglyceride (DGDG), purified by supercritical CO_2 extraction (Andersson et al 1997), was provided by Lars Blomberg, Sweden. Crude oat oil was fractionated into polar and nonpolar fractions by the water-degumming method described by Forssell et al (1992). The crude oat oil was heated at 65°C in a water bath and vigorously stirred. Hot water (10% of the weight of the crude oil) was added and the mixture was agitated for 30 min at 65°C. Hydrated polar lipids were separated from the mixture by centrifuging at 9,100 × *g* at 20°C for 30 min. The polar and nonpolar fractions were dried by lyophilization.

---

[1] Department of Cereal Science, Harris Hall, North Dakota State University, Fargo, ND 58105.

[2] USDA-ARS Hard Red Spring and Durum Wheat Quality Laboratory, Harris Hall, North Dakota State University, Fargo, ND 58105. The mention of firm names or trade products does not imply that they are endorsed or recommended by the U.S. Department of Agriculture over other firms or similar products not mentioned.

[3] Corresponding author. Phone: 701/231-8069. Fax: 701/239-1377. E-mail: Douglas_Doehlert@ndsu.nodak.edu

Publication no. C-2001-0411-06R.

Determination of phosphorous in the oil was based on Bartlett's method (1959) for an estimation for phospholipids, with a sample preparation according to Morrison (1964). A standard curve was constructed using Method Ca 12-55 (AOCS 1998). Each determination was made in triplicate. Carbohydrate content in oat oil was determined by the method of Dubois et al (1956) and was used as an estimate of glycolipids. Because of the high content of neutral fat in the samples, especially in the oat oil and its nonpolar fraction, glycolipids had to be extracted before the reaction using a binary solvent system formed of equal volumes of 87% ethanol and petroleum ether (Galanos and Kapoulas 1965). A galactose (in 87% ethanol) standard curve was constructed and each determination was made with four replicates.

Thin-Layer Chromatography (TLC)

Oat oil polar and nonpolar fractions were separated on precoated silica gel plates (Analtech, Inc., Newark, DE). Nonpolar lipids were separated with a hexane-diethyl ether-glacial acetic acid (80:20:1.5) solvent system. The polar lipids were separated with either chloroform-methanol-water (65:25:4) or chloroform-methanol-ammonia (65:35:5). Lipids were detected on TLC plates after iodine absorption. Identities of lipids were determined by comparing R_f values with those from standards.

Bread Baking Procedures and Quality Evaluations

A straight dough procedure based on AACC Approved Method 10-09 was used to evaluate the effect of oat oil and its fractions on physical properties of bread. All samples were mixed to optimum consistency until a thin membrane was formed and could be seen when stretched. The amount of water added was the water absorption of flour obtained on the farinograph minus 1.5%. The baking formula on a flour basis was flour (14% mb) 100.0 g, 5.0 g of sugar, 2.0 g of salt, 1.0 g of vacuum-packed yeast, 0.1 g of ammonium phosphate monobasic, 1 mL (17 SKB units) of fungal α-amylase (American Ingredients, Co., Kansas City, MO), 20 ppm of ascorbic acid, and fat. The amount and type of fat is indicated for each experiment. For all the experiments performed with HRS wheat flour, a two-step punching procedure was adopted using 180 min of fermentation. For HRW wheat flour with a lower protein content, a fermentation time of 90 min with a one-step punch was used. All doughs were proofed for 55 min before baking. The volume of each loaf was measured by rapeseed displacement 1 hr after bread was removed from oven. Crumb grain and texture, crumb color, crust color, and symmetry were evaluated by visual comparison to a standard under a constant illumination source. Bread loaves were scored by an experienced baker for each attribute using a scale 1 to 10, with higher scores preferred. For the staling study, samples were taken at day 0, 1, 2, 3, and 4. The central slices from each loaf were used to determine firmness with a texture analyzer (TA-XT2, Texture Technologies Corp.) according to the AACC Approved Method 74-09. Crumb moisture was determined as in flour but including an air-drying step before the conventional air-oven drying. To evaluate starch recrystallization, crumb samples taken from each treatment were frozen and lyophilized. The dried crumb (2.89–3.14% moisture) was ground in an ultracentrifugal mill (model ZM1, Brinkmann Instruments Co., Westbury, NY). Enthalpy changes (ΔH) were evaluated by differential scanning calorimetry, where 4.0 ± 0.1 mg of dry crumb in excess of water were scanned (DSC-7, Perkin-Elmer Corp., Norwalk, CT) at 10°C/min, from 5 to 130°C. Indium was used to calibrate the calorimeter. The endothermic peak area was converted to enthalpy, the energy required to melt crystalline material. Enthalpy values were used as an index of the starch recrystallization that occurred during storage (Zeleznak and Hoseney 1987). Each sample was scanned in triplicate.

