FIRMING COMPARISON OF WHITE PAN AND WHOLE WHEAT BREADS

by

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INTRODUCTION

Bread staling has been studied for many years but remains a serious problem to the baking industry. Bread not sold represents a direct economic loss to the baker while staling of bread after purchase leads to decreased consumer satisfaction.

Staling studies in the U.S. have largely dealt with white pan bread. However, production of this type of bread has declined in recent years while variety bread products have shown a substantial increase. Little information is available in the staling literature on wheat bread and other types of variety breads.

The objectives of the present study were to compare the firming properties of wheat bread with those of white pan bread. Breads were made with 100% whole wheat flour and also with several blends of whole wheat and white flours. The breads were stored under controlled conditions, and firming changes were measured utilizing the Instron Universal Testing machine. The effects of crumb-softening surfactants in these bread systems were also investigated. X-ray diffraction techniques were utilized to measure fundamental changes in the crumbs of the breads made during this investigation.

LITERATURE REVIEW

Bread Staling

Losses to the baking industry due to staling are enormous, which makes this a most serious problem. Ponte (1971) indicated that each year the wholesale stale bread returns run approximately 8% of total production. Furthermore, there is a loss to the consumer because of bread which becomes stale and unpalatable following its purchase. Therefore, understanding the staling process and trying to prevent this occurrence are quite important to the industry.

Since bread staling is a complex phenomenon, many changes take place in bread as it ages. Bechtel et al. in 1953 defined the staling process as "a term which indicates decreasing consumer acceptance of bakery products caused by changes in the crumb other than those resulting from the action of spoilage organisms". Geddes and Bice (1946), Bechtel (1955), and Axford and Colwell (1967) listed the characteristics of the staling process as follows: (1) change in taste and aroma through a general loss of flavor and development of "stale" taste in both crumb and crust; (2) increase in firmness of crumb; (3) increase in crumbliness of crumb; (4) increase in opacity of crumb; (5) increase in starch crystallinity as measured by X-ray diffraction; (6) decrease in water absorption capacity of crumb; (7) decrease in the amount of soluble starch that can be leached out; (8) decreased susceptibility of the starch to amylases; (9) change in thermal properties; and (10) increase in softness and leatheriness of crust.

Although the two major types of staling are crust and crumb staling, the majority of the staling studies have primarily involved changes in the bread crumb.

Bread consists predominantly of starch, protein, and water in the ratio of approximately 6:1:5. It also contains other minor components. Several or all constituents in bread probably have some effect on the firmness on aging and, therefore, some of the components will be discussed in further detail.

The theory of what causes bread to stale generally falls into the following three categories: (1) changes in gluten; (2) changes in starch; and (3) changes in the moisture distribution between starch and gluten. At this moment no one theory can be used to explain all facets of bread staling (Willhoft 1973). Roewe et al. (1982) stated that the overall firmness changes of variety breads were less rapid than those of white pan bread and they attributed this phenomenon by dilution of starch with other ingredients and/or grain components.

Role of Starch in Staling

Chemical and biochemical evidence indicates that the starch is a polysaccharide, a glucose polymer, which is in turn made up of two components - amylose and amylopectin. Amylose consists of a straight chain of glucose capable of twisting and coiling in space, while amylopectin has a branched tree-like structure (French 1973).

Starch plays an important role in bread staling. Numerous studies have been conducted to show that changes in starch constitute the primary cause of bread firmness. Subsequent to Katz (1930-1939) who showed the involvement of starch in staling, Meyer (1941) proposed the first theory to suggest that firming of the bread during staling was due to the retrogradation of the amylose. Schoch and French (1947) suggested the second, and more favorite theory, was that the hardening of the crumb structure during staling was due to physical changes occurring in the amylopectin fraction.

The evidence in support of Schoch's theory was as follows: (1) amylose gels rigidify rapidly, much faster than the rate at which bread becomes stale; and (2) amylose gels that have retrograded can be redissolved only by heating to a temperature of around 140°-150°C. Bread, in contrast, can be refreshened by heating it to a temperature of 50°-60°C; in the meantime, a retrograded amylopectin gel can be reverted under this condition.

Furthermore, Schoch (1965) proposed that part of the amylose diffused out of the starch granules during baking and retrograded by the time the loaf had cooled. In the fresh bread, the amylopectin molecules had expanded as much as the limited amount of water present would allow, leading to the formation of soft extensible granules. Then, the dilated amylopectin within the swollen granules gradually folded up and combined with each other during aging, causing the crumb to become rigid. The hardening of these previously soft, flexible granules were considered by Schoch to be the cause of the firming of the crumb. Therefore, he concluded that the stale bread consists of rigid granules embedded in the gel structure of the amylose.

To present a theory which questions Schoch's conclusion, Erlander and Erlander (1969) reported that the aging of the crumb was caused by aggregation of amylose as well as amylopectin. That process can be inhibited by a complex formation of the starch polymers with lipids and proteins. Another team of researchers, Kim and D'Appolonia (1977), demonstrated that both amylose and amylopectin contributed to the starch retrogradation over the first day of storage after which amylopectin alone controlled the retrogradation process.

Most people, therefore, seem to agree that starch retrogradation is considered to be the most important single factor in bread staling, while amylopectin alone is the principal component of starch which causes the staling process.

Effect of Starch Crystallization in Bread Staling

Extensive studies by Katz and co-workers (1930-1939), supported by those of many subsequent investigators, have established that starch in the crumb increases in crystallinity and becomes less soluble as bread ages.

As early as 1930, Katz demonstrated that starch granules possessed a degree of crystallinity and gave a characteristic X-ray pattern. Wheat starch showed an A-pattern which disappeared on gelatinization. On aging, either an A-pattern or a B-pattern developed, depending on the moisture content. For bread, Katz observed similar behavior except that a V-pattern occurred after baking; this was later assigned to complex formation of monoglyceride with single amylose helices by Schoch (1945), because a similar pattern was obtained from a mixture of amylose itself and monoglycerides. According to Schoch, the complex does not exist in the ungelatinized granules and does not develop further during retrogradation of the gelatinized starch.

Katz's pioneer work inspired other researchers to use X-ray diffraction to study bread staling. Senti and Dimler (1960) proposed that there was a tendency for gelatinized starch to revert from the amorphous state to its original crystalline since the crystalline state represented a lower state of energy. During aging, the amorphous X-ray pattern characteristic of freshly baked bread changed to a discrete line pattern typical of partially crystalline material. Wright (1971) had correlated the increase in firmness of bread crumb with the increase in starch crystallinity during storage at 4^{o} and 21^{o}C. Firmness was measured by an Instron compression test (Guy and Wren, 1968) and the amount of crystallinity was indicated by the ratio of the B-pattern level to that of the V, the latter remaining constant during the life of the loaf.

There seemed to be little doubt as to the direct association between starch crysatallinity and bread staling until Dragsdorf and Varriano-Marston (1980) indicated that starch crystallinity and bread firming are not synonymous. Comparison of X-ray patterns of fresh and stored breads showed direct contradiction to bread firming data.

Role of Protein in Staling

Numerous reports have indicated that the flour protein level is an important factor in the rate of staling.

Steller and Bailey (1938) found that breads baked from the higher protein flours do not stale as rapidly as those containing the lower protein flours. They also reported that protein quality could play an important role in the staling rate.

Bechtel and Meisner (1954) using a synthetic dough system (varying levels of gluten, starch, and water) demonstrated that there were few detectable sensory differences during the first several days among breads baked from different protein levels; however, with increased storage time, the breads containing the higher protein level were not as stale as those containing the lowest protein level. They concluded that changes in starch caused the staling early in the storage period and that gluten affects the staling properties through the moisture loss long afterward.

Cluskey et al. (1959) reported similar results of the rigidity of flour and starch gels that increased rapidly within one to two days after preparation. But relatively less firming occurred in gluten during the same period.

