# Effects of Lipids and Emulsifiers on Alveograph Characteristics

K. ADDO[1,2] and Y. POMERANZ[1]

**ABSTRACT**

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The effects of lipids from hard red winter, durum, and commercial soft white winter flours of 12.9, 12.2, and 8.9% protein, respectively, on alveograph rheological dough properties of petroleum-ether (PE) defatted flours were determined. Alveograph parameters, significantly affected by PE defatting, could be restored by reconstitution of the flours. The source of flour lipids had no effect on the properties of reconstituted doughs. Defatting increased alveograph parameters *P*, *W*, and *DM* and decreased *L*. Adding two or four times the amounts of free (PE-extracted) flour lipids beyond the level found in the original flour resulted in slight changes in alveograph characteristics of the reconstituted flour. Nonpolar lipids from the original flour, shortening (at a 2% level), linoleic acid, and (to a limited extent) linolenic acid were more effective in restoring alveograph characteristics of the defatted flour than were polar wheat flour lipids; corn, peanut, and palm oils; and palmitic, stearic, and oleic acids. Adding 2% shortening in combination with 0.2% lecithin, 0.2% hydroxylated lecithin, or 0.1% ethoxylated monoglycerides to the defatted flour made the doughs more similar in rheological properties to the original flour than adding shortening alone.

The functional significance of wheat flour components in breadmaking has been the subject of several comprehensive reviews (Bloksma 1972; Pomeranz 1973, 1988; Morrison 1976, 1978). Of particular interest have been the effects on dough rheology of native wheat flour lipids and of added lipid such as shortening. Rheological properties are important since they determine the behavior of dough pieces during mechanical handling such as dividing, rounding, and molding; they also affect the quality of the finished product (Bloksma and Bushuk 1988).

The availability of several dough testing instruments for the study of the rheological properties of dough has contributed to a better understanding of flour components, including lipids and their roles in the breadmaking process. Several attempts have been made using such intruments to relate dough handling properties to the quality of the baked product (Sullivan et al 1936; Merritt and Bailey 1945; Narayanan and Hlynka 1962; Tsen and Hlynka 1962, 1963; Pomeranz et al 1966; Tao and Pomeranz 1968; Ponte and De Stefanis 1969; De Stefanis and Ponte 1976).

In a study of the role of lipids in relation to flour quality, Sullivan et al (1936) examined the effects of oil from wheat germ and of each oil fraction and its hydrolytic products on normal and sound patent flour as judged by gluten washing and baking tests, as well as by the farinograph and fermentograph. Fresh wheat-germ oil and most of its constituents, such as unsaponifiable material and triglycerides, had little or no effect on the rheological properties of a patent flour. More highly saturated fatty acids had little effect on farinograph curves, and unsaturated fatty acids increased dough development times. Merritt and Bailey (1945) found that fats differed in their effects on doughs made from flours of different strengths. The fats tended to decrease the extensibility and extensigraph areas of doughs from strong flours. In contrast, extensibility, resistance to extension, and extensigraph areas of doughs from weak flours were increased by adding fats.

Pomeranz et al (1968b) compared the effects of commercially available natural and modified soybean lecithins on rheological properties and breadmaking potentialities of untreated and petroleum-ether (PE) extracted flours. Adding alcohol-soluble phosphatides lowered the amylograph temperature and the hot-paste viscosity peak. Hydroxylated phosphatides increased farinograph dough development times, valorimeter values, and mixograph times. No correlation could be established between bread quality and the effects of phospholipids on rheological properties.

[1]Graduate research assistant and research professor, respectively, Department of Food Science and Human Nutrition, Washington State University, Pullman, WA 99164-6376.
[2]Present address: Department of Nutrition and Food Science, University of Kentucky, Lexington, KY 40506-0054.

In a related study, Tao and Pomeranz (1968) studied the effects of shortening, refined corn oil, and wheat-flour lipids (total, nonpolar, and polar) on rheological properties of dough. The lipids were added to seven hard red winter (HRW) wheat flours comparable in milling extraction and protein contents but varying widely in protein quality. Total (unfractionated) and nonpolar wheat-flour lipids substantially increased the length of time needed to reach the point of minimum mobility in the farinograph and mixograph. Water absorption was unaffected, and mixing tolerance was improved by adding nonpolar or total free lipids. The baking strength of the flour from which lipids were extracted had no effect on the contribution of the lipids to mixing characteristics. Nonpolar and total flour lipids exerted similar effects on untreated flour and PE-extracted flour; they increased mixing time and tolerance. The temperature of peak hot-paste viscosity (as assessed by amylograph) was lowered by about 4°C by the addition of 2% flour lipids. Nonpolar lipids substantially increased peak viscosity; polar lipids had little effect. Attempts to examine the effects of lipids on alveograph characteristics using a modified procedure (Shogren et al 1963) were unsuccessful. The procedure called for the addition of shortening and mineral oil in the dough, and therefore masked the possible effects on dough properties of adding wheat flour lipids. In the absence of added shortening and oil coating, the results were erratic. A modified procedure in our laboratory that includes automatic recording and computation of alveograph results (Addo et al 1990) and an improvement in the manometric device permits the handling of dough pressures in excess of 200 mm of water, thereby eliminating the need for those lipids in the dough formulation.