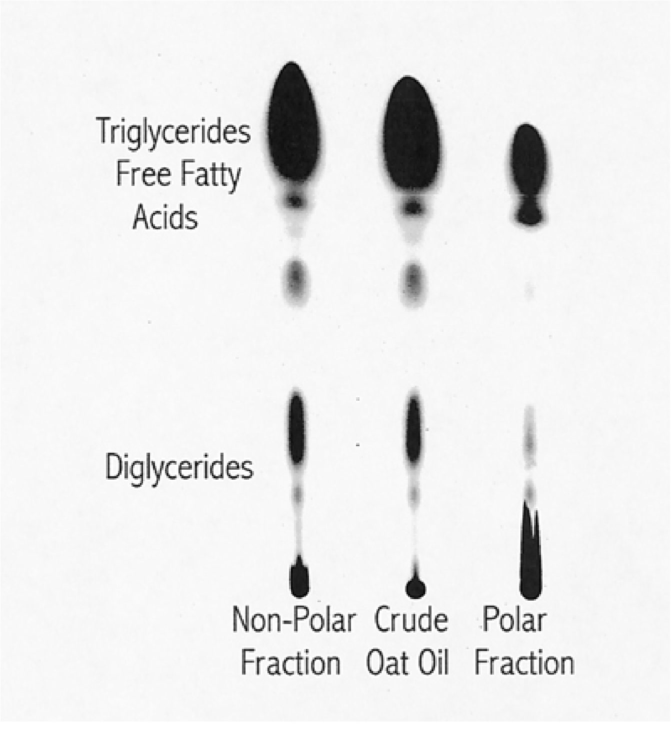

Fig. 1. Thin-layer chromatography plate for nonpolar lipids in crude oat oil and its fractions.

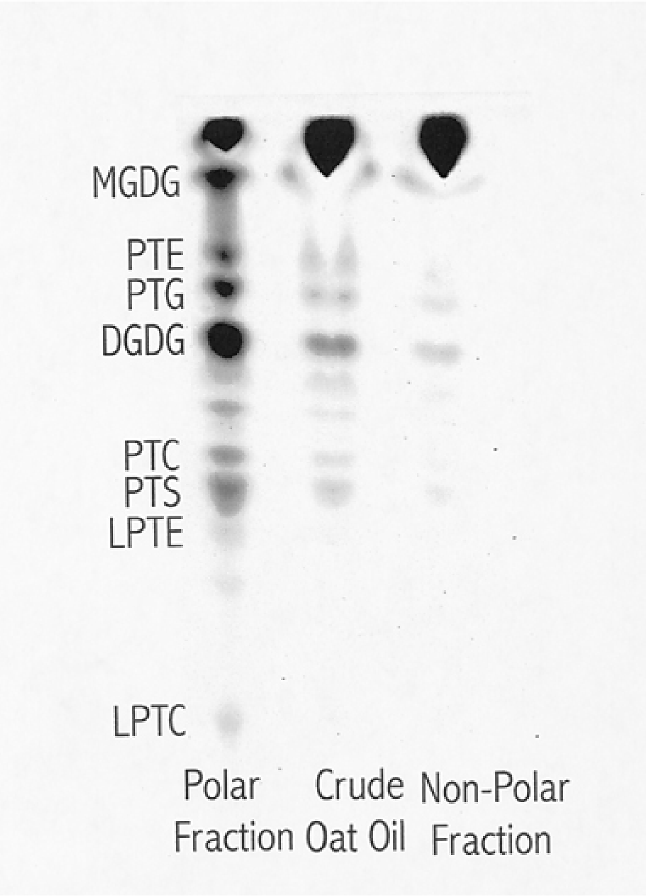

Fig. 2. Thin-layer chromatography plate of polar lipids in oat oil polar fraction. Monogalactosyldiglyceride (MGDG); L-α-phosphatidylethanolamine (PTE); L-α-phosphatidyl-DL-glycerol (PTG); digalactosyldiacylglyceride (DGDG); L-α-phosphatidylcholine (PTC); L-α-phosphatidyl-L-serine (PTS); L-α-lysophosphatidylethanolamine (LPTE); L-α-lysophosphatidylcholine (LPTC).