Erlander and Erlander (1969) proposed that the retrogradation of starch might be inhibited by the formation of a complex with the protein of bread. They suggested that the amide groups of wheat gliadin and glutenin (and possibly albumin) were hydrogen bonded to hydroxyl groups of starch. They concluded that the ratio of starch to protein in the dough is critical in determing the rate of staling.

Three years later, Willhoft (1972) postulated bread staling involved, in addition to the starch retrogradation, an irreversible modification in the water structure of the gluten. This modification would result in a rigidification or firming process because gluten formed the continuous matrix of the crumb. A short time later, he (Willhoft, 1973) explained that the antifirming effect of gluten was due to (a) a direct dilution effect on the starch, and (b) the effect of gluten enrichment on loaf volume and the concomitant effect on loaf softness.

Kim and D'Appolonia (1977) showed no effect of the protein content on basic mechanism of bread staling, and furthermore, that protein quality was not a factor in bread staling. They indicated the primary effect of protein in reducing the staling rate was to dilute the starch.

There seemed to be considerable disagreement among these researchers about what role protein plays in staling. A recent study, Maleki et al. (1980), demonstrated that increasing the protein content of flour increased the loaf volume and resulted in softer bread. Maleki and his co-workers also indicated that gluten was the major factor responsible for differences in the staling rate.

Role of Water in Bread Staling

It has been known for a long time that the loss of moisture is not responsible for staling and that stale bread contains as much moisture as does fresh soft bread (Boussingault, 1852).

Bechtel et al. (1954) stated that the initial level of moisture is an important factor in staling; since breads contain higher levels of water, more starch will be gelatinized at the oven stage and will generally stale at a slower rate.

Probably more important than moisture content in bread is the moisture redistribution between crumb and crust portion of bread and among bread components during storage. It is generally accepted that such a moisture redistribution could not be the main cause of firming, however, it is a contributing factor in staling.

Knjaginciev (1970) further disclosed the possibility that free and bound water may alter the rate and extent of bread staling. Recently, Zeleznak and Hoseney (1986) proved that retrogradation in wheat starch gels was controlled by the amount of water present during aging. The effect of moisture on recrystallization was not significantly different between the bread samples and the starch gels.

Effect of Pentosans on Bread Staling

A minor component of wheat flour is a non-starchy polysaccharide material referred to as pentosans. The pentosans are polymers made up of two sugar units, xylose and arabinose. Patent wheat flours contain approximately 2 to 3% pentosans, of which about 0.8% are solube in water; the rest of them are water insoluble.

Pentosans of flour are highly hydrophylic; thus, they can increase the water capacity of a flour. Neukom et al. (1967) demonstrated that pentosans contribute significantly to dough consistency. Pentosan molecules cannot penetrate the starch granules; instead, they form an intimate association with the gluten in dough in which the starch granules are embedded.

The water-soluble and water-insoluble pentosans have been extensively tested as anti-staling agents. Prentice et al. (1954) showed that the tailings (starch fraction containing about 9% water-insoluble pentosans) had no effect in the bread crumb firming rate, but did decrease initial crumb firmness, probably due to their relatively high hydration capacity. It is generally agreed (Garnatz and Kornreich, 1942; Bechtel et al., 1953; Cluskey et al., 1959) that increasing absorption in bread dough enhances softness and retards the firming process.

Gilles et al. (1961) reported that water-soluble pentosans extracted from fresh bread crumbs inhibited the retrogradation of amylose. However, the pentosan-rich water solubles of wheat flour, although they affected the properties of baked bread, did not alter the staling rate. Casier et al. (1973) claimed that the addition of the water-soluble pentosans resulted in a remarkable increase in loaf volume and retardation of bread staling.

Kim and D-Appolonia (1977) found that loaf volume was not affected by the addition of water-soluble pentosans but was slightly lowered by the addition of water-insoluble pentosans. Pentosans decreased the bread staling rate, and the effect exerted by the water-insoluble components was more pronounced than that by the water solubles. As a result of their data, Kim and D'Appolonia concluded that the reduction of staling by pentosans was attributed to the reduction of the level of starch components available for crystallinization. Hoseney (1984) summarized the structural properties of water-insoluble and soluble wheat pentosans and their gelation behavior on oxidation.

Effect of Surfactants on Bread Staling

Many additives have been investigated in an attempt to retard bread staling, but by far, the most important adjuncts used to delay bread staling (firming) are the surfactants.

In bread systems, after inclusion of certain surfactants, the dough will tolerate increased water absorption and will be somewhat more tolerant of mixing. The baked bread will have an improved symmetry, bigger volume, uniform texture, and softer crumb. Garti et al. (1980) reported that the stearoyl lactylate series of surfactants are the best single powdered conditioners and softners for regular bread.

Although the entire mechanism of what occurs when surfactants are added to bread dough is still unclear, the two main functions of some of these surfactants are: (1) to complex with gluten and stabilize the gluten network in dough in order to strengthen dough handling properties which make a significant contributon to bread quality, and (2) to complex with the amylose, and also to some extent with the amylopectin, in order to retard gelation and retrogradation after baking, thus reducing the crumb firming rate and staling (Garti et al. 1980).

Both Carlin (1947) and Hopper (1949) have reported that monoglycerides retard the typical changes of X-ray diffraction pattern that occur in bread during storage. The crystallization of starch is thus reduced by the incorporation of surfactants. Strandine et al. (1951) found that monoglycerides decrease the swelling of starch granules and possibly inhibit the decrease of soluble starch from them. They also hypothesized that the decreased ability of starch granules to swell increases the moisture content of the gluten; thus, the crumb softens and firms more slowly.

Lagendijk and Pennings (1970) found that monoglycerides formed a complex with both amylose and amylopectin but to a much greater extent with amylose. They proposed that because of the reduced flexibility of complexed amylose, the ability of hydrogen bridges to form between amylose chains, as well as between amylose and amylopectin, is reduced. Therefore, the complexing of monoglycerides with the amylose of starch in bread decreases the rate of starch retrogradation resulting in a reduced firming rate.

Schoch (1965) attributed the action of surfactants to their complexing with amylose within the granules, retarding the migration of the amylose from the granules and thus preventing the formation of the rigid gel surrounding the granules. This resulted in a crumb so soft that it yielded an acceptable loaf only after the amylopectin had associated enough to make the granule rigid.

Zobel (1973) reported that, from X-ray diffraction studies, the added surfactants have a definite influence upon the amylose fraction as demonstrated by the presence of the V-pattern. The influence arises from the interaction of a surfactant with tight α-helix of the amylose. In contrast, retrograded starch produces a B-pattern. Bread containing surfactants has a consistently higher line intensity for the V-pattern (confirming complex formation between surfactants and amylose) and is also softer and has less B crystallinity (showing interference with crystallization of the amylopectin) than the control without surfactants. That some surfactants retard the rate of crumb firming was, therefore, explained by the formation of fewer ordered regions within the amylopectin fraction. The effect of surfactants on starch crystallization is probably because of: (1) fewer B-type nuclei being provided for crystallization through complex formation with amylopectin, and (2) the regions of V-structured (helices) interfering with B-type crystallinity (extended chains) through the interaction with amylose.

It is well established that surfactants also interact with proteins in the bread system. De Stefanis et al. (1977) found that during mixing, the surfactants became strongly bound to the protein of the gluten; during baking, the surfactants translocated from the gluten to the starch. Also, when bread is enriched with soy flour, the surfactants accelerate the binding of the lipids to the soy proteins instead of interacting with the lipids; consequently, the addition of surfactants promotes compatibility between soy or other proteins and wheat flour proteins to produce bread without volume loss or quality deterioration.

