Defatted and Reconstituted Wheat Flours. V. Bread-Making Response to Shortening of Flour Differentially Defatted by Varying Solvent and Temperature[1]

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ABSTRACT

A composite hard red winter wheat flour with good loaf volume potential and medium mixing and oxidation requirement was defatted at 4–75° C by four solvents. The solvents extracted the following amounts of lipids: Skellysolve B, 0.89–1.05%; benzene, 0.96–1.12%; acetone, 1.02–1.13%; and 2-propanol, 0.96–1.32%. The variation in total lipid yields was almost entirely due to polar lipids, the amounts of nonpolar lipids extracted being nearly constant. The defatted flours contained little residual nonpolar lipids but various amounts of polar lipids. An increase in mixing time of the defatted flours depended mainly on the quantity and the types of lipids in the flour and on the specific effect of 2-propanol on flour components other than lipids. Loaf volume (LV) was affected by the quantity of flour lipids and the addition of 3% shortening. Without shortening, removing up to about 1% total lipids had little effect on LV, but removing more than 1% increased LV significantly. The data suggested a possible minimum LV near 0.2% polar lipid removal from flour containing practically no nonpolar lipids. With 3% shortening, removing lipids had a detrimental effect on LV, most significantly at 1.13% total (0.46% polar) lipid removal. In the absence of native flour lipids, shortening had detrimental effects on LV and on crumb grain; these effects were linearly related to the amount of polar lipids removed from the defatted flour. In conclusion, in flour containing no nonpolar lipids, LV was governed by the quantity of polar lipids and shortening and by the interaction of the two.

Shortening, or fat, is one of the essential ingredients in commercial baking. The term "shortening effect" is used to describe an increase in loaf volume (LV) of up to 25% and an improvement of crumb grain from the addition of 0.7–3% shortening or hardened vegetable fat (Bell et al 1977). Although ample indirect evidence suggests the interaction of shortening and native flour lipids (Chung and Pomeranz 1977, Daftary et al 1968, Lin et al 1974) we know of no systematic study on the changes in LV response to shortening that also considers the various amounts of native flour lipids present in wheat flour. In several reports on lipids in wheat flours and their function in bread making (Mecham 1971, Morrison 1976, Pomeranz and Chung 1978, Ponte and Baldwin 1972), the role of native flour lipids has been demonstrated by adding extracted lipids to the flours and then baking the reconstituted flours. MacRitchie and Gras (1973) reported that the apparently conflicting effects of flour lipids on bread making may have resulted from variations in baking formulations (including shortening or other lipid-related additives such as surfactants), different amounts and types of lipids in flours (originally present, removed, or added), and methods of extracting and restoring the lipids.

We have established the conditions for differentially extracting lipids from flours by a combination of solvents and extraction temperatures that do not damage the LV potentials of the flours reconstituted with the extracted lipids (Chung et al 1977). Heat treatment without solvent had little effect, if any, on water absorption, mixing time, loaf volume, and bread crumb grain (Chung et al 1977). In the present study, we examined the role of native flour lipids in bread making by differentially removing lipids from flour rather than by differentially adding these lipids to the defatted flour. The effect of shortening on bread-making properties of such differentially defatted flours would explain, at least in part, the mechanism of shortening effects in relation to the native flour lipids present in wheat flour.

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MATERIALS AND METHODS

Materials

Regional Baking Standard (RBS-74), an untreated, straight-grade flour, was milled in the laboratory with an Allis mill from a composite grist of many hard red winter wheat varieties harvested at many locations throughout the Great Plains in 1973. The flour contained 13.4% protein (N × 5.7) and 0.41% ash (14% mb) and had a good LV potential and medium mixing and oxidation requirements.

Organic solvents were analytical reagent grade, and solutions were prepared from analytical reagent-grade compounds. Silicic acid for chromatography of lipids was from Mallinckrodt (New York), and shortening was a commercial vegetable product (Crisco) that is partly hydrogenated and has a melting point of 41° C.