Statistical Analyses

All experiments were performed in triplicate. Data were analyzed by analysis of variance (ANOVA) and means compared by the least significant difference (LSD). Some data were further analyzed by linear regression. All statistical values were calculated with the Statistix (Analytical Software, Tallahassee, FL) computer package.

RESULTS

The water-degumming of crude oat oil yielded 13.5% of polar and 77% of nonpolar fraction. The remainder was a fraction of nonsoluble aggregates. Crude oat oil and its polar and nonpolar fractions were analyzed by TLC using a solvent system designed to separate nonpolar lipids (Fig. 1). Polar lipids were immobile in this solvent and remained at the origin. Nonpolar lipids, as evaluated by the size and darkness of spots on the plate, were predominantly in the supernatant fraction of the water degumming system. Monoacyl-, diacyl-, and triacylglycerides, and free fatty acids were the dominant species of the crude oat oil and its nonpolar fraction. The TLC confirmed that the precipitate from the water degumming was enriched in polar lipids (Fig. 2). Phospho- and glycolipids identified in this fraction included lysophosphatidylethanolamine, phosphatidylcholine, lysophosphatidylcholine, phosphatidylethanolamine, phosphatidylglycerol, phosphatidylserine, digalactosyldiglyceride and monogalactosyldiglyceride (Fig. 2). Of these, the most abundant appeared to be digalactosyldiglyceride.

The determination of phosphorous and total carbohydrates (Table I) in oat oil and its fractions provided a quantification of the enrichment of polar lipids in the precipitate from water degumming. The oat oil polar fraction was enriched nearly threefold in phosphorous and over fourfold in carbohydrates, whereas the nonpolar fraction contained only ≈60% of the phosphorous and carbohydrate concentrations in the crude oat oil.

The addition of 3% shortening, 3% crude oat oil, or 0.5% oat oil polar fraction to bread formulations resulted in improved loaf volume and appearance of bread (Table II). Shortening and crude oat oil improved loaf volume of bread by ≈11% compared with the no-fat control, whereas the oat oil polar fraction improved loaf volume by ≈8%. Nonpolar oat lipids had no influence on loaf volume. The comparison of grain and texture indicated that breads with 3% crude oat oil, 0.5% polar fraction, or 3% shortening were all improved over the no fat control, although the bread with 3% oat oil nonpolar fraction was not. Symmetry scores for all the treatments were >9.0, and no difference was detected among them. Color was clearly negatively affected by the addition of crude oat oil and its nonpolar fraction. Color for these treatments were scored at least one point lower than the nonfat and 3% shortening controls. Color of the bread made with 0.5% polar oat oil fraction was not significantly different from the bread made with shortening.

Shortening added to a bread formulation improved loaf volume at all concentrations tested (Fig. 3). Maximum loaf volumes were obtained with 0.5, 1.0 and 2.0% shortening, which did not significantly differ among themselves. Loaves baked with 3 and 5% shortening had lesser volumes. Loaf volume also increased with bread formulations with different concentrations of oat oil polar fraction (Fig. 4). The increase in loaf volume with oat oil polar fraction concentration from 0 to 1.5% appeared linear and could be described by the regression formula: loaf volume = 920 + 30 (oat oil polar fraction concentration) ($R^2 = 0.88$, $P = 0.005$). Comparison of means by *t*-test indicated that the volume reached at 1.0% of oat oil polar fraction (Fig. 4) was not significantly ($P < 0.05$) different from the volume of bread with 1.0% of shortening (Fig. 3).

When shortening and oat oil polar fraction were added together to a bread formulation, loaf volume increased with the addition of oat oil polar fraction in 0.5 and 1.0% shortening (Fig. 5). Without oat oil polar fraction, there was no significant difference between loaf volumes derived from formulations containing 0.5 and 1.0% shortening, which is consistent with data presented in Fig. 3. How-

TABLE I
Phosphorous and Total Carbohydrates in Oat Oil and Its Fractions

Specie	Phosphorous (mg/g)[a]	Total Carbohydrates (mg/g)[b]
Oat oil	1.61 ± 0.13	18.4 ± 2.50
Nonpolar fraction	0.90 ± 0.11	10.6 ± 1.12
Polar fraction	4.58 ± 0.26	86.2 ± 0.66

[a] Mean ± standard deviation, $n = 3$.
[b] Mean ± standard deviation, $n = 4$.