The objective of the present study was to establish the effects of wheat flour lipids and added lipids on alveograph characteristics.

## MATERIALS AND METHODS

### Materials

An HRW wheat (cv. Montana) from crop year 1988 was grown in Richland, Washington. The wheat was milled on a Miag Multomat mill into a patent (white) flour. The flour contained 12.9% protein (N × 5.7) and 0.38% ash (14% mb). A commercial soft wheat flour marketed as White Spear (8.9% protein and 0.41% ash, 14% mb) was obtained from Fisher Flour Mills, Seattle, Washington. A laboratory-milled durum flour (12.2% protein and 0.91% ash, 14% mb) was obtained from the U.S. Department of Agriculture Agricultural Research Service WWQL in Pullman, Washington.

Commercial products used were vegetable shortening (partly hydrogenated, with a melting point of 41°C) and corn, peanut, palm, and canola oils.

Commercial lecithin (LEC) and hydroxylated-lecithin (OH-LEC) were obtained from Central Soya, Fort Wayne, Indiana. The sample of EMG was from Grindsted Products, Inc., Industrial Airport, Kansas. The pure fatty acids (lauric, myristic, palmitic, heptadecanoic, stearic, oleic, linoleic, and linolenic) were from Sigma Chemical Co., St. Louis, Missouri.

Organic solvents were analytical reagent grade. Solutions were prepared from analytical reagent-grade compounds.

### Analytical Methods

Ash, moisture, and protein contents of the flours were determined by AACC methods 08-11, 44-15A, and 46-12, respectively (AACC 1983).

### Lipid Extraction

Lipids were extracted overnight with PE (bp 35–60°C) in a Soxhlet apparatus. The solvent in the PE extract was removed under vacuum in a rotary evaporator, and the extracted lipids were stored at −80°C under nitrogen until ready to use.

### Fractionation of Flour Lipids

Flour lipids (0.5-g lots) were fractionated by silicic acid column chromatography into nonpolar and polar lipids. Silicic acid (60-g lots, 100 mesh) for chromatography of lipids from Mallinkrodt, New York, were washed with distilled water and dried at 120°C for 4 hr. The silicic acid was then washed twice with 160 ml of a chloroform-methanol mixture (7:1), once with 160 ml of chloroform-methanol 15:1, and finally with 200 ml of chloroform (Pomeranz et al 1966). The slurry was poured into the column, which was fitted at the bottom with a tightly packed glass wool plug, the silicic acid being packed under nitrogen pressure to a constant volume. Columns measured 500 mm in length and 20 mm in diameter, in which 60 g of silicic acid (when fully packed down) occupied a length of approximately 200 mm. Nonpolar lipids were eluted with 200–250 ml of chloroform and polar lipids with 200–250 ml of methanol. Completion of elution was ascertained by thin-layer chromatography (TLC). The polar lipids were further subfractionated into acetone-soluble (glycolipids-rich) and acetone-insoluble (phospholipids-rich) fractions as follows: Acetone (5 ml) was added to about 1 g of the polar lipids in a test tube; the mixture was vortexed and then centrifuged to separate the acetone-soluble fraction from the acetone-insoluble fraction. The acetone-soluble fraction was evaporated to dryness under nitrogen. Both fractions were then stored at −80°C under nitrogen until ready to use.

### Thin-Layer Chromatography

The lipid extracts were separated and characterized by TLC on precoated silica gel G plates (20 × 20 cm and 0.25 mm thick) from Fisher Scientific Co., Springfield, New Jersey. Lipid spots were developed in a mixture of chloroform, methanol, and water (65:25:4) or a mixture of hexane-ethyl, ether, ethanol, and methanol (80:18:2:1) (Chung et al 1978). Spots were located and visualized by spraying dried plates with a molybdenum blue spray (Sigma) to detect phospholipids, followed by heating for 4–10 min at 120°C to detect glycolipids and all nonspecific lipids (Dittmer and Lester 1964). Lipids separated by TLC were tentatively identified by comparing $R_f$ values with those of standards and by use of the specific spray, molybdenum blue. The nonpolar lipid standards were: 1,3-dipalmitin, tristearin, trilinolein, and linoleic acid. The polar lipids were: monogalactosyl diglyceride, L-α-phosphatidylcholine, L-α-phosphatidylethanolamine, and L-α-phosphatidylserine (Sigma).

### Gas Chromatography

Lipid samples for fatty acid profile analysis by gas chromatography (GC) were prepared as follows: Approximately 100 mg of lipid was butylated by heating the sample in a 0.5*N* butanolic potassium hydroxide solution on a hot plate for 2 min. The resulting mixture was cooled to room temperature, followed by the addition of 3 ml of 12.5% boron trifluoride-butanol reagent (Supelco Inc., Bellefonte, PA), and heated again for 3 min. Upon cooling, fatty acid butylesters were extracted from the reaction mixture with hexane and analyzed directly (Iverson and Sheppard 1977). The fatty acid butylesters were analyzed using a Varian 2700 GC equipped with a flame ionizing detector on a stainless steel column (1.8 m × 2 mm i.d.) containing 10% SP2330 impregnated on 100- to 120-mesh Chromosorb W-AW (Supelco). Carrier gas (nitrogen) flow rate was set at 20 ml/min, and the injector and detector temperatures were 250°C. Initial column temperature was set at 150°C for 1 min and then increased to 200°C at a rate of 20°C/min. Column temperature was maintained at 200°C for the complete elution of all fatty acid butylesters. Identification of individual fatty acids was based on the elution profile of standards (Sigma), and quantitation was based on detector response relative to known concentrations of standards (AOCS 1989).

