Effect of Native Lipids, Shortening, and Bread Moisture on Bread Firming[1]

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ABSTRACT

Moisture content was found to be inversely proportional to the rate of firming. Low-moisture bread, which firmed at a fast rate, had a slow rate of starch retrogradation. Therefore, firming is not simply a function of starch retrogradation, but both are influenced, in different ways, by bread moisture content. Shortening was quite effective in decreasing the firming rate of bread made with intact flour. However, it had no effect on firming rate when used with defatted flour. Therefore, shortening acts through the flour lipids. The influence of flour lipids on firming rate is concentration dependent. At low levels, total free lipids enhanced firming and at higher levels the lipids delayed firming. This pattern is a mirror image of the effect of total free lipids on loaf volume.

The firming of bread has been studied extensively for many years. The overall staling phenomenon has been reviewed by a number of authors (Willhoft 1973, Maga 1975, Knightly 1977, Kulp and Ponte 1981). Most of the work on firming has dealt with the role of starch and its retrogradation since Katz (1934) showed by X-ray that starch again became semicrystalline during storage time. The fact that bread becomes firm during roughly the same time suggested that the two phenomena might be related.

Schoch (1965) attributed the firming of bread crumb during staling to physical changes in the amylopectin fraction of the wheat starch granules. This conclusion was based mainly on the fact that the amylose fraction retrograded rapidly during the initial cooling of the bread. However, it is well known that shortening is effective in reducing the rate of firming (Ghiasi et al 1984). This is particularly noteworthy because shortening does not complex with amylose (Krog 1971).

More recently, thermal analysis has been used to study starch retrogradation (Axford and Colwell 1967, Colwell et al 1969, Longton and LeGrys 1981, Fearn and Russell 1982, Russell 1983, Ghiasi et al 1984, Zeleznak and Hoseney 1986). Longton and LeGrys (1981) and Zeleznak and Hoseney (1986) reported that recrystallization of starch is profoundly affected by the moisture content of the starch gel or bread. A similar conclusion had been reached by Hellman et al (1954) from X-ray data.

Those studies indicate that water plays an integral role in controlling retrogradation. One of the purposes of this study was to determine how water affects the firming of bread. Shortening is known to greatly affect (lower) the firming rate of bread but does not react with starch. A second goal of this study was to determine how shortening affects the rate of firming.

MATERIALS AND METHODS

Flour used in this study was obtained from Ross Mills, Wichita, KS. It had a protein content of 11.8% and an ash of 0.46%. The same flour was defatted with petroleum ether to remove total free lipids. The lipids were recovered by removal of the solvent under reduced pressure and reconstituted by the procedure of Pomeranz et al (1965). The lipids were not heated above 35° C. The shortening used was from Durkee (D-10) and the monoglyceride was Amidan ES, Grindsted Products, Inc. The manufacturer states that it is 90% α-monoglyceride.

Bread was baked by the standard pup loaf procedure of Finney (1984), using 180 min of fermentation. The bread was stored in polyethylene bags at 25° C for five days. Firmness was measured by a compression test with an Instron universal testing machine at one, three, and five days of storage. Compression was the force (g) required to compress the crumb 6 mm, with a probe of 35 mm diameter. The reported mean firmness values represent measurements taken from the center of three slices per loaf, two or three loaves per treatment.

Bread of Different Moisture Contents

Full formula bread was baked as described above. Baking time was incrementally shortened (9 and 12 min) to produce higher moisture loaves. In general, the volume of a loaf of bread reaches its maximum in about 8 min in the oven, after which the bread is dried and browned. To reduce the moisture content of the bread, the standard 24 min bake was followed by fan-drying (with the crust intact) for times ranging from 2 to 26 hr. After drying, the loaves were placed in plastic bags and stored for one to seven days. A compression test (Instron) was performed at several intervals during that time, as well as a two-stage moisture determination (including crust) on one slice from each loaf. Compressibility and moisture data represent mean values from three loaves per treatment per day. Bread samples that had been dried for 3.5, 19, and 26 hr were frozen and lyophilized for differential scanning calorimetry (DSC) analysis.

Bread Containing Different Levels of Monoglyceride and Shortening

Bread was baked with 3, 6, and 12% shortening and 3% shortening plus 0.5% monoglyceride. In a second study, bread was baked with no shortening but with 0.5, 1.0, and 1.5% monoglyceride and 1.5% monoglyceride plus 3% shortening. These breads were tested for firmness.