TABLE II
Effect of Different Fats on Loaf Volume (LV) and Appearance of Hard Red Spring Wheat Bread

		Appearance[a]		
Treatment	LV (cm^3)	Grain-Texture	Crumb Color	Symmetry
No fat	897c[b]	7.6c	8.7a	9.4a
3% Shortening	996ab	8.2ab	8.4ab	10.0a
3% Crude oat oil	998a	8.5a	7.4c	10.0a
3% Nonpolar fraction	911c	7.9bc	7.2c	9.6a
0.5% Polar fraction	972b	8.0b	8.0b	9.2a

[a] Scores from 0 to 10 (best).
[b] Values followed by the same letter in the same column are not significantly different ($P < 0.05$).

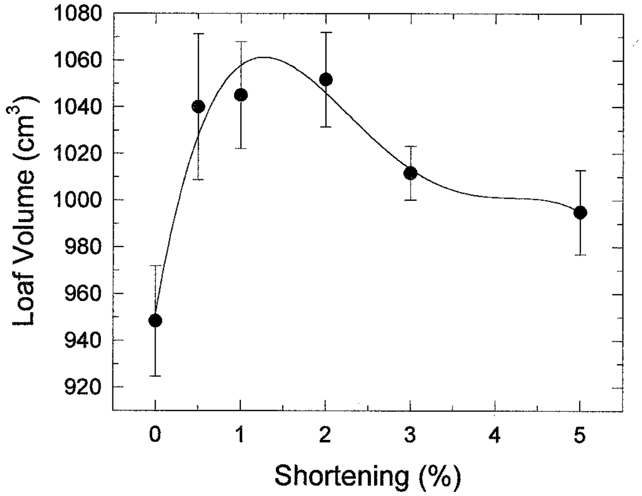

Fig. 3. Effect of shortening on loaf volume of bread baked with hard red spring wheat flour.

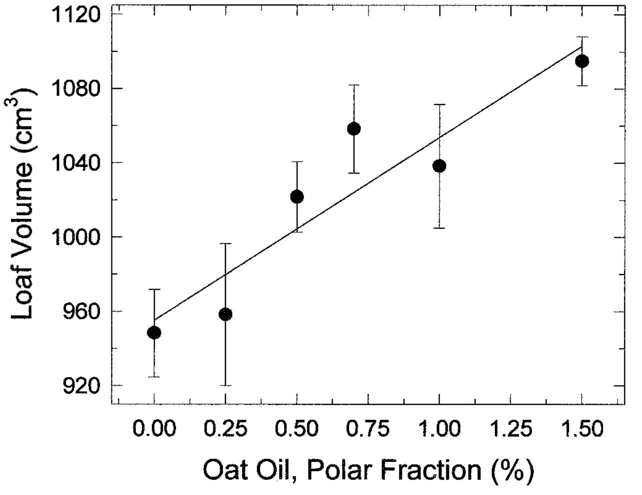

Fig. 4. Effect of oat oil polar fraction on loaf volume of bread baked with hard red spring wheat flour.

ever, the addition of up to 0.7% oat oil resulted in an additional increase in loaf volume of ≈22% over the shortening-alone volume. ANOVA indicated no significant interaction and significant main effect of only oat oil on loaf volume with no significant main effect of shortening (not shown).

Because several studies (Daftary et al 1968; Lin et al 1974; Chung et al 1984) had indicated the importance of DGDG in reconstituted flour systems, we hypothesized that the addition of exogenous DGDG into a native flour system might have a beneficial effect on bread quality. We found that the addition of 0.5% purified DGDG to a bread formulation had positive effects on loaf volume, but the improvement was not better than that of shortening alone (data not shown).