### Reconstitution of Defatted Flours

Defatted flours were air-dried at room temperature in a hood until solvent odors were no longer detected and then were sifted through a sieve (100-mesh, 149-μm openings). Defatted flours were reconstituted (whenever appropriate) by thorough blending with lipids in a mortar. No mechanical device, such as a Stein

mill, was used to avoid damage to the starch and possible effect on alveograph characteristics (Chung et al 1982). The moisture contents of the defatted or reconstituted flours were raised to that of the original flours by placement in a cold room for about 6 hr at 4°C and 98% rh.

### Alveograph Testing

Alveograph measurements were performed under conditions of constant dough water content and mixing times using the standard AACC Method 54-30 (AACC 1983). For data recording and storage, the modified procedure of Addo et al (1990) was used. The following alveograph parameters were automatically recorded by a computer software program: the maximum overpressure needed to blow the dough bubble, *P*, which is an index of resistance to extension; the average abscissa at bubble rupture, *L*, an index of dough extensibility; the deformation energy, *W*, an index of dough strength; and the minimum point on the first derivative of the alveogram, *DM*, which is inversely related to pan breadmaking quality.

### Statistical Analysis

All determinations were made at least in duplicate. Data were analyzed using the statistical analysis system described by the SAS Institute (1985).

## RESULTS AND DISCUSSION

Protein, rheological, and baking properties of wheat flours used for study are summarized in Table I. These samples represent a wide range in all of the variable parameters measured. Results are expressed on a 14% moisture basis.

The effects of defatting and reconstituting on alveograph characteristics of three wheat flours are summarized in Table II. In all three flours, PE defatting resulted in significant changes in dough properties, as reflected by a decrease in *L* (except for durum) and increases in *P*, *W*, and *DM*. Although measurements *W* and *DM* reflect opposite properties (Addo et al 1990), both parameters increase with defatting. The increase in *W* is the result of its dependence on both *P* and *L* and therefore is not a true reflection of the changes brought about by defatting as by the other two single parameters. Reconstituting the PE-defatted flours with the original flour lipids restored alveograph properties. Alveograms of the three flours showing similar effects of defatting and reconstituting are compared in Figure 1. The source of flour lipids had no effect on the properties of the reconstituted flours (Table II). Lipids from any of the three flours could be added to bring about the restoration, at least in part, of almost all alveograph characteristics of each defatted flour.

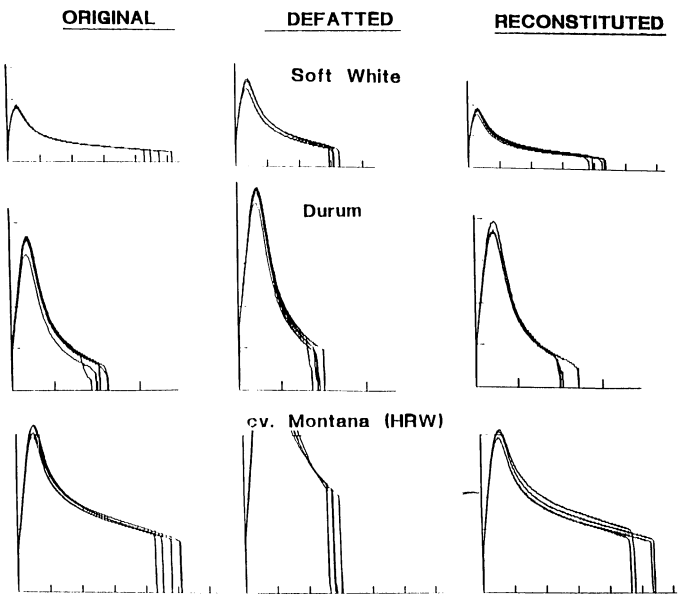


**Fig. 1.** Alveograms of original, defatted, and reconstituted soft white, durum, and hard red winter (HRW) wheat flours.

Characteristics for *P*, and in general *L* and *DM*, were restored (although there was no significant change in the *L* parameter for durum). Changes in *W* were less consistent. Reconstitution did not completely restore *W* for the HRW wheat, and addition of HRW lipids to soft or durum flour significantly lowered *W* below its initial level. The interrelationships among *P*, *L*, and *W* are not strictly linear. Small changes in either *P* or *L* may have disproportionate effects on *W*. Even averaging results from automatic recording and computation of five sample pieces from two separately mixed doughs cannot entirely eliminate effects of differences in shapes of alveograph curves, calculated results of *W*, and the relatively large variations in *L* values.

The effects of increasing levels of flour lipids on alveograph characteristics of the defatted HRW flour are shown in Figure 2. The curves shown were drawn by the computer. Adding two or four times the amounts of free flour lipids to the PE-defatted flour resulted in an effect that differed from that of defatting. In general, adding excess lipids changed alveograph parameters of defatted flour little beyond the restoration effect of the original flour lipids.