Analytical and Baking Procedures

Protein, ash, and moisture contents were determined by AACC methods. The 10-g baking procedure has been described elsewhere (Shogren et al 1969). The oxidants used in this study were potassium bromate (5 ppm) and ascorbic acid (50 ppm). The amount of yeast per 10 g of flour ranged from 0.2 to 0.275 g, depending on the yeast's activity as measured by a gassing power test (Shogren et al 1977). Doughs were fermented for 150 min and proofed to a dough height of 3.6 cm (unextracted control dough) at 30° C. Bakes were replicated five times. The loaves were cooled to 25° C, and LV was determined by the displacement of dwarf rapeseed. Loaves were cut and their crumb grains were evaluated as satisfactory, questionable, or unsatisfactory.

Extraction and Fractionation of Flour Lipids

Conditions for lipid extraction were selected to result in little, if any, damage to the bread-making ability of the flour and in the widest possible range in content and composition of extracted lipids.

Lipids were extracted for 2 hr from 30 g (db) of flour and 240 ml of solvent—Skellysolve B (mostly *n*-hexane), benzene, acetone, or 2-propanol—in a water-bath shaker (Lab-line Instruments, No. 3581) that provided a gentle horizontal agitation (Chung et al 1977). Extraction temperature was maintained by the water bath at 30, 45, 60, or 75° C for Skellysolve B, benzene, and 2-propanol; 75° C was omitted for acetone because of its low boiling point.

Using 2-propanol as an extractant for 2 hr at 4° C, we established two additional extracting conditions, one using a water bath shaker, the other a wrist-action shaker (Burrel Corp., Pittsburgh, PA). Solvents were evaporated from the lipid extracts at reduced pressure below 40° C. Lipids were purified from the dried extracts by redissolving the extracts in petroleum ether and centrifuging the mixture (Chung et al 1978). The defatted flours were air dried at room temperature in a hood until the solvent odors were no longer detected and were then sifted through a 100-mesh sieve (149-μm openings).

Flour lipids were fractionated by silicic acid column chromatography (Pomeranz et al 1966) into nonpolar and polar lipids, with chlorofrom and methanol, respectively, as eluting solvents. Lipid extractions were replicated six times and fractionations four times. Total recovery from silicic acid column fractionation ranged from 89.7 to 98.4%; average recovery was 95.4%.

RESULTS AND DISCUSSION

Flour Lipids

Use of solvents with different solubility parameters (Hoy 1970) showed that the extractability of unfractionated, or total, lipids increased with increased parameters (Table I and Fig. 1). The solvents extracted the following amounts of lipids: Skellysolve B, 0.89–1.05%; benzene, 0.96–1.12%; acetone, 1.02–1.13%; and 2-propanol, 0.96–1.32%. Lipid extractability for all solvents increased significantly with temperatures of extraction. 2-Propanol at 4° C extracted significantly more lipids with the vigorous wrist-action shaker than with the bath shaker, which provided a gentle horizontal agitation. Analysis of variance and Fisher's least significant difference (LSD) were used to determine statistical significance. For total and polar lipids, solvent (S) and temperature (T) effects were significant at the 0.01 level and T × S interaction effects insignificant; for nonpolar lipids none of the effects was significant. A test for LSD further confirmed the significant effects of solvent and temperature on amounts of lipids extracted. At the 0.05 level, the LSD values were 0.06, 0.12, and 0.036% for total, nonpolar, and polar lipids, respectively. For all solvents, with each increase in total extracted lipids the amounts of nonpolar lipids were about the same, whereas the amounts of polar lipids increased significantly. Therefore, all defatted flours probably contained nearly no nonpolar lipids and various amounts of polar lipids.

Water Absorption and Mixing Requirements

Although Johnson (1928) reported that extracting flours with ether did not affect the water absorption, in our experiments the removal of lipids increased water absorption, an average of 4.0 percentage points for defatted flours with 3% shortening and 3.3 percentage points for defatted flours without shortening (Table II). In earlier experiments (Chung et al 1977), in which the extracted lipids were added back to the defatted flours, we found that water absorption was increased an average of 1.5 and 1.0 percentage points, respectively, for reconstituted RBS-74 flours with and without added shortening. In the present work, therefore, about one third of the increase in water absorption could be attributed to the extraction process rather than to low lipid levels. Tests for LSD showed that differences in water absorption larger than 0.79% were significant at the 0.05 level and differences larger than 1.06%, at the 0.01 level.