The relative effects of oat oil on bread made from higher protein HRS wheat flour and lower protein HRW flour was determined (Table III). ANOVA indicated significant differences in loaf volume of bread made from HRS flour baked with no fat, 3% shortening, and 0.7% oat oil polar fraction, with the last providing the highest loaf volume. In bread baked with HRW flour, shortening and oat polar lipids additions both yielded significantly higher loaf volumes than no fat but did not differ from each other. Volumes of bread baked with the same type of fat but different flour (HRS or HRW) were compared using the *t*-test ($\alpha = 0.05$). On a proportional basis, oat oil increased loaf volume of bread baked with HRS flour by 11%, which was less than the 18% increase observed for HRW flour bread. However, the absolute changes in volume brought about by oat oil, 110 cm^3 for HRS and 119 cm^3 for HRW, were not significantly different.

The possibility that oat oil was functioning as an emulsifier was tested in an experiment where interaction of oat oil and shortening were tested with respect to some commercial emulsifiers (Table IV). Each of these components produced important improvement on loaf volume of bread baked with HRW wheat flour. The additive with the strongest activity when added alone was DATEM. The addition of either commercial emulsifier (SSL or DATEM) to either fat preparation (shortening or oat oil polar fraction) resulted in a greater loaf volume.

The time-dependent relationship of crumb moisture, firmness, and starch recrystallization during the process of bread staling was determined with different fat formulations (Fig. 6A–C). For all the treatments, crumb moisture decreased with storage time. The loss of moisture was greater in bread with shortening than with the other formulations (Fig. 6A).

Bread firmness increased for all treatments during the staling experiment (Fig. 6B). ANOVA of force data indicated that at days 0 and 1, there were no significant differences ($P < 0.05$) among treatments. At day 2, there was a significant increase in the firmness of

TABLE III
Effect of Flour Protein and Added Fat on Loaf Volume (cm^3) of Hard Red Spring (HRS) and Hard Red Winter (HRW) Bread

Treatment	HRS 14.4% Protein	HRW 10.1% Protein
No fat	948c[a]	635b
3% Shortening	1,011b	737a
0.7% Oat oil polar fraction	1,058a	754a

[a] Values followed by the same letter in the same column are not significantly different ($P < 0.05$).

TABLE IV
Effect of Oat Oil Polar Fraction, Shortening, and Emulsifiers on Loaf Volume of Hard Red Winter Wheat Bread

Treatment	Loaf Volume (cm^3)
No fat	635e[a]
3% Shortening	737d
0.7% Polar fraction	754d
0.5% SSL[b]	771cd
0.5% DATEM[c]	817b
0.7% PF (0.5% SSL)[d]	800bc
0.7% PF (0.5% DATEM)	822ab
3% Shortening (0.5% DATEM)	832ab
3% Shortening (0.5% SSL)	856a

[a] Values followed by the same letter in the same column are not significantly different ($P < 0.05$).

[b] Sodium stearoyl -2-lactylate.

[c] Diacetyl tartaric acid esters of mono- and diglycerides.

[d] Oat oil polar fraction.

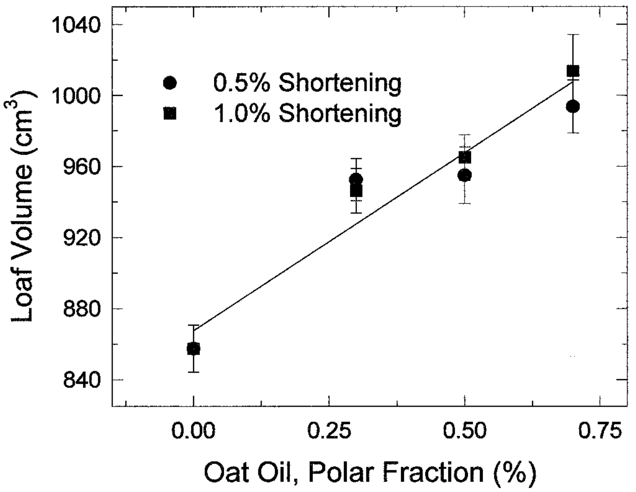

Fig. 5. Effect of oat oil polar fraction combined with shortening on loaf volume of bread baked with hard red spring wheat flour.