To identify the flour component(s) responsible for changes in dough properties, the original HRW flour lipids were fractionated into nonpolar and polar fractions on silicic acid columns. The polar fraction was further fractionated into acetone-soluble (AS) (glycolipids-rich) and acetone-insoluble (AI) (phospholipids-rich) fractions. Comparisons of components of the total lipids and of the lipid fractions, as indicated by TLC, are shown in Figures 3–5. The nonpolar lipid fraction was characterized by the presence of free fatty acids and glycerides, whereas the polar fractions were essentially free of those components, as shown by developing the plates in a nonpolar solvent system (Fig. 3). A comparison of the same lipid fraction using a more polar solvent system to induce migration of the polar components is shown in Figure 4. The nonpolar fraction appeared to contain small amounts of polar components. The polar fractions contained mostly phospholipids and glycolipids. The presence of phospholipids in the AI fraction and the lack of those components in the AS fraction is confirmed by the TLC shown in Figure 5. Spraying the plate with molybdenum blue (specific for phospholipids) without charring revealed phospholipids in the AI fraction but very little or none in the AS fraction. The glycolipids in the AS fraction are revealed after charring the plate (Fig. 4).

The effects on alveograph characteristics upon adding lipid fractions at the levels found in the original flour to the defatted flour are summarized in Table III. As stated earlier, the total unfractionated lipids largely restored practically all alveograph

**TABLE I**
**Analytical, Rheological, and Breadmaking Properties of Wheat Flours**

| Flour | Protein (N × 5.7, %) | Water Absorption (%) | Mixing Time (min) | Alveograph Characteristics | | | | Loaf Volume ($cm^3$) |
|---|---|---|---|---|---|---|---|---|
| | | | | *P* (mm) | *L* (mm) | *W* ($\times 10^{-4}$ J) | *DM* | |
| Commercial soft white | 8.9 | 53.0 | 2.2 | 43 | 110 | 115 | 2.21 | 660 |
| Durum | 12.2 | 65.0 | 2.1 | 93 | 52 | 139 | 5.53 | 520 |
| cv. Montana (hard red winter) | 12.9 | 70.0 | 3.5 | 126 | 119 | 481 | 3.47 | 1,000 |

properties. *W* was partially restored. However, total fractionated lipids were not as effective as total unfractionated lipids in restoring those properties. The results suggest either that the fractionation procedure resulted in some alteration in the chemical properties of the lipids or that certain essential constituents were not fully recovered. The nonpolar fraction, in general, largely restored alveograph parameters in a manner similar to reconstituting with total fractionated lipids. However, the results were not the same for all parameters. Thus, *L* was restored to a lesser degree and *W* to a greater degree by addition of the nonpolar lipids than by the total fractionated lipids. The polar fraction and its subfractions had little or no effect on the properties of the defatted flour. These results support earlier findings by Tao and Pomeranz (1968) that the effects of the lipid fractions on dough mixing properties differ from the effects of the lipids on baking properties such as loaf volume and retention of crumb freshness. Daftary et al (1968), Ponte and De Stefanis (1969), De Stefanis and Ponte (1976), and Chung et al (1982) reported that polar lipids, especially glycolipids, improved loaf volume, whereas nonpolar lipids, particularly the free fatty acids, were detrimental. In the present study, parameter *DM*, which is inversely related to the flour's breadmaking properties, is almost restored after adding nonpolar lipids and virtually unaltered after adding polar lipids. Apparently, different reaction mechanisms

**TABLE II**
**Effects of Defatting and Reconstitution on Alveograph Characteristics[a] of Wheat Flours**

| Flour and Flour Lipids | Alveograph Characteristics | | | |
|---|---|---|---|---|
| | *P* (mm) | *L* (mm) | *W* ($\times 10^{-4}$ J) | *DM* |
| cv. Montana (HRW)[b] | | | | |
| Original | 126 b | 119 a | 481 e | 3.47 c |
| Defatted | 247 a | 69 b | 560 a | 10.21 a |
| Reconstituted (original lipids) | 127 b | 121 a | 509 c | 3.53 c |
| Reconstituted (soft white lipids) | 132 b | 116 a | 499 d | 3.73 b |
| Reconstituted (durum lipids) | 129 b | 124 a | 545 b | 3.36 c |
| Commercial soft white (White Spear) | | | | |
| Original | 43 b | 110 a | 115 b | 2.21 b |
| Defatted | 66 a | 74 c | 139 a | 2.94 a |
| Reconstituted (original lipid) | 45 b | 103 b | 115 b | 2.20 b |
| Reconstituted (HRW lipids) | 40 b | 114 a | 107 c | 2.06 c |
| Durum | | | | |
| Original | 93 b | 52 a | 139 c | 5.53 c |
| Defatted | 117 a | 46 a | 165 a | 7.03 a |
| Reconstituted (original lipids) | 95 b | 52 a | 149 b | 5.60 b |
| Reconstituted (HRW lipids) | 90 b | 51 a | 130 d | 5.53 c |

[a] Means of two determinations. Means followed by the same letter within flours are not significantly different at the $P = 0.01$ level.
[b] Hard red winter.