Finally, there are different opinions as to whether surfactants actually decrease the rate of firming or merely produce softer bread whose crumb then firms at the same rate as that without adjunct. The team of Favor and Johnson (1947), Freilich (1948), and Hopper (1949) showed little difference in crumb compressibility with the incorporation of the surfactants in the fresh bread but a significant decrease in the rate of firming when bread staled. These data were later confirmed by other researchers (Edelmann et al. 1950, Skovholt and Dowdle 1950).

On the other hand, Coppock et al. (1954) found that monoglyceride both softened bread and reduced the rate of crumb firming, and they also disclosed that stale bread containing surfactant refreshed at a slower rate when heated than did the control loaf. Further, Kulp and Ponte (1981) indicated that an effect in retarding the firming rates is more important than that in producing initially softer crumb in fresh baked bread.

Some Kinetic Aspect of Bread Staling Based Upon the Avrami Equation

As cited before, a considerable amount of evidence has suggested that the major factor in bread staling is increased crystallization of the starch. Avrami (1939, 1940, 1941) and other researchers (Evans 1945, Morgan 1955) had developed the Avrami equation, which described the kinetics of phase change and the rate of crystallization of supercooled mold. The equation was given by

$$\theta = \exp\ (-kt^n)$$

Where θ is the uncrystallized fraction at time t, k is a rate constant which increases as temperature decreases, and n is a constant depending on the mode of nucleation and the type of crystal growth.

Prompted by Avrami's equation, Conford et al. (1964) twenty-eight years later sought to study the relationships between the elastic modulus of bread crumb and time and temperature above the freezing point. The elastic modulus used in evaluating crumb staling is derived from Hook's Law

$$\sigma = E\varepsilon$$

Where σ is the force per unit area of compression applied, E is elastic (Young's) modulus, and ε is the fractional deformation caused by σ (stress). The values of σ and ε can be measured experimentally by using an Instron Universal Testing Instrument or a similar instrument. Under the assumption that crumb elastic modulus is a linear measurement of the extent of crystallization, Conford et al. (1964) applied Avrami's equation in bread staling to describe quantitatively the rate of firming as follows:

$$\theta = \frac{(E_L - E_t)}{(E_L - E_0)} = \exp(-kt^n)$$

In this formula E_L represents the limiting modulus which is generally estimated experimentally and is the state at which the starch is entirely crystallized. E_t represents the modulus at time t, and E_0 the initial modulus.

McIver et al. (1968) used Avrami's equation to study the kinetic change of retrogradation of gelatinized starch and found that the values the Avrami exponent and time constant of starch gel at 21°C were very close to those of bread. Their result tends to confirm the role of starch retrogradation as the major factor in bread staling, indicating that starch recrystallizes in a similar manner in and out of bread.

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The application of Avrami's equation to study kinetics of bread staling was further confirmed by the techniques of differential thermal analysis (DTA) (McIver 1968), differential scanning calorimeters (DSC) (Russell 1979) and quantitated the x-ray diffraction patterns by estimating the degree of crystallinity of strch in bread crumbs (Wright 1971). All results imply that elastic modulus values reflect essentially the change of crystallization in the starch component of the bread system.

MATERIALS AND METHODS

Flour Samples

In the present study, a wheat variety, Plainsman V (hard red winter), from a commercial source was used. Its protein content was 15%, and the ash content was 1.7%. The whole wheat flour was produced on the Mikrobud mill, while the straight grade flour was produced on the Multomat mill, to an extraction of 70.56%. Three blends of whole wheat and straight grade flours were also prepared (75% whole wheat + 25% straight grade; 50% whole wheat + 50% straight grade; 25% whole wheat + 75% straight grade).

Table 1 gives the chemical analysis of these five flour samples. Flour protein, moisture, ash, fat, and crude fiber contents were determined by standard AACC methods at the Analytical Laboratory, Department of Grain Science, Kansas State Unviersity.

The data indicates that as the percentage of whole wheat flour increased, the percentage of protein, ash, fat and crude fiber content became greater.

Physical Dough Testing

Physical dough properties of all five flours were tested by using the Amylograph (AACC Method 22-10), Mixograph (AACC Method 55-40) and Farinograph (AACC Method 54-21). Results are shown in Table 2.

In the Amylograph test different amounts of malted barley flour were added to the flour sample to reach the 500 B.U. line. The requirement increased with higher amount of the straight grade flour. In the mixograph study the optimum water absorption and the mixing time were estimated from the shape of the mixogram. The five mixograph curves

Table 1. Flour Samples Analysis*

Flour**	Moisture (%)	Protein (%)	Ash (%)	Fat (%)	Crude Fiber (%)
100% WW + 0% SG	9.9	14.13	1.62	1.53	2.77
75% WW + 25% SG	10.6	13.76	1.35	1.35	2.42
50% WW + 50% SG	11.6	13.13	0.97	1.17	1.47
25% WW + 75% SG	12.6	12.99	0.70	0.99	1.09
0% WW + 100% SG	13.5	12.33	0.35	0.72	0.30

* Data given on 14% m.b.
** WW = Whole wheat flour
SG = Straight grade flour

Table 2. Physical Dough Testing Results

	Amylograph	Mixograph			Farinograph		
Flour*	% Malt added to reach 500 B.U. peak	Mixing time (min)	Abs. (%)	Peak height (cm)	Mixing time (min)	Abs. (%)	Stability (min)
100% WW + 0% SG	0.08	3.8	70.0	4.7	4.25	70.2	5.75
75% WW + 25% SG	0.09	4.1	69.0	4.8	4.25	66.4	6.50
50% WW + 50% SG	0.10	4.2	66.0	5.0	5.25	63.4	6.75
25% WW + 75% SG	0.12	4.3	64.0	5.3	6.75	59.4	9.00
0% WW + 100% SG	0.13	5.1	63.0	5.3	10.00	57.1	14.00

* WW = Whole wheat flour
SG = Straight grade flour

represent the five different flours as shown in Figure 1. As the percentage of straight grade content increase, the band width of the mixogram (which is an indication of the strength of flour) also increased. The Farinograms showed the same trend, as is evident in Figure 2.

Surfactant

The surfactant used for this study was: sodium stearoyl-lactylate (SSL). A sample of SSL was received from C. J. Patterson Co., Kansas City, MO.

Baking Procedure

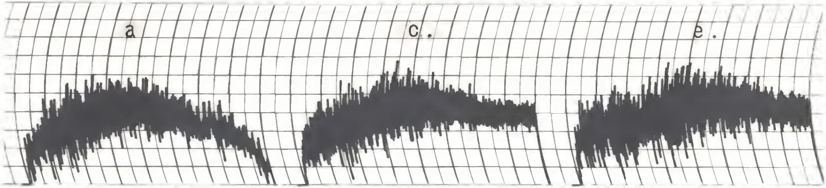
A typical straight dough procedure under optimized operational conditions was used in all baking experiments. The formula used in the study appears in Table 3. Doughs were made with 16.8 lbs flour.

Hobart Mixer, Model A-802, which was made by the Hobart Manufacturing Co., Troy, OH, was used for mixing the dough.

1. The dough temperature after mixing was 82+1°F (27.8°C).
2. The dough was placed in the fermentation cabinet at 85°F (29.4°C) and 86% R.H. for a 2.5 hours rest. It was then scaled to 539 g per piece.
3. Each piece of dough was sheeted separately on the National Roller Punching Machine, first at 5/16" and then 1/4". The dough was reversed through an angle of 180° for sheeting on the second setting and was given a triple fold.
4. The pieces of dough were put into the fermentation cabinet at 85°F (29.4°C) and 86% R.H. for an intermediate proof period of 15 min.