DSC

DSC was performed on lyophilized bread crumb. Preliminary experiments had shown that lyophilization did not change the DSC values. In the aluminum DSC sample pan, two parts water were added to one part crumb. Samples were heated at 10° C/min, from 7 to 127° C. The melting of amylopectin is represented by an endothermic peak on the DSC thermogram (Von Eberstein et al 1980). The areas of the amylopectin endotherms were measured by planimetry and converted to enthalpy (cal/g). All samples were at least duplicates, and the standard deviation of ΔH values was 0.06 cal/g. The enthalpy value is proportional to the amount of recrystallized starch in the bread crumb sample. The onset temperature for these samples did not change.

RESULTS AND DISCUSSION

Effect of Bread Moisture on Firming Rate

Reduced bake time and fan-drying both altered bread moisture contents. When bake time was less than 15 min, the loaves collapsed slightly. However, bake times of 9 and 12 min produced breads with higher moisture. The fan-drying method was effective but took much longer than anticipated to drive water off. Even in the bread dried for 4 hr, the moisture and the rate of firming were equivalent to those of the control (undried) bread. When drying time was extended to 26 hr, the reduction in moisture was only 8%.

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The moisture values reported were averaged across the entire storage period for each treatment (Table I). In all cases bread moisture decreased slowly during storage in the plastic bags. This might be expected because most plastic bags are permeable to moisture vapor.

The rate of firming was found to be a function of bread moisture content. As moisture content was decreased, rate of firming increased, rising dramatically in the bread dried for 19 and 26 hr (26 and 22% moisture). Relative to the control bread (31% moisture), firming was retarded in the higher moisture (35 and 37% moisture) breads (Fig. 1).

The rate of starch retrogradation, calculated from DSC enthalpy values (Fig. 2), did not correlate with the rate of firming in the same bread samples. The firming rate of 22% moisture bread was extremely rapid. However, starch retrogradation increased very little over the same time interval and, in fact, was the least of all the samples analyzed. In short, the fastest firming bread had the slowest retrogradation rate. Therefore, it is clear that firming is not simply a function of starch retrogradation.

The differences in retrogradation rate between the treatments are probably related to the differences in moisture content. Previous work (Zeleznak and Hoseney 1986) showed that the retrogradation rate in starch gels is a bell-shaped function of moisture content during aging. Retrogradation was minimal in starch gels of less than 20% moisture but increased sharply between 20 and 30%. Moisture differences appear to affect starch retrogradation rate in bread in much the same way. In the present study, the driest bread (22% moisture) gave significantly lower retrogradation values than the samples with 25 and 30% moisture. Thus, moisture differences appear to affect retrogradation rate in bread crumb just as in starch gels.

Effect of Shortening on Firming Rate

The firming rates of bread made from the unfractionated and defatted flours, with and without shortening, suggest that the antifirming action of shortening is dependent on the presence of the native flour lipids (Fig. 3). The well-known effect of shortening was shown with the unfractionated flour. However, there was no effect of shortening on the firming rate of the bread made from defatted flour. In addition, the unfractionated flour baked with no shortening gave bread that firmed at a slightly faster rate than similar bread baked from defatted flour containing no shortening. It appeared that the native lipids present in flour actually enhanced firming. When the native flour lipids were removed, firming was slightly retarded. This suggests that a shortening-lipid interaction is involved in retarding firming, and that the level of lipid present may be a critical factor.

Effect of Flour Lipids on Bread Firming

It has been shown that adding small amounts of polar lipids to defatted flour results in decreased loaf volume, whereas adding higher levels of polar lipids increases volume (MacRitchie and Gras 1973). It is thought that the effect of lipids on loaf volume involves their interaction with protein.

Reconstitution of defatted flour with low levels of total free lipids gave an increased firming rate compared to that of bread made from unfractionated or defatted flours (Fig. 3). To further examine the influence of total free lipid levels on firming rate, two (0.4 and 1.6%) levels of lipids were reconstituted with defatted flour (Fig. 4). As shown in Figure 5, the effect on firming rate is the

TABLE I
Bread Crumb Moisture

Bake Time (min)	Moisture (%)	Fan Drying (hr)	Moisture (%)
9	37.4	2	31.0
12	35.0	4	30.8
24	30.8	18	28.2
		19	25.9
		26	22.3

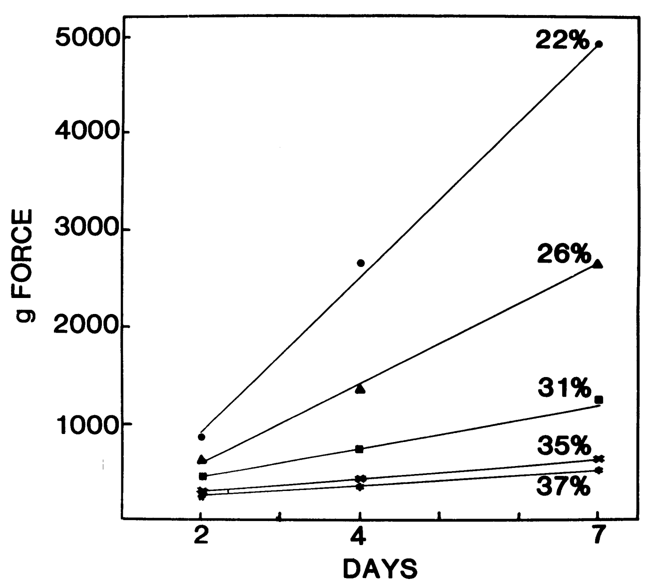

Fig. 1. Effect of bread moisture content on firming rate (% = moisture of bread).