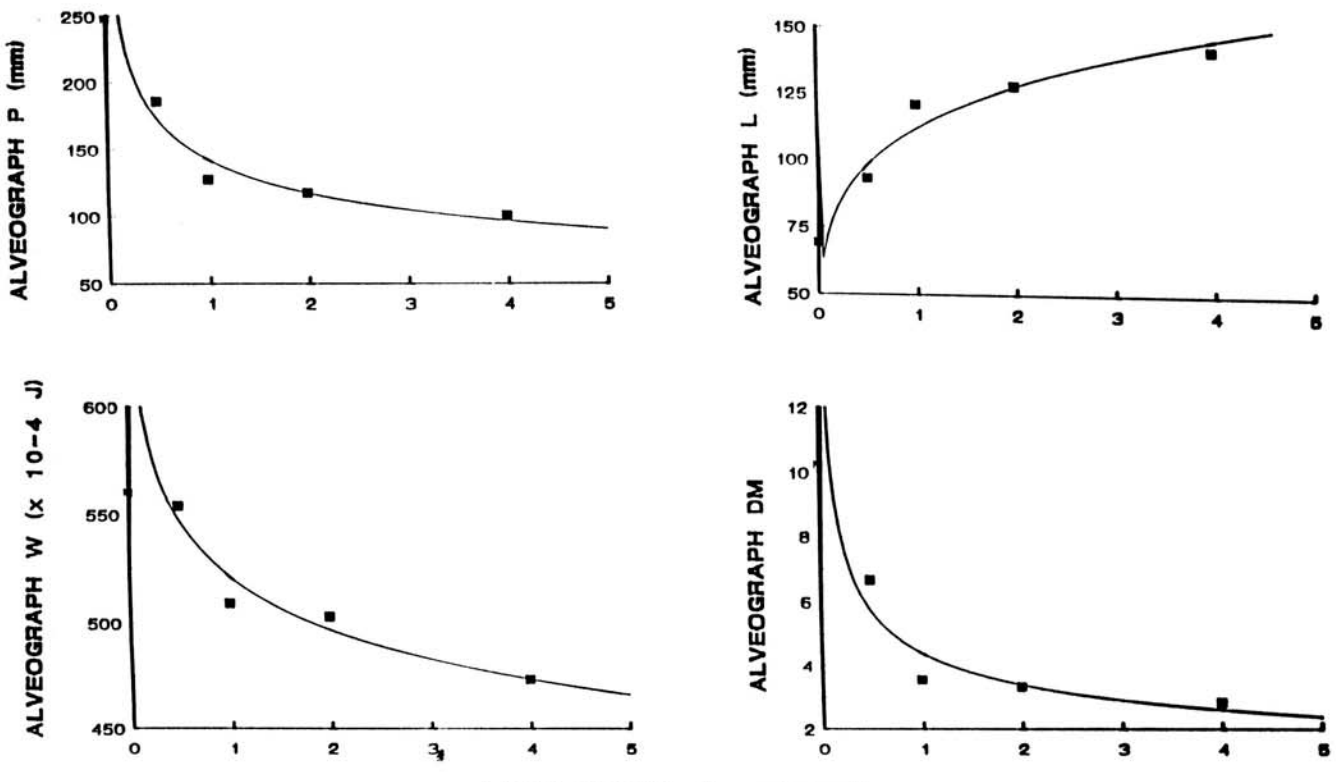


**Fig. 2.** Effects of lipid level on alveograph characteristics of defatted hard red winter wheat flour.

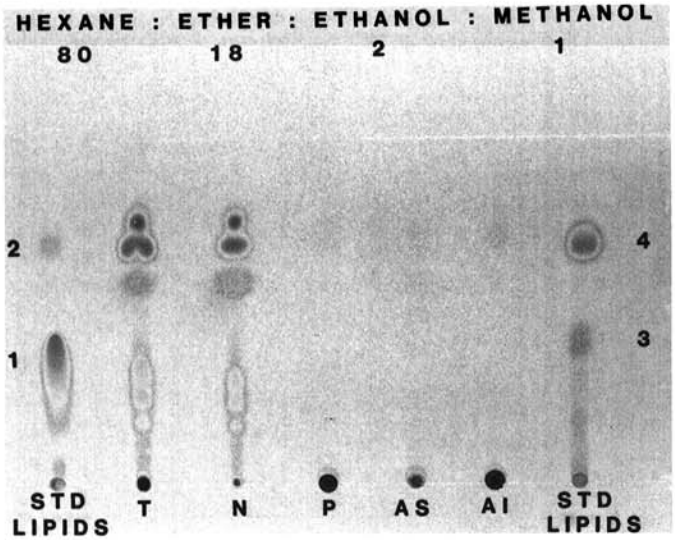


**Fig. 3.** Thin-layer chromatogram of standard lipids and flour lipids developed with a mixture of hexane, diethyl ether, 95% ethanol, and methanol (80:18:2:1, v/v/v/v), charred with 1.3% molybdenum oxide in 4.2*M* $H_2SO_4$. 1 = linoleic acid, 2 = 1,3-dipalmitin, T = total lipids, N = nonpolar lipids , P = polar lipids, AS = acetone-soluble lipids, AI = acetone-insoluble lipids, 3 = trilinolein, and 4 = tristearin.