Fig. 1. Mixograph of flour samples.

a. 100% Whole Wheat flour + 0% Straight Grade Flour
b. 75% Whole Wheat flour + 25% Straight Grade Flour
c. 50% Whole Wheat flour + 50% Straight Grade Flour
d. 25% Whole Wheat flour + 75% Straight Grade Flour
e. 0% Whole Wheat flour + 100% Straight Grade Flour



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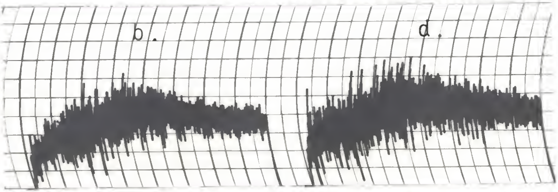

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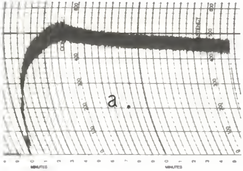
Fig. 2. Farinograph of flour samples.

a. 100% Whole Wheat flour + 0% Straight Grade Flour
b. 75% Whole Wheat flour + 25% Straight Grade Flour
c. 50% Whole Wheat flour + 50% Straight Grade Flour
d. 25% Whole Wheat flour + 75% Straight Grade Flour
e. 0% Whole Wheat flour + 100% Straight Grade Flour



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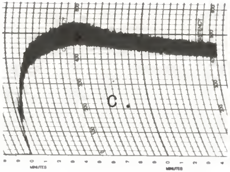

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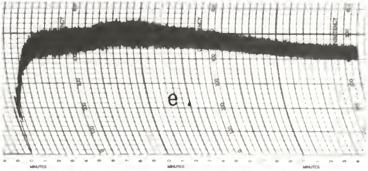

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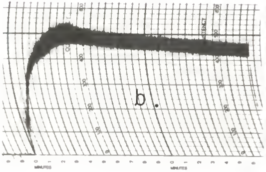

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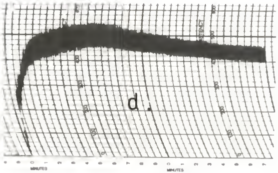

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Table 3. Straight Dough Formula

Ingredient	Baker%
Whole wheat flour	variable (100-0)
Straight grade flour	variable (0-100)
Water	optimum
Instant dry yeast	0.829
Salt	2.0
Sugar	6.0
Nonfat dry milk	2.0
Shortening	3.0
Potassium bromate	optimum
Calcium propionate	0.2
Malted barley flour	optimum
Surfactant	optimum

5. The pieces of dough were moulded (the head rollers on the Moline 100 moulder were adjusted to 1.5 and 1 units, respectively, and the pressure board was adjusted to 1-1/8 inch in the front and 7/8 inch in the back from belt level). The dough pieces were panned and proofed to height (1.5 cms above pan) at 100°F (37.8°C) and 90% R.H.
6. The loaves were baked at 425°F (218.3°C) for 22 min.
7. Loaf volume and weight were measured immediately after baking.

The optimum water absorption and optimum amount of oxidant required for each flour sample were determined by preliminary baking tests. Optimized conditions in regard to water absorption, mixing time, oxidant level, and proof time for each flour sample are shown in Table 4.

The results clearly indicated that when the amount of whole wheat flour decreased, the water absorption and proof time decreased, and the amount of oxidant required as well as the mixing time became greater.

Bread Samples

All breads were cooled one hour after baking and sealed in double plastic bags. These breads were stored at 24°C, and taken out at day 1, day 3, and day 7. Some of the breads were stored at 2°C for 14 days to achieve the maximum staling effect.

Firming Measurements

Six-1" slices were taken from each loaf for firmness measurement using Instron Universal Testing Machine (Model 1132) with drive speed at 5 cm/min, and chart speed at 25 cm/min. The measurements were taken from the ends toward the center of each loaf, and each slice was compressed

Table 4. Optimized Operation Parameters

Flour*	Absorption (%)	Mixing Time (min.)	$KBrO_3$ ppm (flour)	Proof Time (min.)	
				Without SSL	With SSL
100% WW + 0% SG	72.1	7.5	10	57	57
75% WW + 25% SG	69.6	8.0	11	55	53
50% WW + 50% SG	67.1	8.5	12	54	52
25% WW + 75% SG	64.6	9.0	13	52	53
0% WW + 100% SG	62.1	9.5	14	53	53

* WW = Whole wheat flour
SG = Straight grade flour

in the center. As shown in Figure 3, two readings were taken from the Instron curve: one was the compressibility by 25% of the thickness of each slice; another one was the slope at the initial rising portion of the curve to calculate the modulus value used to obtain the rate of firmness.

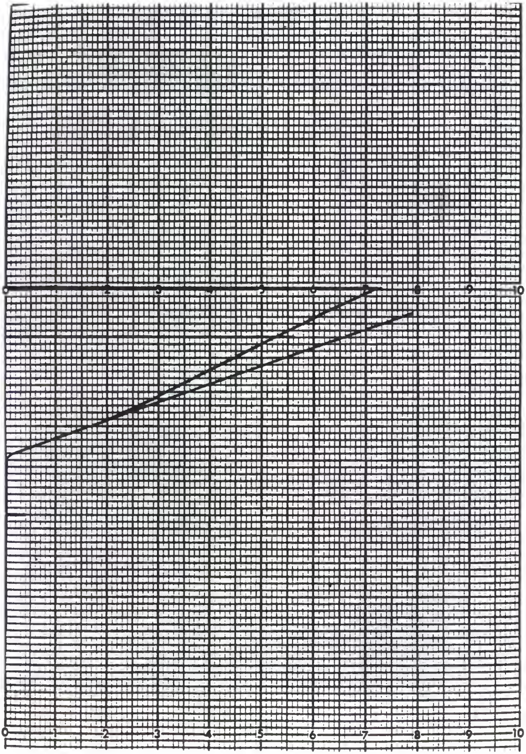
X-Ray Diffraction

Bread crumb samples of whole wheat and white pan breads with and without SSL were freeze-dried and ground before taken with CuK_{α} radiation on a Philips X-Ray Diffractometer. Operation was at 35KV, 18MA, Time Constant = 2 and Prop. KV = 1.60. X-ray patterns of bread crumb were designated according to the d-spacings and intensities given by Zobel (1981, personal communication).

Statistical Analysis

The statistical analysis included Analysis of Variance Procedure and General Linear Model Procedure. The experimental design for this study was assisted by Dr. Dallas Johnson, Statistical Laboratory, Kansas State University.

Fig. 3. Trace of Instron curve of bread sample.


0
1
2
3
4
5
6
7
8
9
10
0
1
2
3
4
5
6
7
8
9
10

RESULTS AND DISCUSSION

Breads

The breads are shown in Figure 4. All breads were acceptable. The top row shows breads without SSL, and the bottom row shows breads with SSL. Obviously, SSL improves the loaf volume and quality of the grain of the crumb. The moisture content, loaf volume and crumb grain score of bread samples are shown in Table 5.

Figure 5 presents the relationship between the specific volume of bread and the straight grade flour content. It is evident from this plot that the specific volume increased as the amount of straight grade flour increased. This holds true for breads with and without SSL. Sodium stearoyl-lactylate definitely improved the specific volume of all breads, although the effect on bread made from 100% straight grade was significant ($\alpha = 5\%$). To ascertain the effect of SSL on bread specific volume, the analysis of variance was performed and results are shown in Table 6. The analysis of variance on the specific volume of breads and the straight grade flour content was summarized and listed in Table 7.

Staling

The changes in crumb firmness of control breads without surfactant during storage are shown in Figure 6. The firmness was increased as the time of storage increased. The fresh and stale white pan breads were softer than those of whole wheat breads probably due in part to the greater specific volume of the former. However, 75% WW + 25% SG bread showed a different firming pattern, in spite of its relatively low specific volume as compared to white pan bread. Overall, at day 7 storage, all the wheat blend breads were softer than white pan bread.