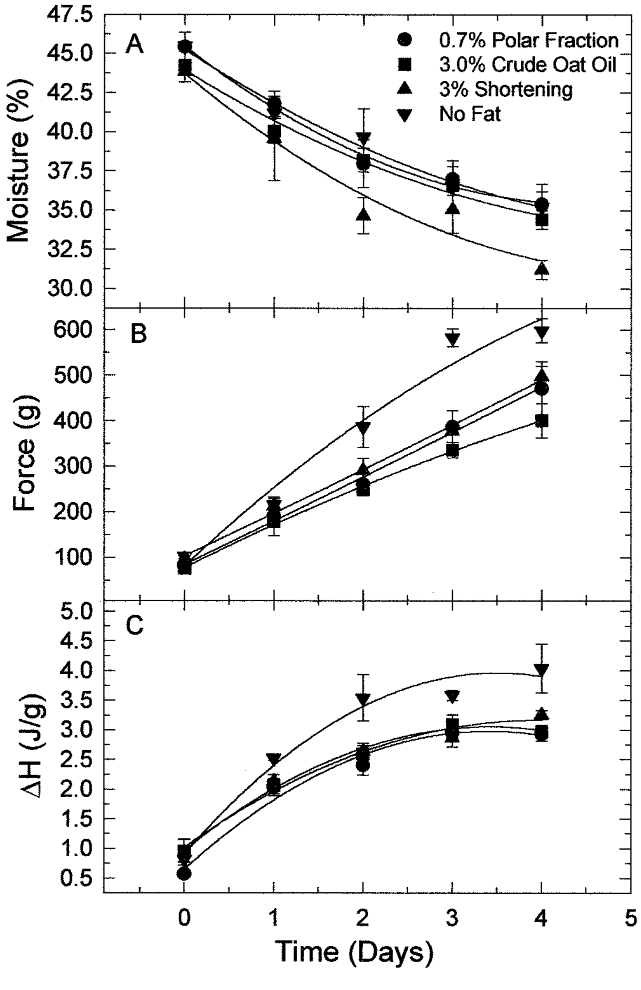

Fig. 6. Effect of added fat on the bread staling process: **A,** changes in moisture; **B,** changes in firmness; **C,** changes in starch retrogradation of bread with time.

bread with no fat over those with added fat. After day 4, bread with 0.7% polar oat lipids was significantly less firm (softer) than bread with 3% shortening or no fat. Bread with 3% oat oil was not softer than the formulation with shortening, but both the 3% oat oil and the 3% shortening formulations were softer than the no fat control.

Starch recrystallization has been identified as one of the causes of bread staling. Differential scanning calorimetry measures the amount of heat (ΔH) required to melt starch crystals. This ΔH is a measure of the extent of bread staling. The effect of different fats on the enthalpy change (ΔH) in crumb samples during the staling process is shown in Fig. 6C. The ΔH increased with time for all formulations. However, bread with no fat registered greater increases in ΔH within days 1 and 2 than those formulations containing fat. Among formulations containing fat, none showed significant differences in ΔH until day 4, when the ΔH of the crumbs from the breads with 0.7% oat oil polar fraction and 3% crude oat oil were significantly lower ($P < 0.05$) than that of bread with 3% shortening.

DISCUSSION

Crude oat oil and oat polar lipids had beneficial effects on loaf volume and on the appearance of bread. When compared with bread made with no fat as a control, both fats yielded bread of superior quality. When compared with shortening, both crude oat oil and oat oil polar fraction were comparable to shortening in their beneficial effects, although the effect for the oat oil polar fraction was obtained at concentration as low as 0.5%. For crude oat oil, the optimal concentration appears to be ≈3%. The beneficial effects of fats in baked products could be the result of the combination of their emulsifying, foam stabilizing, wetting, lubricating, and bridging capacities (Carr et al 1992). The presence of oat oil in bread formulations had a negative effect on the color of the bread (Table II). Crude oat oil was opaque and olive green in color, which carried over partially to the bread when added at the 3% level. The green color appeared to be primarily associated with the polar fraction, which was semisolid and deep olive green. But because the polar fraction was added to the bread formulations in a much lower concentration than the crude and nonpolar fractions, there was less of a color problem with it.

When the oat oil polar fraction was added to a bread formulation containing 0.5 and 1.0% shortening, there was a linear increase in loaf volume with oat oil polar fraction concentration (Fig. 5), even though there was no difference in loaf volumes between 0.5 and 1.0% shortening at any oat oil polar fraction concentration. This suggests that the oat oil may be acting through a mechanism separate from that of the shortening to improve bread quality.