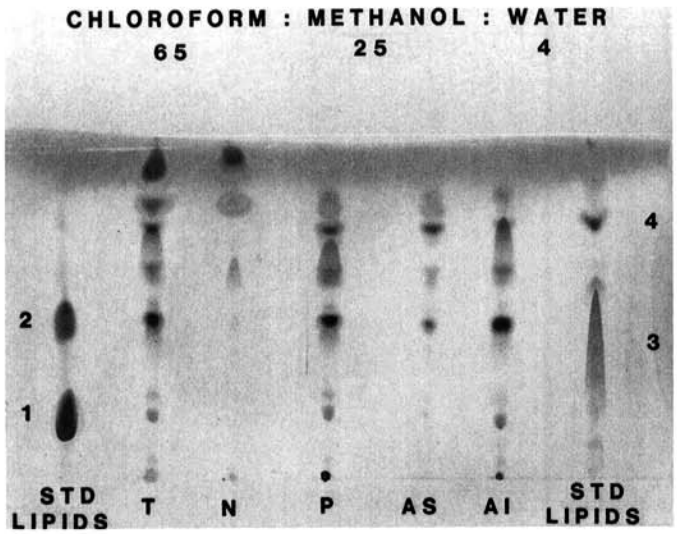


**Fig. 4.** Thin-layer chromatogram of standard lipids and flour lipids developed with a mixture of chloroform, methanol, and water (65:25:4, v/v/v), charred with 1.3% molybdenum oxide in 4.2*M* $H_2SO_4$. 1 = L-α-phosphatidylcholine, 2 = L-α-phosphatidylethanolamine, T = total lipids, N = nonpolar lipids, P = polar lipids, AS = acetone-soluble lipids, AI = acetone-insoluble lipids, 3 = L-α-phosphatidylserine, 4 = monogalactosyldiglyceride.

account for the effects of lipids during various stages of the breadmaking process.

Inasmuch as the nonpolar fractions, particularly the free fatty acids, have been shown to be detrimental to baking quality (Daftary et al 1968, De Stefanis and Ponte 1976), the effects of commercial free fatty acids on alveograph characteristics of the defatted HRW flour were examined (Table IV). Linoleic and (to a limited extent) linolenic acids were most effective in restoring alveograph characteristics. Palmitic, stearic, and oleic acids were largely ineffective. However, it should be emphasized that the levels of free fatty acids added were far in excess of levels normally present in native wheat flour, and relating the results obtained from such a model system to the situation in an untreated bread must be interpreted with caution. Nonetheless, the fact that linoleic acid, which is the predominant fatty acid and the main substrate for lipoxygenase in flour lipids, could partially restore alveograph characteristics of the defatted flour raises questions as to the possible mechanisms involved. Also, the fact that the total free fatty acids could only partially restore alveograph characteristics seems to indicate that other components, in addition to free fatty acids, may be responsible for the observed changes in dough properties.

The effects of vegetable oils and of shortening on alveograph characteristics of the defatted flour are presented in Table V. The 2% level of shortening was selected for comparison with

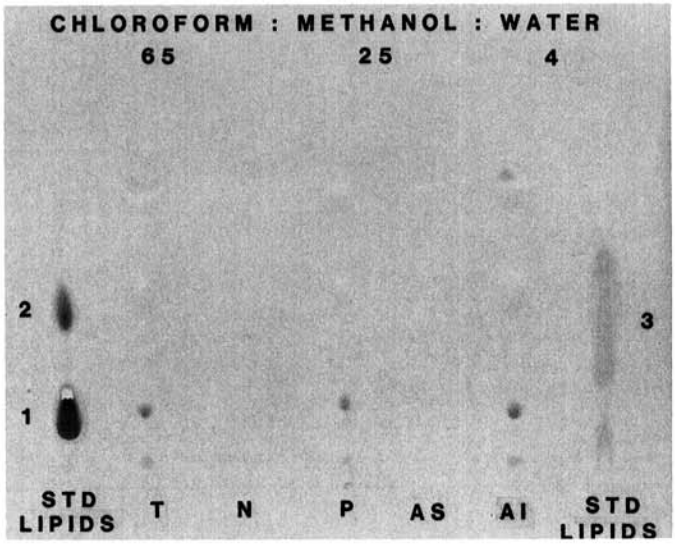


**Fig. 5.** Thin-layer chromatogram of standard lipids and flour lipids developed with a mixture of chloroform, methanol, and water (65:25:4, v/v/v) sprayed with 1.3% molybdenum oxide in 4.2*M* $H_2SO_4$. 1 = L-α-phosphatidylcholine, 2 = L-α-phosphatidylethanolamine, T = total lipids, N = nonpolar lipids, P = polar lipids, AS = acetone-soluble lipids, AI = acetone-insoluble lipids, 3 = L-α-phosphatidylserine, 4 = monogalactosyldiglyceride.