Fig. 2. Pictures of bread samples.

a. 100% Whole Wheat flour + 0% Straight Grade Flour

b. 75% Whole Wheat flour + 25% Straight Grade Flour

c. 50% Whole Wheat flour + 50% Straight Grade Flour

d. 25% Whole Wheat flour + 75% Straight Grade Flour

e. 0% Whole Wheat flour + 100% Straight Grade Flour

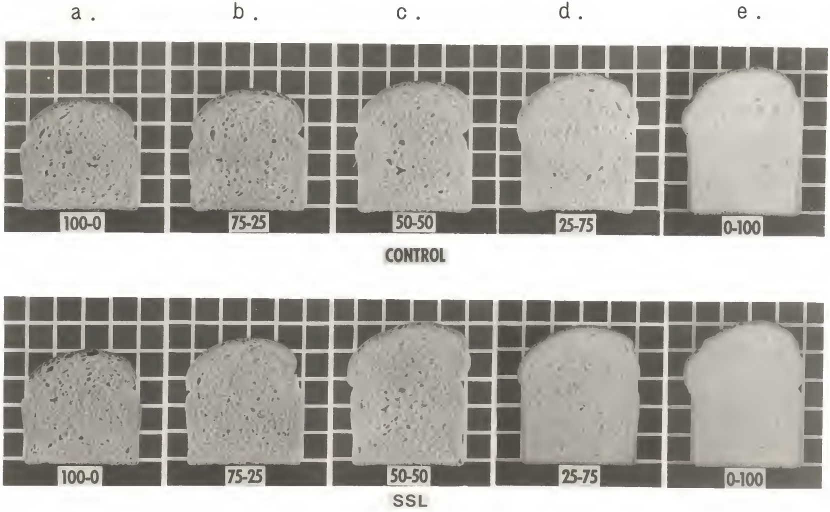

a.
b.
c.
d.
e.
100-0
75-25
50-50
25-75
0-100
CONTROL
100-0
75-25
50-50
25-75
0-100
SSL

Table 5. Moisture Content, Loaf Volume and Crumb Grain Score of Bread Samples

Flour*	Loaf Moisture Content (%) without SSL	Loaf Moisture Content (%) with SSL	Loaf Volume (cc)# without SSL	Loaf Volume (cc)# with SSL	Crumb Grain Score** without SSL	Crumb Grain Score** with SSL
100% WW + 0% SG	38.67	38.75	2399	2575	S	S+
75% WW + 25% SG	39.23	38.64	2605	2777	S	S+
50% WW + 50% SG	38.30	38.25	2810	3003	S	S+
25% WW + 75% SG	37.09	37.02	2992	3151	S	S+
0% WW + 100% SG	36.83	36.44	3211	3273	S	S+

* WW = Whole wheat flour
SG - Straight grade flour
** S = Represents satisfactory score
# The Ave. Specific Loaf Volume (cc/g) will be presented in Table 6

Fig. 5. The relationship between the specific volume and the straight grade flour content.

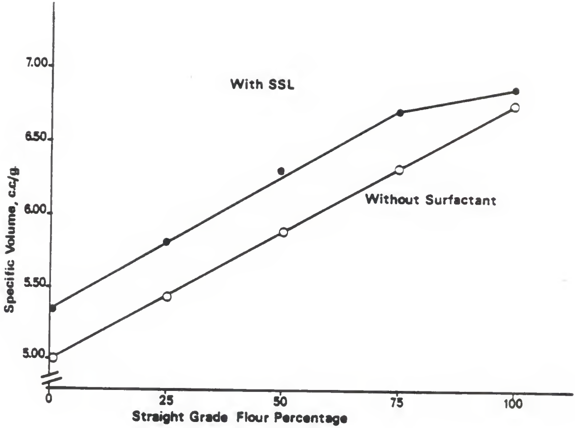

With SSL
Without Surfactant
Specific Volume, c.c/g
7.00
6.50
6.00
5.50
5.00
0
25
50
75
100
Straight Grade Flour Percentage

Table 6. Analysis of Specific Volume of Breads With or Without SSL (d.f.=22.0)

Sample*	Mean	S.D.	t value	p
100% WW + 0% SG W SSL	5.3627	0.0257	24.3184	0.0001
100% WW + 0% SG W/O SSL	4.9828	0.0476		
75% WW + 25% SG W SSL	5.7964	0.0780	14.1222	0.0001
75% WW + 25% SG W/O SSL	5.4225	0.0473		
50% WW + 50% SG W SSL	6.3172	0.0927	13.115	0.0001
50% WW + 50% SG W/O SSL	5.8991	0.0600		
25% WW + 75% SG W SSL	6.6786	0.1059	9.2491	0.0001
25% WW + 75% SG W/O SSL	6.3213	0.0818		
0% WW + 100% SG W SSL	6.8981	0.1372	2.1252	0.0450
0% WW + 100% SG W/O SSL	6.7942	0.0937		

* WW = Whole wheat flour
SG = Straight grade flour

Table 7. Summaries of Analysis of Variance on the Specific Volume of Breads and the Straight Grade Flour Content.

General Linear Model Procedure

Student-Newman-Keuls Test for the variable: bread specific volume

---

A. Without SSL

Alpha = 0.05, d.f. = 4,55, F value = 1342.18, P = 0.0001

Flour Content*	Grouping	Mean	N	Group
100% SG	A	6.79717	12	5
75% SG	B	6.32125	12	4
50% SG	C	5.89908	12	3
25% SG	D	5.42250	12	4
0% SG (100% WW)	E	4.98283	12	1

Means with different letter are significantly different at alpha = 5%.

* SG = Straight grade flour
WW = Whole wheat flour

B. With SSL

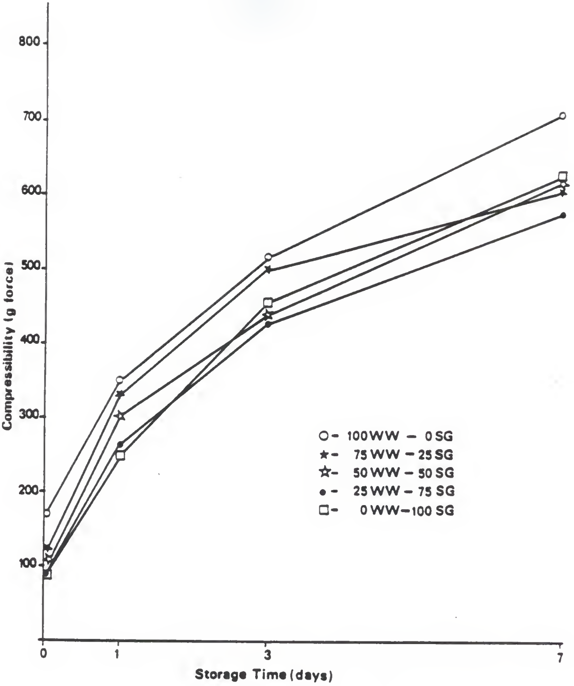
Alpha = 0.05, d.f. = 4,55, F value = 515.62, P = 0.00010

Flour Content*	Grouping	Mean	N	Group
100% SG	A	6.90383	12	5
75% SG	B	6.67858	12	4
50% SG	C	6.31725	12	3
25% SG	D	5.79485	12	2
0% SG (100% WW)	E	5.36267	12	1

Means with different letter are significantly different at alpha = 5%.

* SG = Straight grade flour
WW = Whole wheat flour

Fig. 6. Crumb firmness of breads without SSL during storage.