In general, mixing time was longer for defatted flour than for unextracted flour (Table II). Effects of T, S, shortening (Sh), and the interactions T × S and S × Sh were significant at the 0.01 level. The temperature effect was most significant, the interaction T × S and solvent effects next, and the shortening effect least significant. The interaction T × Sh effect was significant only at the 0.05 level, and the interaction T × S × Sh was insignificant. According to the LSD test, differences in mixing time longer than 0.214 (< 1/4) min were significant at the 0.05 level and differences longer than 0.283 (< 3/8) min at the 0.01 level.

For each solvent, mixing time tended to increase with temperature of lipid extraction. Mixing time was affected least by temperature when the most nonpolar solvent, Skellysolve B, was used as an extractant; mixing time was affected by the type of solvents most at the highest extraction temperature. Adding 3% shortening significantly affected mixing time only for the control

TABLE I
Lipids Extracted from RBS-74[a] Flour with Four Solvents

Solvent[b]	Extraction Temperature (° C)	Lipids (%, db)[c]		
		Total	Nonpolar	Polar
Skellysolve B (7.27)	30	0.89	0.66	0.23
	45	0.92	0.67	0.25
	60	1.00	0.70	0.30
	75	1.05	0.71	0.34
Benzene (9.16)	30	0.96	0.66	0.30
	45	1.04	0.69	0.35
	60	1.06	0.68	0.38
	75	1.12	0.70	0.42
Acetone (9.62)	30	1.02	0.63	0.39
	45	1.08	0.66	0.42
	60	1.13	0.67	0.46
2-Propanol (11.44)	4	0.96	0.63	0.33
	4[d]	1.07	0.67	0.40
	30	1.18	0.64	0.54
	45	1.24	0.67	0.57
	60	1.30	0.68	0.62
	75	1.32	0.68	0.64

[a] A regional baking standard of hard red winter wheat harvested in 1973.
[b] Solvent solubility parameters at 25 °C, according to Hoy (1970) are given in parentheses; that for Skellysolve B is the solubility parameter of hexane.
[c] Averages of six extractions for total lipids (overall standard deviation = 0.005) and of four fractionations into nonpolar and polar lipids (overall standard deviation = 0.009).
[d] Lipid extraction by a wrist-action shaker; all others, a gentle horizontal shaker.

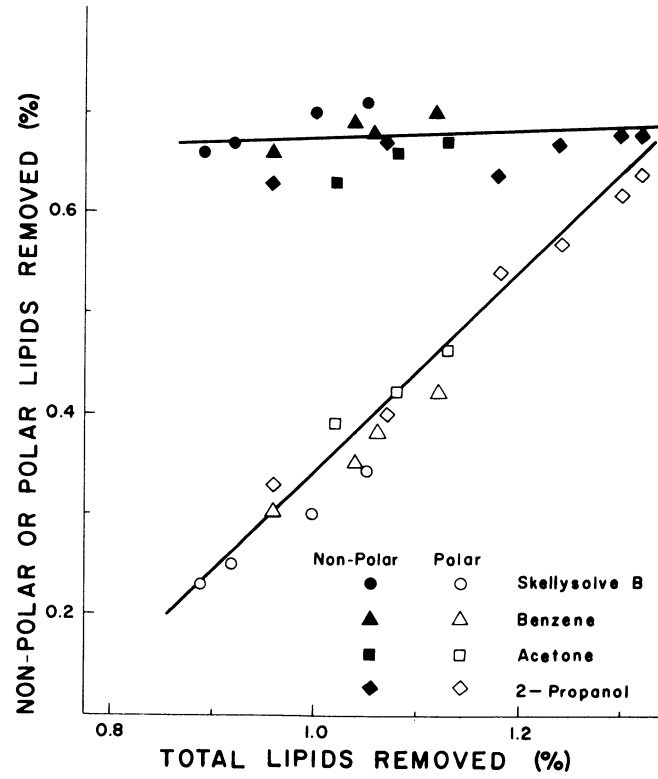

Fig. 1. Nonpolar and polar lipids removed plotted against total lipids removed at various temperatures from flour by Skellysolve B, benzene, acetone, and 2-propanol.

flour and flours defatted with Skellysolve B at 45 and 60° C, with acetone at 60° C, and with 2-propanol by water-bath shaker at 4° C.