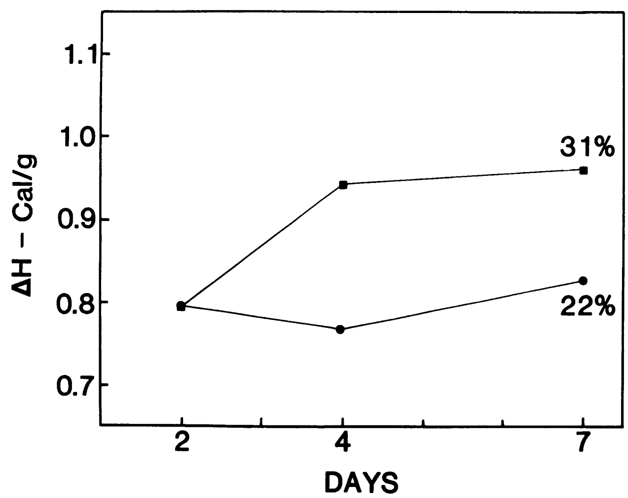

Fig. 2. Effect of moisture content on the rate of starch retrogradation (% = moisture of bread).

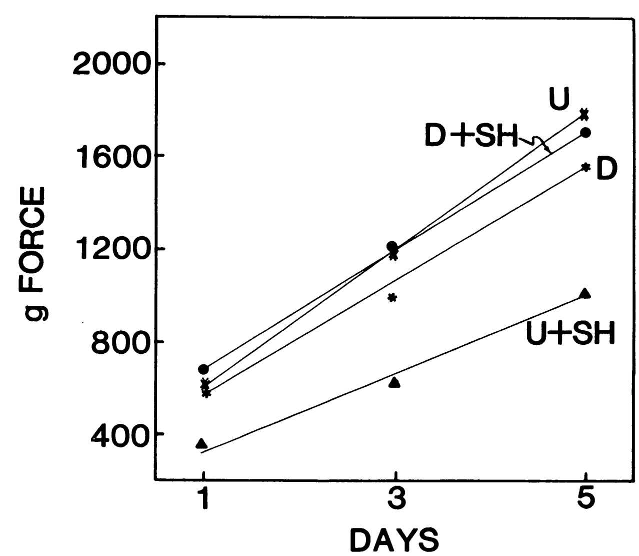

Fig. 3. Effect of defatted flour (**D**) and shortening (**SH**) on bread firming rate; **U** = untreated flour.

reverse of the effect on loaf volume. That is, low lipid levels (0.4%) caused an increase in firming rate and a decrease in loaf volume, when compared to the defatted flour (0%), the unfractionated flour (0.8% total free lipids), and the defatted flour reconstituted with the high level (1.6%) of total free lipids. This implies that the same mechanism, possibly a lipid-protein interaction, is affecting both parameters of the bread system.

DSC analysis of bread crumb enabled us to quantify starch retrogradation. Breads prepared from defatted flour and those prepared from unfractionated flour and baked with shortening had similar levels of starch retrogradation (Table II). However, those two breads firmed at different rates (Fig. 3). Those data support the suggested protein-lipid interaction. Both native lipids and shortening affect firming rate tremendously but have minimal effects on starch retrogradation. The slightly higher ΔH values for samples containing shortening probably reflect an overlap of the shortening and amylopectin melting peaks.

Effect of Shortening and Monoglycerides on Firming

Monoglycerides and other surfactants are widely used as antifirming agents. The mechanism by which they retard firming is not clear, although complexing with starch has been suggested (Krog 1971). However, shortening is also effective and it does not complex with starch. The objective of this part of the study was to compare the antifirming rates of shortening and monoglyceride alone or combined. If shortening cannot replace monoglycerides or vice versa, their mechanisms are probably different.

Bread was baked with higher levels of shortening in the formula to attempt to simulate the antifirming effect of monoglycerides. Although shortening at 3% was effective in reducing firming (Fig. 3), there was no significant improvement in firming rate with the higher levels of shortening. However, the addition of monoglycerides resulted in an improvement over the action of shortening alone (Table III). These data show that high levels of shortening cannot replace monoglycerides. Therefore, the action of monoglycerides is different from that of shortening.