The commercial emulsifiers tested (SSL and DATEM) both had positive effects on loaf volume when included in a bread formulation alone or in combination with either 3% shortening or 0.5% oat oil polar fraction (Table IV). This indicated that loaf volume derived from formulations containing shortening could be increased by the addition of an emulsifier and suggested the possibility that the effect of the oat oil polar lipid fraction on formulations containing shortening (Fig. 5) was from an emulsifying action of the polar oat lipids. However, the commercial emulsifiers also had a positive effect on the formulations containing oat oil polar fraction (Table IV) which may not be consistent with a hypothesized emulsifying action of the oat oil polar fraction.

Our experiment indicating that the addition of 0.5% DGDG did not improve loaf volume any more than 3% shortening suggested that purified DGDG was no better at improving bread loaf volume than the oat oil polar fraction. It seems unlikely that such a highly purified preparation would be economically feasible as a bread ingredient because less purified preparations functioned just as well.

Protein quantity and quality are the major factors responsible for baking performance of flour (Finney and Barmore 1948). In our study, this was also apparent in comparing loaf volume and physical appearance of bread made with HRS wheat flour (14.4% protein) and HRW wheat flour (10.1% protein). The addition of shortening or oat oil polar fraction resulted in improved loaf volume with breads made from either HRS or HRW wheat flour. Although the absolute increase in loaf volume between the two formulations was similar (110 and 119 cm^3), because the base volume of the HRW wheat bread was much lower than that of the HRS wheat bread, the relative increase in the HRW wheat bread flour (18%) was significantly ($P < 0.05$) greater than that of the HRS wheat bread (11%). Different fermentation procedures were used with the two flours to optimize the loaf quality from each flour. The HRS wheat samples were fermented for 180 min with two punches to take advantage of its good fermentation tolerance. Such a long fermentation would not have been as optimal for the lower protein HRW wheat flour samples. Thus, fermentation was reduced to 90 min with one punch. The different fermentation procedures were chosen to generate the best quality loaf possible from the flour used.

Experiments on the effect of oat oil fractions and shortening on bread staling suggested that oat oil was more effective than shortening in retarding staling. All formulations produced breads that exhibited decreased crumb moisture, increased firmness (decreased softness), and increased ΔH during the time interval tested. The formulation with the polar fraction was both softer and had lower starch retrogradation (ΔH) than the formulation with shortening after four days. It is also notable that the oat oil polar fraction had a stronger staling retardation effect at one sixth the concentration of the shortening (0.5% oat oil polar fraction vs. 3.0% shortening). Because the oat oil polar fraction was more effective than the crude oat oil in delaying staling, and because a direct effect on starch retrogradation is documented, it seems likely that at least part of the effect of oat oil on bread quality is due to an interaction of the amphipathic polar lipids with the starch.

Crude oat oil or its polar fraction could be added in the bread formulations to increase loaf volume and extend shelf life. Our results have indicated that comparable benefits form 3% shortening could be obtained with much lesser concentrations of oat oil. Bread made from oat oil could be more healthful because of their lower fat content and because of the absence of *trans*-fatty acids. Depending on the availability of a commercial oat lecithin preparation, bread formulations made with oat oil polar lipids could also be more economical.

LITERATURE CITED

Allison, D. B., Denke, M. A., Dietschy, J. M., Emken, E. A., and Nicolosi, R. J. 1995. Trans fatty acids and coronary heart disease risk. Am. J. Clin. Nutr. 63:655S-708S.

American Association of Cereal Chemists. 2000. Approved Methods of the AACC, 10th ed. Method 10-09, Method 44-15A, Method 46-30, Method 54-21, Method 74-09. The Association: St. Paul, MN.

AOCS. 1998. Official Methods and Practices of the American Oil Chemists' Society, 5th ed. Method Ca 12-55. The Society: Champaign, IL.

Andersson, M. B. O., Demirbuker, M., and Blomberg, L. G. 1997. Semi-continuous extraction/purification of lipids by means of supercritical fluids. J. Chromatography 785:337-343.

Bartlett, G. R. 1959. Phosphorous assay in column chromatography. J. Biol. Chem. 234:466-468.

Carr, N. O., Daniels, N. W. R., and Frazier P. J. 1992. Lipid interactions in breadmaking. Crit. Rev. Food Sci. Nutr. 31:237-258.

Chung, O. K., and Pomeranz, Y. 1983. Recent trends in usage of fats and oils as functional ingredients in the baking industry. J. Am. Oil Chem. Soc. 60:1848-1851.