800
700
600
500
400
300
200
100
Compressibility (g force)
0
1
3
7
Storage Time (days)
○ - 100 WW - 0 SG
★ - 75 WW - 25 SG
☆ - 50 WW - 50 SG
● - 25 WW - 75 SG
□ - 0 WW - 100 SG

A similar relationship for breads containing SSL is shown in Figure 7. However, the softening effect of SSL was only observed in bread aged for one day and longer. SSL did not soften fresh breads (less than 24 hours) to any extent. Seventy-five percent WW + 25% SG breads still followed a different pattern of firmness. Tables 8, 9, 10, and 11 are summaries of the analysis of variance performed on the results of peak height from Instron experiments to ascertain the effect of SSL on bread firmness of fresh and aged breads. Summaries of analysis of variance on the bread firmness and the straight grade flour at different day storage are presented in Tables 12, 13, 14 and 15.

Kinetic Aspect of Bread Staling

The kinetic aspects of bread staling, discussed here, are based upon the Avrami equation. Conford et al. (1964) investigated the relationships between the elastic modulus of bread crumb and storage time and temperature. The elastic modulus used in evaluating crumb staling was measured experimentally, using an Instron Universal Testing Instrument as cited before, from the slope of the Instron curve. All experimental results were presented in the Appendix.

Conford et al. applied the Avrami equation in bread staling to describe quantitatively the rate of firming as follows:

$$\theta = \frac{(E_L - E_t)}{(E_L - E_0)} = \exp\ (-Kt^n)$$

In this formula θ is the fraction of uncrystallized material at time t, the exponent n represents the original and the type of nucleation and K is the rate constant. E_L represents the limiting modulus which is generally extimated experimentally and is the state at which the starch

Fig. 7. Crumb firmness of breads with SSL during storage.

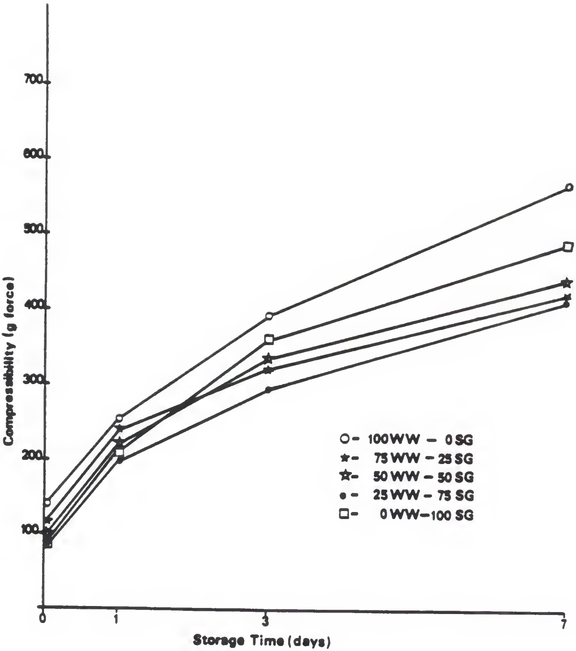

Compressibility (g force)
700
600
500
400
300
200
100
0
1
3
7
Storage Time (days)
○- 100WW - 0SG
★- 75WW - 25SG
☆- 50WW - 50SG
●- 25WW - 75SG
□- 0WW-100SG

Table 8. Analysis of Bread Firmness With or Without SSL (d.f. = 22.0) at Day 0 Storage

Sample*	Mean	S.D.	t value	p
100% WW + 0% SG W/O SSL	170.53	11.10	5.7524	0.0001
100% WW + 0% SG W/ SSL	139.51	15.02		
75% WW + 25% SG W/O SSL	126.96	9.07	2.5401	0.0180
75% WW + 25% SG W SSL	116.68	10.69		
50% WW + 50% SG W/O SSL	110.46	6.88	3.2024	0.0040
50% WW + 50% SG W SSL	101.28	7.17		
25% WW + 75% SG W/O SSL	93.89	6.29	3.4472	0.0020
25% WW + 75% SG W SSL	84.38	7.20		
0% WW + 100% SG W/O SSL	89.67	8.06	0.5472	0.5890
0% WW + 100% SG W SSL	88.13	5.50		

*WW = Whole wheat flour
SG = Straight grade flour

Table 9. Analysis of Bread Firmness With or Without SSL (d.f. = 22.0) at Day 1 Storage

Sample*	Mean	S.D.	t value	p
100% WW + 0% SG W/O SSL	348.23	13.83	12.7141	0.0001
100% WW + 0% SG W/ SSL	255.83	21.09		
75% WW + 25% SG W/O SSL	330.38	18.16	12.3802	0.0001
75% WW + 25% SG W SSL	241.63	16.94		
50% WW + 50% SG W/O SSL	302.58	13.82	16.9589	0.0001
50% WW + 50% SG W SSL	221.67	9.07		
25% WW + 75% SG W/O SSL	270.14	25.30	9.0982	0.0001
25% WW + 75% SG W SSL	198.29	10.41		
0% WW + 100% SG W/O SSL	262.00	12.75	7.8735	0.0001
0% WW + 100% SG W SSL	213.92	16.88		

*WW = Whole wheat flour
SG = Straight grade flour

Table 10. Analysis of Bread Firmness With or Without SSL (d.f. = 22.0) at Day 3 Storage

Sample*	Mean	S.D.	t value	p
100% WW + 0% SG W/O SSL	516.67	44.24	7.6208	0.0002
100% WW + 0% SG W/ SSL	392.50	36.28		
75% WW + 25% SG W/O SSL	498.75	31.49	15.4412	0.0001
75% WW + 25% SG W SSL	322.08	24.07		
50% WW + 50% SG W/O SSL	435.83	25.57	9.4147	0.0001
50% WW + 50% SG W SSL	335.00	26.88		
25% WW + 75% SG W/O SSL	425.83	33.23	12.6603	0.0001
25% WW + 75% SG W SSL	293.33	14.51		
0% WW + 100% SG W/O SSL	456.67	21.14	11.7246	0.0001
0% WW + 100% SG W SSL	362.92	17.89		

*WW = Whole wheat flour
SG = Straight grade flour

Table 11. Analysis of Bread Firmness With or Without SSL (d.f. = 22.0) at Day 7 Storage

Sample*	Mean	S.D.	t value	p
100% WW + 0% SG W/O SSL	712.08	63.44	5.6600	0.0009
100% WW + 0% SG W/ SSL	570.42	59.10		
75% WW + 25% SG W/O SSL	607.50	82.56	6.7853	0.0004
75% WW + 25% SG W SSL	423.33	44.99		
50% WW + 50% SG W/O SSL	613.75	79.32	6.7739	0.0001
50% WW + 50% SG W SSL	440.42	39.67		
25% WW + 75% SG W/O SSL	575.42	56.18	7.1823	0.0001
25% WW + 75% SG W SSL	418.33	50.83		
0% WW + 100% SG W/O SSL	625.83	91.52	4.3465	0.0006
0% WW + 100% SG W SSL	488.75	59.67		

*WW = Whole wheat flour
SG = Straight grade flour

Table 12. Summaries of Analysis of Variance on the Bread Firmness and the Straight Grade Flour Content at Day 0 Storage.

Analysis of Variance Procedure

Duncan's Multiple Range Test for the Variable: Bread Firmness

A. Without SSL

Alpha = 0.05, d.f. = 4, F value = 431.50, P = 0.0001

Flour Content*	Grouping	Mean	N
100% WW + 0% SG	A	170.52	12
75% WW + 25% SG	B	126.96	12
50% WW + 50% SG	C	110.45	12
25% WW + 75% SG	D	93.90	12
0% WW + 100% SG	D	89.67	12

Means with the same letter are not significantly different at alpha = 5%.

* SG = Straight grade flour
WW = Whole wheat flour

B. With SSL

Alpha = 0.05, d.f. = 4, F value = 109.71, P = 0.0001

Flour Content*	Grouping	Mean	N
100% WW + 0% SG	A	139.48	12
75% WW + 25% SG	B	116.67	12
50% WW + 50% SG	C	101.25	12
0% WW + 100% SG	D	88.13	12
25% WW + 75% SG	D	84.38	12

Means with the same letter are not significantly different at alpha = 5%.