Increased mixing time was previously reported for defatted flours (Bloksma 1966, Mecham and Pence 1957). We examined the possible relationship between mixing time and the amount of lipids removed from flour. In this experiment, with complete baking formulation except for shortening, we found that the results could be separated into two groups represented by a composite curve for Skellysolve B, benzene, and acetone and another curve for 2-propanol (Fig. 2). The composite showed that mixing time increased slightly, although statistically significantly, with the removal of up to 1% total lipids and substantially with the removal of over 1% total (0.3% polar) lipids. The increase in mixing time, like that in water absorption, was partly due to the extraction process; in earlier tests, we found that mixing time was slightly higher for reconstituted flours than for untreated flour (Chung et al 1977). In contrast to the composite curve, the one for 2-propanol showed a sharp increase in mixing time when lipid removal was 1.3% rather than 1%. The results suggest that 2-propanol has a specific effect on mixing time, possibly by modifying flour components (presumably proteins) other than lipids, that results in the 4-min difference in mixing time for a change in lipid

TABLE II
Water Absorption (14% mb) and Mixing Characteristics of Defatted Flours[a]

Solvent	Extraction Temperature (° C)	Water Absorption (%) with Shortening at 0%	Water Absorption (%) with Shortening at 3%	Mixing Time (min) with Shortening at 0%	Mixing Time (min) with Shortening at 3%
None (control)	···	65.9	63.4	4¼	4⅜
Skellysolve B	30	68.8	65.4	4¾	4⅞
	45	67.0	66.1	4¾	5.0
	60	67.8	66.5	4⅞	5¼
	75	68.5	66.8	5¼	5⅜
Benzene	30	69.0	67.4	4½	4½
	45	69.3	67.6	5¼	5⅛
	60	69.6	68.7	5¼	5¼
	75	71.7	68.8	7⅜	7⅜
Acetone	30	69.2	67.6	5½	5½
	45	69.2	67.7	6	6
	60	69.9	68.4	7¾	7⅛
2-Propanol	4	68.1	66.6	4¼	4½
	4[b]	68.8	66.8	4⅜	4½
	30	68.6	66.9	4¾	4¾
	45	69.6	68.0	5.0	5.0
	60	70.3	68.1	5.0	5.0
	75	70.0	68.8	9.0	8⅞

[a]Averages of five values; overall standard deviation: 0.567 for water absorption and 0.095 < ⅛ for mixing time.
[b]Lipid extraction by a wrist-action shaker; all others, a gentle horizontal shaker.

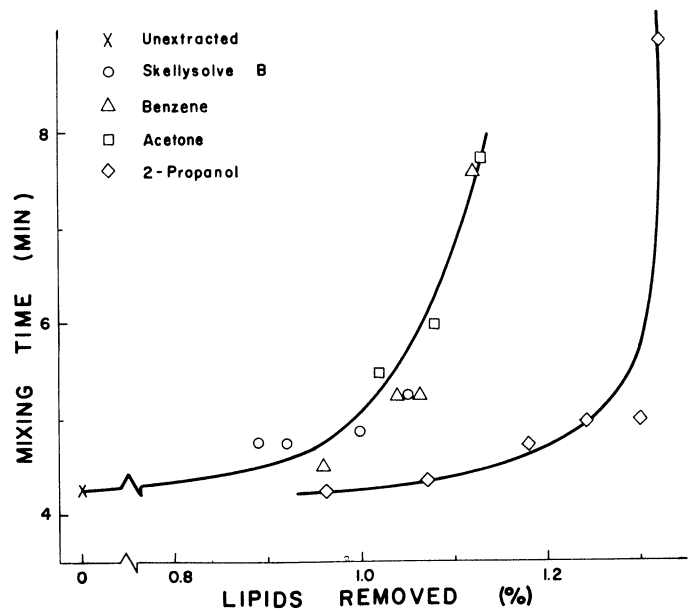

Fig. 2. The effect on mixing time of lipid removal by four solvents at various temperatures in tests with no added shortening.