Chung, O. K., Pomeranz, Y., and Jacobs, R. M. 1984. Solvent solubility parameter and flour moisture effects on lipid extractability. J. Am. Oil Chem. Soc. 61:793-797.

Daftary, R. D., Pomeranz, Y., Shogren, M. D., and Finney, K. F. 1968. Functional breadmaking properties of wheat flour lipids. II. The role of flour lipid fractions in breadmaking. Food Technol. 22:327-330.

Dubois, M., Gilles, K. A., Hamilton, J. K., Rebers, P. A., and Smith F. 1956. Colorimetric method of determintion of sugars and related substances. Anal. Chem. 28:350-356.

Finney, K. F., and Barmore, M. A. 1948. Loaf volume and protein content of hard red winter and spring wheats. Cereal Chem. 25:291-312.

Forssell, P., Kervinen, R., Alkio, M., and Poutanen, K. 1992. Comparison of methods for separating polar lipids from oat oil. Fat Sci. Technol. 94:355-358.

Galanos, D. S., and Kapoulas, V. M. 1965. Preparation and analysis of lipids extracts from milk and other tissues. Biochim. Biophys. Acta 98:278-292.

Gerrard, J. A., Every, D., Sutton, K. H., and Gilpin, M. J. 1997. The role of maltodextrins in the staling of bread. J. Cereal Sci. 26:201-209.

Hoseney, R. C., Finney, K. F., Pomeranz, Y., and Shogren, M. D. 1969. Functional (breadmaking) and biochemical properties of wheat flour components. V. Role of total extractable lipids. Cereal Chem. 46:606-613.

Jayasinghe, G., Larsson, K., Miezis, Y., and Sivik, B. 1991. Oat lipids-interaction with water and characterization of aqueous phases. J. Dispersion Sci. Technol. 12:443-451.

Juttelstad, A. 1998. Walking the trans fat tightrope. Food Processing 59:42-44.

Kinsella, J. E. 1988. Food lipids and fatty acids: Importance in food quality, nutrition and health. Food Technol. 42:124-140.

Lin, M. J. Y., D'Appolonia, B. L., and Youngs, V. L. 1974. Hard red spring and durum wheat polar lipids. II. Effect on quality of bread and pasta products. Cereal Chem. 51:34-45.

MacRitchie, F. 1977. Flour lipids and their effects in baking. J. Sci. Food Agric. 28:53-62.

MacRitchie, F., and Gras, P. W. 1973. The role of flour lipids in baking. Cereal Chem. 50:292-302.

Martin, M. L., and Hoseney, R. C. 1991. A mechanism of bread firming. II. Role of starch hydrolyzing enzymes. Cereal Chem. 68:503-507.

Martin, M. L., Zeleznak, K. J., and Hoseney, R. C. 1991. A mechanism of bread firming. I. Role of starch swelling. Cereal Chem. 68:498-503.

Morgan, K. R., Lower H., Gerrard, J., Every D., Ross, M., and Gilpin, M. 1997. Staling in starch breads: The effect of antistaling α-amylase. Starch 49:54-59

Morrison, W. R. 1964. A fast, simple and reliable method for the micro–determination of phosphorous in biological materials. Anal. Biochem. 7:218-224.

Pomeranz, Y., and Chung, O. K. 1978. Interaction of lipids with proteins and carbohydrates in breadmaking. J. Am. Oil Chem. Soc. 55:285.

Roach, R. R., and Hoseney. R. C. 1995. Effect of certain surfactants on the starch in bread. Cereal Chem. 72:578-582.

Sahasrabudhe, M. R. 1979. Lipid composition of oats (*Avena sativa* L.). J. Am. Oil Chem. Soc. 56:80-84.

Sultan, W. J. 1980. Shortenings and Their Uses. Pages 5-10 in: Practical Baking, 3rd Ed. W. J. Sultan, ed. AVI: Westport, CT.

Youngs, V. L. 1986. Oat lipids and lipid-related enzymes. Pages 205-227 in: Oats Chemistry and Technology. F. H. Webster, ed. Am. Assoc. Cereal Chem.: St. Paul, MN.

Zeleznak, K. J., and Hoseney, R. C. 1987. Characterization of starch from bread aged at different temperatures. Starch 39:231-233.

[Received August 28, 2000. Accepted January 15, 2001.]