* SG = Straight grade flour
WW = Whole wheat flour

Table 13. Summaries of Analysis of Variance on the Bread Firmness and the Straight Grade Flour Content at Day 1 Storage.

Analysis of Variance Procedure

Duncan's Multiple Range Test for the Variable: Bread Firmness

A. Without SSL

Alpha = 0.05, d.f. = 4, F value = 64.20, P = 0.0001

Flour Content*	Grouping	Mean	N
100% WW + 0% SG	A	348.23	12
75% WW + 25% SG	B	330.45	12
50% WW + 50% SG	C	302.58	12
25% WW + 75% SG	D	270.14	12
0% WW + 100% SG	D	262.00	12

Means with the same letter are not significantly different at alpha = 5%.
* SG = Straight grade flour
WW = Whole wheat flour

B. With SSL

Alpha = 0.05, d.f. = 4, F value = 73.85, P = 0.0001

Flour Content*	Grouping	Mean	N
100% WW + 0% SG	A	255.83	12
75% WW + 25% SG	B	241.63	12
50% WW + 50% SG	C	221.67	12
0% WW + 100% SG	D	213.92	12
25% WW + 75% SG	E	198.29	12

Means with the same letter are not significantly different at alpha = 5%.
* SG = Straight grade flour
WW = Whole wheat flour

Table 14. Summaries of Analysis of Variance on the Bread Firmness and the Straight Grade Flour Content at Day 3 Storage.

Analysis of Variance Procedure

Duncan's Multiple Range Test for the Variable: Bread Firmness

A. Without SSL

Alpha = 0.05, d.f. = 4, F value = 122.70, P = 0.0001

Flour Content*	Grouping	Mean	N
100% WW + 0% SG	A	516.67	12
75% WW + 25% SG	B	498.75	12
0% WW + 100% SG	C	456.67	12
50% WW + 50% SG	D	435.83	12
25% WW + 75% SG	D	425.83	12

Means with the same letter are not significantly different at alpha = 5%.

* SG = Straight grade flour
WW = Whole wheat flour

B. With SSL

Alpha = 0.05, d.f. = 4, F value = 61.58, P = 0.0001

Flour Content*	Grouping	Mean	N
100% WW + 0% SG	A	392.50	12
0% WW + 100% SG	B	362.92	12
50% WW + 50% SG	C	335.00	12
75% WW + 25% SG	D	322.08	12
25% WW + 75% SG	E	293.33	12

Means with the same letter are not significantly different at alpha = 5%.

* SG = Straight grade flour
WW = Whole wheat flour

Table 15. Summaries of Analysis of Variance on the Bread Firmness and the Straight Grade Flour Content at Day 7 Storage.

Analysis of Variance Procedure

Duncan's Multiple Range Test for the Variable: Bread Firmness

---

A. Without SSL

Alpha = 0.05, d.f. = 4, F value = 43.90, P = 0.0001

Flour Content*	Grouping	Mean	N
100% WW + 0% SG	A	712.08	12
0% WW + 100% SG	B	625.83	12
50% WW + 50% SG	B	613.75	12
75% WW + 25% SG	B	607.50	12
25% WW + 75% SG	C	575.42	12

Means with the same letter are not significantly different at alpha = 5%.
* SG = Straight grade flour
WW = Whole wheat flour

B. With SSL

Alpha = 0.05, d.f. = 4, F value = 67.96, P = 0.0001

Flour Content*	Grouping	Mean	N
100% WW + 0% SG	A	570.42	12
0% WW + 100% SG	B	488.75	12
50% WW + 50% SG	C	440.42	12
75% WW + 25% SG	C	423.33	12
25% WW + 75% SG	C	418.33	12

Means with the same letter are not significantly different at alpha = 5%.
* SG = Straight grade flour
WW = Whole wheat flour

is entirely crystallized. E_t represents the modulus at time T, and E_0 the initial modulus.

When Log $\left(-\text{Log}_e \dfrac{E_L - E_t}{E_L - E_0}\right)$ is plotted against Log T, the rate constant is obtained from the intercept, Log K, 1/K is equivalent to time constant. Figures 8 and 9 show the plots of the Avrami equation of breads with and without SSL. The results were analyzed by a linear least-square-fit program.

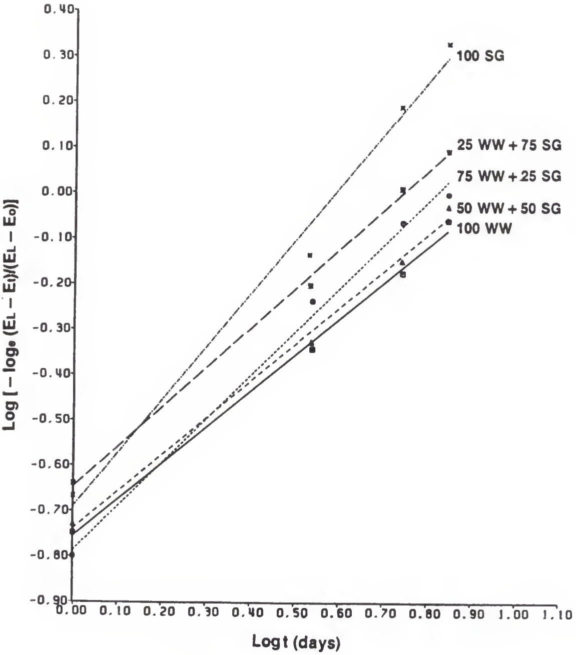
From the intercept of the plot, one can calculate the time constant of bread. Data on the experimental breads are shown in Table 16. In this Table, the higher the time constant, the slower the staling process becomes. Apparently, the 75% WW + 25% SG blend gave the slowest firming rate. White pan bread and 25% WW + 75% SG bread firmed faster both with and without SSL. Sodium stearoyl-lactylate is definitely an antifirming agent, and it decreased the firming rate of all samples to a certain degree.

X-Ray Diffraction

Crumb compressibility tests measure a bulk property of the loaf, in other words, a combination of the firmness of the crumb and the amount of air it contains. There is evidence, however, that the firming of the crumb is due at least in part to a development of crystallization in the starch fraction. X-ray measurement gives direct information on the crystalline order of the starch, that is how much crystallinity occurs in a given portion of the solid bread crumb. Therefore, this technique would be expected to be much less dependent on specific loaf volume.

The X-ray diffraction patterns of fresh and stored whole wheat and

Fig. 8. Plot of Avrami equation of breads without SSL.



0.40
0.30
0.20
0.10
0.00
-0.10
-0.20
-0.30
-0.40
-0.50
-0.60
-0.70
-0.80
-0.90
Log [– $\log_e$ (E_L – E_i)/(E_L – E_o)]
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
1.10
Log t (days)
100 SG
25 WW + 75 SG
75 WW + 25 SG
50 WW + 50 SG
100 WW

Fig. 9. Plot of Avrami equation of breads with SSL.