TABLE III
Loaf Volume and Crumb Grain of Bread Baked with 10 g of Defatted Flours

Solvent	Extraction Temperature (° C)	Loaf Volume (cc)[a] with Shortening at 0%	Loaf Volume (cc)[a] with Shortening at 3%	Crumb Grain[b] with Shortening at 0%	Crumb Grain[b] with Shortening at 3%
None (control)	···	69.3	85.8	U	S
Skellysolve B	30	69.7	73.1	Q-U	Q-U
	45	71.4	71.1	Q	Q-U
	60	70.5	69.1	Q-S	U
	75	70.0	65.8	Q	U
Benzene	30	71.5	70.3	Q-S	U
	45	72.9	67.5	Q-S	U
	60	74.2	66.1	Q-S	U
	75	73.8	64.5	Q	U
Acetone	30	70.5	66.4	Q	U
	45	71.9	66.2	Q-S	U
	60	73.6	62.5	Q-S	U
2-Propanol	4	72.6	69.4	S	U
	4[c]	72.3	65.0	Q-S	Q-U
	30	74.6	65.6	Q-S	Q
	45	75.4	66.3	Q-S	Q
	60	78.4	70.6	S	Q-S
	75	78.4	72.8	Q-S	Q-S

[a]Averages of five values; overall standard deviation = 1.56.
[b]S = satisfactory, Q = questionable, U = unsatisfactory (the higher the number, the poorer the crumb grain).
[c]Lipid extraction by a wrist-action shaker; all others, a gentle horizontal shaker.

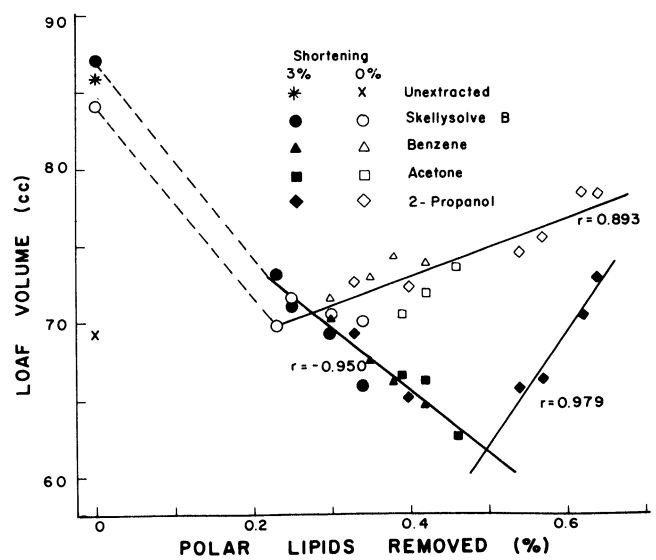

Fig. 3. The effect of removal of polar lipids on loaf volume of bread baked from defatted flour (containing almost no residual nonpolar lipids) with no shortening and with 3% shortening. The closed and open circles at 0% removal of polar lipids represent LV of breads baked with or without shortening, respectively, from flour defatted by Skellysolve B at 30° C and then reconstituted with the extracted polar lipids to the original level. The line connecting these circles to the next circles is dotted because no data exist for the intermediate levels of polar lipid removal.

concentration of only 0.02%. The exact mode of 2-propanol effect on mixing time is not known at this time.

Loaf Volume and Crumb Grain

According to the analysis of variance, LV (Table III) was affected significantly at the 0.01 level by Sh most and by S next but insignificantly by T. All the interactions (Sh × S, S × T and Sh × S × T, listed in decreasing order of significance) had significant effects on LV. The LSD test showed that differences in LV greater than 2.2 cc were significant at the 0.05 level and differences greater than 2.9 cc were significant at the 0.01 level.