**TABLE III**
**Effects of Fractionated (Flour) Lipids on Alveograph Characteristics[a] of Petroleum-Ether Defatted Flour[b]**

| Flour | Lipid Level (%) | Alveograph Characteristics | | | |
|---|---|---|---|---|---|
| | | *P* (mm) | *L* (mm) | *W* ($\times 10^{-4}$ J) | *DM* |
| Original | | 126 e | 119 a | 481 f | 3.47 e |
| Defatted | | 247 a | 69 d | 560 a | 10.21 b |
| Reconstituted with: | | | | | |
| Original lipids | 1.00 | 127 e | 121 a | 509 e | 3.53 e |
| Fractionated-recombined lipids | 1.00 | 148 d | 107 b | 537 c | 4.18 d |
| Nonpolar lipids | 0.70 | 151 d | 98 c | 510 e | 4.13 d |
| Polar lipids | 0.30 | 225 c | 69 d | 524 d | 10.30 a |
| AS[c] polar lipids | 0.17 | 233 b | 71 d | 561 a | 8.02 c |
| AI[d] polar lipids | 0.13 | 238 b | 66 d | 553 b | 8.02 c |

[a] Means of two determinations. Means followed by the same letter are not significantly different at the $P = 0.01$ level.
[b] cv. Montana (hard red winter).
[c] Acetone soluble.
[d] Acetone insoluble.

that used in baking, and the 1% level of commercial oils for comparison with the level of oils in wheat flour. Vegetable oils low and high in saturated and unsaturated fatty acids (Table VI) did not restore alveograph characteristics. Palm oil, which has a relatively high level of saturated fatty acids, was slightly effective. Similar findings were reported by Frazier et al (1977), who showed that dough relaxation and mixing times of a normal flour could not be fully restored upon defatting and reconstituting with coconut oil. In this study, commercial shortening was by far the most effective in restoring alveograph characteristics. The shortening contained unknown amounts of emulsifiers, including monoglycerides and diglycerides.

To determine whether the presence of other lipid components (in addition to the triglycerides) such as emulsifiers in the shortening could affect the alveograph characteristics, the effects of adding shortening alone and in combination with some commercial emulsifiers were examined. The levels of lecithin and hydroxylated lecithin were twice those of EMG to reflect the differences in their effects on functional breadmaking potential (Schuster and Adams 1984). Results show that none of the

**TABLE IV**
**Effects of 1% Individual or Total Free Fatty Acids on Alveograph Characteristics[a] of Petroleum-Ether Defatted Flour[b]**

| Flour | Alveograph Characteristics | | | |
|---|---|---|---|---|
| | *P* (mm) | *L* (mm) | *W* ($\times 10^{-4}$ J) | *DM* |
| Original | 126 h | 119 a | 481 g | 3.47 h |
| Defatted | 247 b | 69 c,d | 560 c | 10.21 b |
| Reconstituted with: | | | | |
| Original lipids | 127 h | 121 a | 509 d | 3.53 h |
| Palmitic acid (16:0) | 282 a | 62 e,f | 601 a | 11.68 a |
| Stearic acid (18:0) | 237 c | 60 f,g | 497 e | 9.52 c |
| Oleic acid (18:1) | 231 d | 56 g | 490 f | 7.87 d |
| Linoleic acid (18:2) | 174 g | 73 c | 478 g | 4.82 g |
| Linolenic acid (18:3) | 185 f | 65 d,e | 440 h | 5.47 e |
| Total free fatty acids[c] | 191 e | 85 b | 569 b | 5.41 f |

[a] Means of two determinations. Means followed by the same letter are not significantly different at the $P = 0.01$ level.
[b] cv. Montana (hard red winter).
[c] Fatty acids added in proportions found in original flour lipids.

**TABLE V**
**Effects of Commercial Vegetable Oils and Shortening on Alveograph Characteristics[a] of Petroleum-Ether Defatted Flour[b,c]**

| Flour | Alveograph Characteristics | | | |
|---|---|---|---|---|
| | *P* (mm) | *L* (mm) | *W* ($\times 10^{-4}$ J) | *DM* |
| Original | 126 g | 119 a | 481 g | 3.47 g |
| Defatted | 247 a | 69 f | 560 d | 10.21 a |
| Reconstituted with: | | | | |
| Original lipids | 127 g | 121 a | 509 f | 3.53 g |
| Corn oil | 231 c | 80 c | 609 a | 8.30 c |
| Peanut oil | 240 b | 71 e,f | 588 b | 8.70 b |
| Palm oil | 210 e | 77 c,d | 542 e | 7.68 e |
| Canola oil | 224 d | 75 d,e | 569 c | 8.00 d |
| Shortening | 172 f | 91 b | 507 f | 6.42 f |

[a] Means of two determinations. Means followed by the same letter are not significantly different at the $P = 0.01$ level.
[b] Levels added were: original lipids and oils, 1%; shortening, 2%.
[c] cv. Montana (hard red winter).

**TABLE VI**
**Percent Distribution of Fatty Acids in Wheat Flour Lipids, Commercial Vegetable Oils, and Shortening Used for Reconstitution[a]**

| Sample | Saturated | | | Unsaturated | | | | S:U[b] | Grand Total |
|---|---|---|---|---|---|---|---|---|---|
| | 16:0 | 18:0 | Total | 18:1 | 18:2 | 18:3 | Total | | |
| cv. Montana (HRW)[c] | 11.3 c | 0.7 d | 12.0 c,d | 9.1 e | 38.9 b | 2.0 b | 50.0 d | 0.24 c | 62.0 d |
| Canola oil | 4.3 e | 1.3 c | 5.6 e | 47.9 a | 17.4 e | 9.2 a | 74.5 a | 0.08 e | 80.1 c |
| Peanut oil | 10.5 d | ... | 10.5 d | 43.0 b | 31.0 c | 0.7 c,d | 74.7 a | 0.14 d | 85.2 b |
| Corn oil | 10.2 d | 1.2 c | 13.9 c | 22.6 d | 49.4 a | 0.4 d,e | 72.4 b | 0.19 c,d | 86.3 b |
| Palm oil | 34.4 a | 5.8 b | 40.2 a | 38.0 c | 7.6 f | 0.2 e | 45.8 e | 0.88 a | 86.0 b |
| Shortening | 15.1 b | 9.5 a | 24.6 b | 40.4 c | 25.1 d | 1.0 c | 66.5 c | 0.37 b | 91.9 a |