When monoglyceride was tested with no shortening, its effectiveness continued to increase through the 1.5% level (Table IV). The addition of shortening to the highest level of monoglyceride did not give a significant improvement in firming rate. It appears from these results that monoglycerides can replace shortening but shortening cannot replace monoglycerides. Apparently, the mechanism by which they retard firming is different.

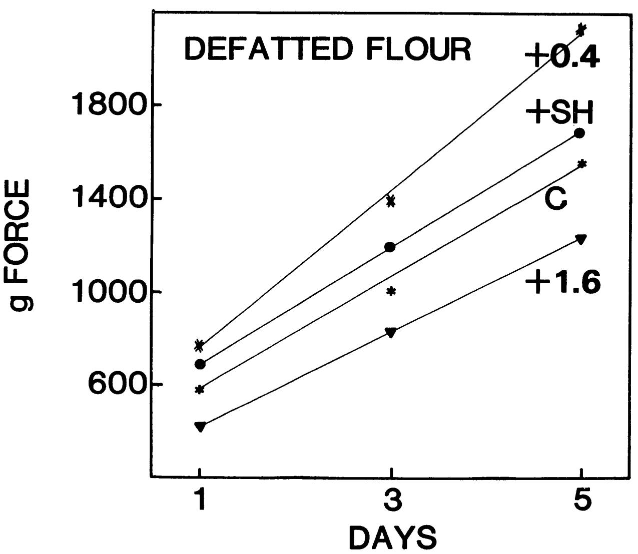

Fig. 4. Effect of adding native flour lipids, at the indicated levels, and shortening (+**SH**, 3%) to defatted flour on the firming rate of bread produced from the reconstituted flours.

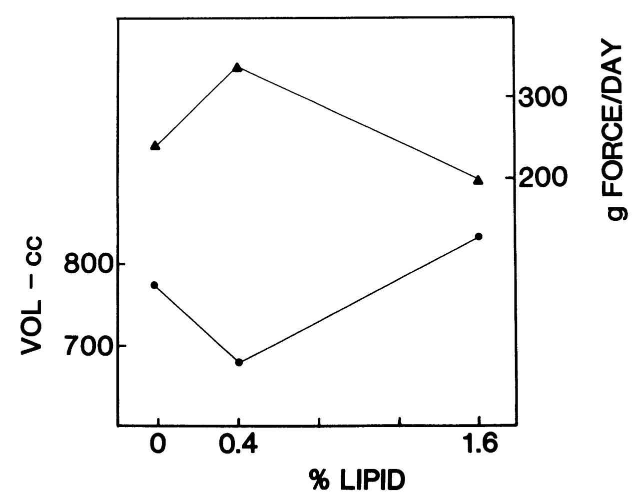

Fig. 5. Effect of reconstituted lipid level on bread loaf volume and firming rate.

CONCLUSIONS

The evidence presented here clearly shows that moisture content is a major factor regulating the firming rate in bread and is inversely proportional to rate of firming. It was also demonstrated that the fastest-firming bread has the slowest rate of starch retrogradation. Therefore, firming is not just a function of retrogradation, but both are influenced, in quite different ways, by bread moisture content. The nature of the mechanism by which water regulates firming rate requires much further study.

Shortening was quite effective in retarding the rate of bread firming. However, shortening had no effect on firming rate of bread made from defatted flour. This implies that shortening has its effect through the native flour lipids. It is clear that the monoglycerides are effective in reducing the firming rate by a mechanism that is different from that by which shortening reduces firming. It is also well known that monoglycerides complex with starch; however, it is not clear whether they also react with other flour components.

TABLE II
Enthalpy of Bread Crumb (cal/g)

Treatment	Day 1	Day 5	Day 7
Unfractionated flour	0.42	0.80	···
+ Shortening	0.49	0.88	0.99
Defatted flour	0.51	···	0.84
+ Shortening	0.59	···	0.91

TABLE III
Effect of Shortening Level on Loaf Firming

	Firmness (grams of force)		
Treatment	Day 1	Day 3	Day 5
3% Shortening	279	658	990
6% Shortening	282	693	966
12% Shortening	322	684	972
3% Shortening + 0.5% Monoglycerides	288	460	800

TABLE IV
Effect of Monoglyceride Level on Loaf Firming

	Firmness (grams of force)				
Treatment	Day 0	Day 1	Day 2	Day 5	Rate (g/day)
0.5% Monoglycerides	102	248	427	883	157
1.0% Monoglycerides	118	262	390	814	139
1.5% Monoglycerides	158	239	360	648	99
1.5% Monoglycerides + 3% Shortening	110	211	325	569	91

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