In a no-shortening formula, LV was greater for defatted flours than for the unextracted control flour, although increases in LV were statistically insignificant for flours with Skellysolve B extractions at all four temperatures and with benzene and acetone extractions at 30° C. Loaf volume was generally lowest for flours with Skellysolve B extractions and highest for flours with 2-propanol extractions; LV increased, in general, with increased extraction temperature for each solvent.

In the presence of shortening, LV was significantly smaller for defatted flour, irrespective of treatment, than for the control flour; LV decreased substantially, from 85.8 cc for the control to 73.1 cc for the least defatted flour (by Skellysolve B at 30° C). For flours defatted with Skellysolve B, benzene, and acetone, LV decreased with increasing extraction temperature; with 2-propanol, LV first decreased and then increased (Table III).

Loaf volume was affected by the quantity of lipids in the flour; LV responses to lipid removal were related to the quantity of lipids removed and also to the presence of shortening. Because levels of extracted polar lipids, but not of nonpolar lipids, increased significantly with increase in total extracted lipids (Fig. 1), LV response to lipid removal was related directly to the quantity of polar lipids removed from the defatted flours containing little residual nonpolar lipids. Consequently, the general relationship between LV and either total or polar lipids removed was basically similar. In the absence of shortening, LV increased linearly (r = 0.893) with polar lipid removal of 0.23–0.64% (Fig. 3), although LV (78.4 cc) of bread baked with the most defatted flour (by 2-propanol at 75° C) was still smaller than LV (85.8 cc) of the control flour baked with 3% shortening. Loaf volumes above 71.5 cc were significantly greater, at the 0.05 level, than the LV of the control flour (69.3 cc). A 71.5-cc LV corresponded to 0.3% polar (1.0% total) lipids removed; thus removing more than 0.3% polar lipids increased LV significantly.

For comparison, the flour defatted by Skellysolve B at 30° C was reconstituted with the extracted polar lipids; the reconstituted flour contained nearly no nonpolar lipids but the original level of polar lipids. The average LV of the reconstituted flour was 84 cc in the absence of shortening. We did not have baking data for defatted flours with polar lipid removal between 0.23 and 0%. Although the exact level of lipid removal for the minimum LV in the absence of shortening was not known, we could visualize a U-shaped LV-polar lipid removal curve with minimum level at around or somewhat below the 0.2% level of polar lipid removal.

In the presence of shortening, LV decreased linearly (r = −0.950) with removal of 0.23–0.46% polar lipids or (r = −0.981) with removal of 0–0.46%, and then increased (r = 0.979) with removal of 0.54–64% polar lipids (Fig. 3). The two straight lines intersecting at 0.49% polar (1.14% total) lipid removal indicate that, possibly, minimum LV would be obtained from the defatted flour from which practically all nonpolar lipids and about 0.5% polar lipids were removed (Fig. 3). The level of lipid removal for minimum LV may vary for flours that differ in composition and bread-making quality. Unlike mixing time, which had a separate curve, LV of flours defatted by 2-propanol at 4° C fell on a composite line for Skellysolve B, benzene, and acetone, indicating that a decrease in LV was primarily due to lipid removal of up to 1.14% total lipids (0.49% polar lipids). However, we do not exclude other possible causes for minimum LV, because the increase in LV at removal of polar lipids above 0.49% occurred with flours that were defatted by 2-propanol at 30° C or higher temperatures.