[a] Means of two determinations. Means followed by the same letter are not significantly different at the $P = 0.01$ level.
[b] Ratio of saturated to unsaturated.
[c] Hard red winter.

**TABLE VII**
**Effects of Commercial Emulsifiers[a] on Alveograph Characteristics of Petroleum-Ether Defatted Flour[b]**

| Flour | Alveograph Characteristics[c] | | | |
|---|---|---|---|---|
| | *P* (mm) | *L* (mm) | *W* ($\times 10^{-4}$ J) | *DM* |
| Original | 126 g | 119 a | 481 h | 3.47 i |
| Defatted | 247 a | 69 f | 560 d | 10.21 a |
| Reconstituted with: | | | | |
| Original lipids | 127 g | 121 a | 509 e,f | 3.53 i |
| Shortening | 172 d | 91 c,d | 507 f | 6.42 e |
| Lecithin | 247 a | 85 e | 685 a | 9.70 b |
| Lecithin + shortening | 165 e | 92 c,d | 500 g | 6.04 f |
| OH-LEC[d] | 229 b | 89 d,e | 641 b | 9.13 c |
| OH-LEC+ shortening | 163 e | 94 c | 512 e | 5.20 g |
| EMG[e] | 217 c | 89 d,e | 615 c | 8.50 d |
| EMG + shortening | 151 f | 100 b | 505 f,g | 5.11 h |

[a] Levels added were: shortening, 2%; lecithin and OH-LEC, 0.2%; EMG, 0.1%.
[b] cv. Montana (hard red winter).
[c] Means of two determinations. Means followed by the same letter are not significantly different at the $P = 0.01\%$ level.
[d] Hydroxylated lecithin.
[e] Ethoxylated monoglycerides.

**TABLE VIII**
**Effects of Ethoxylated Monoglycerides (EMG), Shortening, and Corn Oil on Alveograph Characteristics of Defatted Flour[a]**

| Flour | Alveograph Characteristics[b] | | | |
|---|---|---|---|---|
| | *P* (mm) | *L* (mm) | *W* ($\times 10^{-4}$ J) | *DM* |
| Original | 126 f | 119 a | 481 f | 3.47 g |
| Defatted | 247 a | 69 e | 560 c | 10.21 a |
| Reconstituted with: | | | | |
| Flour lipids | 127 f | 121 a | 509 e | 3.53 g |
| Shortening | 172 d | 91 c | 507 e | 6.42 d |
| EMG | 217 c | 89 b | 615 a | 8.50 b |
| EMG + shortening | 151 e | 100 b | 505 e | 5.11 f |
| Corn oil | 231 b | 80 d | 609 b | 8.30 c |
| Corn oil + EMG | 175 d | 87 c | 531 d | 5.63 e |

[a] cv. Montana (hard red winter).
[b] Means of two determinations. Means followed by the same letter are not significantly different at the $P = 0.01\%$ level.

emulsifiers alone could restore alveograph characteristics of the defatted flour (Table VII), thus confirming the earlier results obtained with polar fractions from the flour lipids. However, the emulsifiers in combination with shortening restored alveograph characteristics in the order LEC < OH-LEC < EMG. The effects were more pronounced than by adding shortening alone. The results provide evidence that triglycerides in combination with polar lipids were probably responsible for the restoration of alveograph characteristics. This may also explain some of the observed effects of the nonpolar fraction, which was characterized by the presence of small amounts of polar components (Fig. 4). The results were further confirmed (Table VIII) when corn oil in combination with EMG brought about a restoration of alveograph characteristics similar to that brought about by adding shortening alone to the defatted flour.

While the qualitative effects of defatting and reconstitution of flours were consistent, no complete restoration of alveograph characteristics by the addition of lipids could be attained. Several reasons for the incomplete restoration can be proposed:

1. Not all lipids fractionated by column chromatography were recovered (eluted).
2. Some modification of functional properties occurred as a result of extraction and/or fractionation of flour lipids.
3. There are differences between flour lipids and commercial lipids.
4. Some modification of the flours takes place as a result of treatment with PE.
5. The incomplete restoration of alveograph parameters is due to a combination of 1–4.

Finally, whereas shortening has been reported to have a detrimental effect on loaf volume and crumb grain of defatted flour (Pomeranz et al 1968a), the dough-handling properties of the latter, as measured by the alveograph, are improved when shortening is added alone or in combination with emulsifiers. These results demonstrate that the mechanism of the effects of shortening on dough rheology, as measured on an alveograph, like the effects of lipid fractions, differs from the mechanism of the shortening effects in breadmaking.

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