Our series of differentially defatted flours is comparable to that

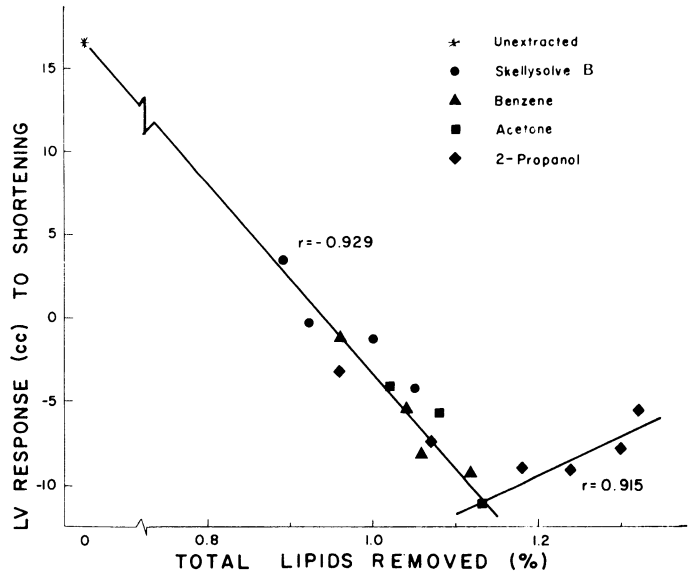

Fig. 4. The effect of total lipid removal on loaf volume (LV) response to shortening. LV response to shortening was calculated by substracting the LV of bread baked without shortening from the LV of bread baked with shortening for comparably defatted flours.

of MacRitchie (1977), in which polar lipids were added to defatted flours. MacRitchie (1977) reported that in bread made from 30.2 g (db) of flour defatted by chloroform, LV decreased with the addition of up to about 0.1 g (0.33% of the flour weight) of polar lipids and increased with the addition of 0.1–0.43 g (0.33–1.42% of the flour weight) of polar lipids. He observed a generally U-shaped LV-lipid content curve for a series of defatted flours baked without shortening.

In the absence of shortening, LV of the control bread (baked from unextracted flour) was 69.3 cc and of defatted flour reconstituted with polar lipids, 84.0 cc. The large LV difference may be due to the detrimental effect of nonpolar lipids in the control bread. In the presence of shortening, however, no significant LV difference between the control bread (85.8 cc) and the bread from flour reconstituted with polar lipids (87.0 cc) was found. The addition of shortening appeared to counteract or mask (in a yet inexplicable manner) the detrimental effect of nonpolar lipids.

The addition of shortening improved crumb grain substantially for the control bread but not for the bread baked from defatted flours. Shortening had, in general, a detrimental effect on crumb grain of defatted flour (Table III).

Loaf volume response to shortening (Fig. 4) was calculated by subtracting the LV of bread baked without shortening from the LV of bread baked with shortening for comparably defatted flours. For unextracted flour containing native flour lipids, adding 3% shortening significantly increased LV by 16.5 cc (a 23.8% increase). When 0.89% total lipids were removed, adding shortening increased LV by 3.4 cc (a 4.9% increase); when 0.92% total lipids were removed, shortening had no significant effect on LV. We estimated from Fig. 4 that shortening effects were insignificant at the 0.05 level for flours from which 0.90–0.96% total lipids were removed. Shortening had a detrimental effect on LV for all defatted flours from which more than 0.96% total lipids were removed. Loaf volume response to shortening decreased linearly (r = −0.929) with total lipid removal from 0–1.13% and slightly increased (r = 0.915) with total lipid removal from 1.13–1.32% (Fig. 4).

A similar relationship was established between LV response to shortening and the amount of polar lipids removed from the flour (not shown): LV response to shortening decreased linearly (r = −0.937) with removal of 0.23–0.46% or (r = −0.855) with removal of 0–0.46% polar lipids and slightly increased (r = 0.937) with 0.46–0.64% polar lipid removal; the minimum point was at 0.48% polar lipid removal. Insignificant shortening effects were shown for

flours from which 0.24–0.30% polar lipids were removed.

At 1.14% total (0.49% polar) lipid removal, LV and LV response to shortening were minimum. A possible explanation for the minimum LV response could be that removal of more than about 0.5% polar lipids facilitates interactions among proteins.

In conclusion, in flour containing no nonpolar lipids, LV is governed by the quantity of polar lipids and shortening, and by their interaction. Therefore, flour polar lipids play a major role in positive LV and crumb grain response of bread to 3% shortening. The results reported here did not take into account one of the most significant variables, inherent differences among wheat flours. The effects of those differences on the shortening response are reported in a subsequent paper in this series.

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