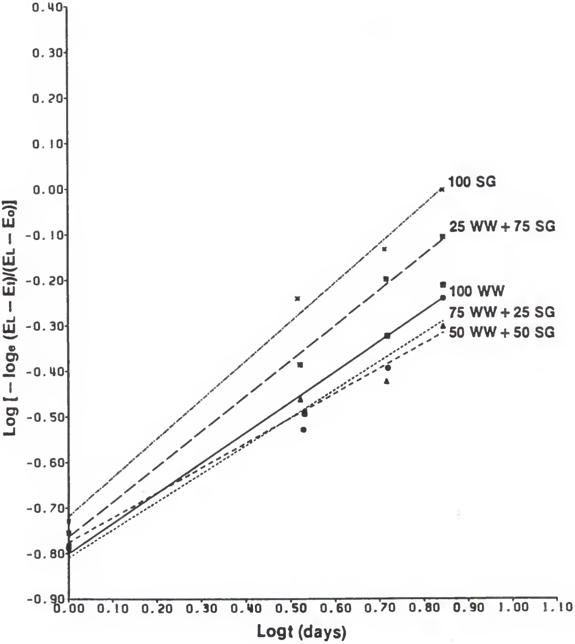

100 SG
25 WW + 75 SG
100 WW
75 WW + 25 SG
50 WW + 50 SG
Log [– logₑ (EL – Et)/(EL – Eo)]
0.40
0.30
0.20
0.10
0.00
-0.10
-0.20
-0.30
-0.40
-0.50
-0.60
-0.70
-0.80
-0.90
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
1.10
Logt (days)

Table 16. Time Constants of Breads

Breads*	Time constant without SSL (days)	Time constant with SSL (days)
100% WW + 0% SG	5.5	6.2
75% WW + 25% SG	5.8	6.4
50% WW + 50% SG	5.3	6.0
25% WW + 75% SG	4.3	5.8
0% WW + 100% SG	4.7	5.2

*WW = Whole wheat flour
SG = Straight grade flour

white pan breads with and without SSL were studied. Figure 10 shows the X-ray pattern of fresh bread after being cooled for one hour. A represents white pan bread with SSL; B represent whole wheat bread with SSL; C represents white pan bread without adding SSL; and D represents whole wheat bread without SSL. The 4.42 Å peak indicates a V-pattern structure representing the helical polymorph of amylose combined with fatty acid residue, while the 5.16 Å peak is a B-pattern structure which is typical for retrograded starch. In this case, the 5.16 Å peak is very small in the fresh breads.

Figures 11 and 12 represent a pattern obtained from day 1 and day 7 stored breads kept at 25°C. Apparently the 5.16 Å peak increased as the breads staled.

Figure 13 shows a pattern obtained from the breads stored for 14 days under 2°C (which represents the state at which the starch reaches the limiting state of staleness). There was a faint indication of a doublet at 3.78 Å and 4.00 Å confirming that stale bread starch is predominantly a B-pattern structure.

The intensity of the V-pattern at 4.42 Å remained reasonably constant during the staling process for each type of bread with and without SSL. The breads with SSL were higher in V-pattern than those without SSL. This would be expected because the V complex was formed by this compound.

The tracings clearly indicate that the intensity of B structure at 5.16 Å changed most pronouncedly during the staling process. Apparently, this is the dominant peak to show starch retrogradation during storage. Therefore, we should focus on the intensity at 5.16 Å to observe the

Fig. 10. X-Ray pattern of fresh bread.

- a. White Pan Bread With SSL
- b. Whole Wheat Bread With SSL
- c. White Pan Bread Without SSL
- d. Whole Wheat Bread Without SSL

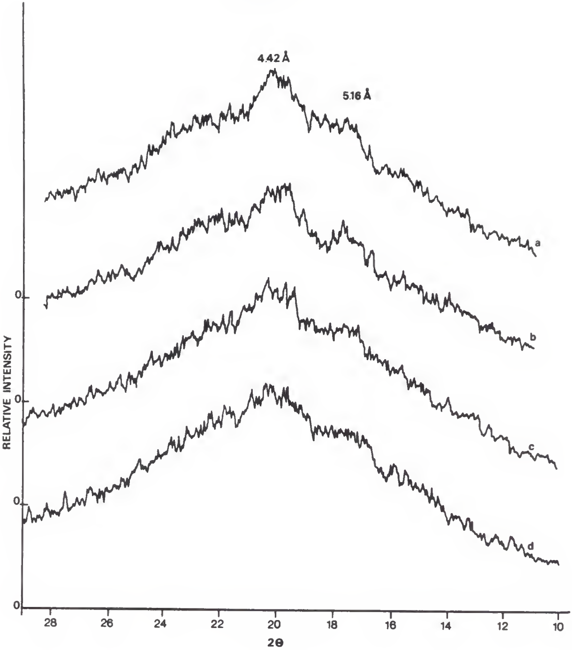

4.42 Å
5.16 Å
a
b
c
d
0
0
0
0
RELATIVE INTENSITY
28
26
24
22
20
18
16
14
12
10
2θ

Fig. 11. X-Ray pattern of bread at day 1 storage (24°C).

a. White Pan Bread With SSL

b. Whole Wheat Bread With SSL

c. White Pan Bread Without SSL

d. Whole Wheat Bread Without SSL

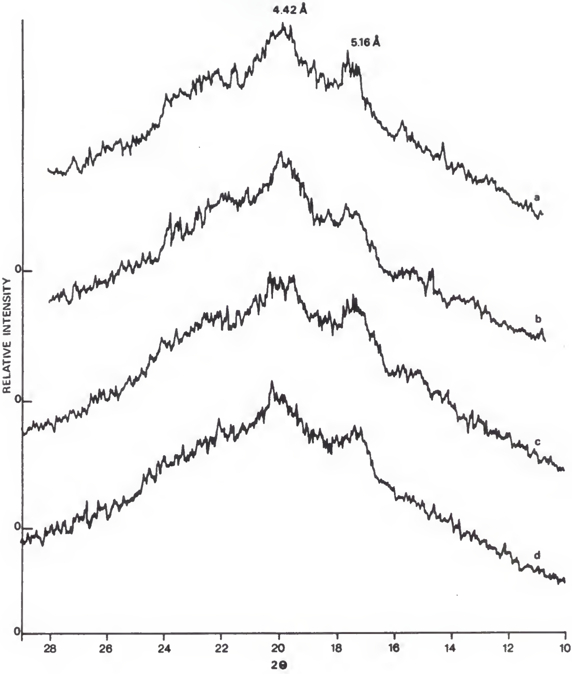

4.42 Å
5.16 Å
a
b
c
d
RELATIVE INTENSITY
0
0
0
0
28
26
24
22
20
18
16
14
12
10
2Θ

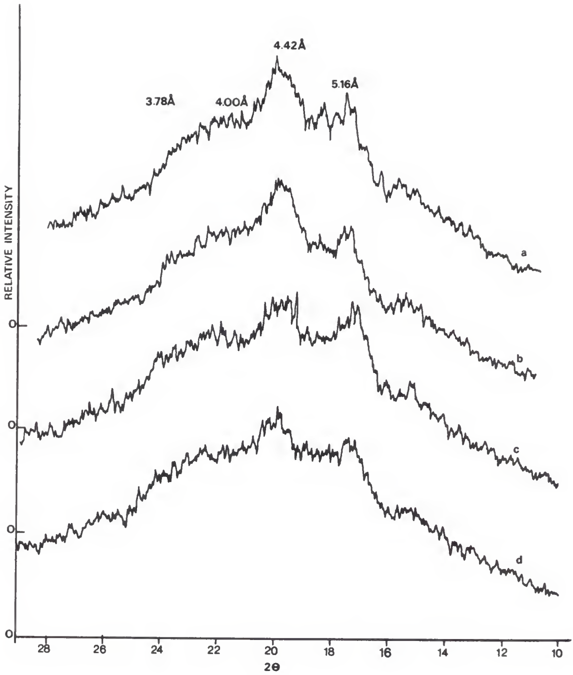
Fig. 12. X-Ray pattern of bread at day 7 storage (24°C).

a. White Pan Bread With SSL

b. Whole Wheat Bread With SSL

c. White Pan Bread Without SSL

d. Whole Wheat Bread Without SSL



4.42Å
5.16Å
3.78Å
4.00Å
RELATIVE INTENSITY
a
b
c
d
0
0
0
0
28
26
24
22
20
18
16
14
12
10
2θ

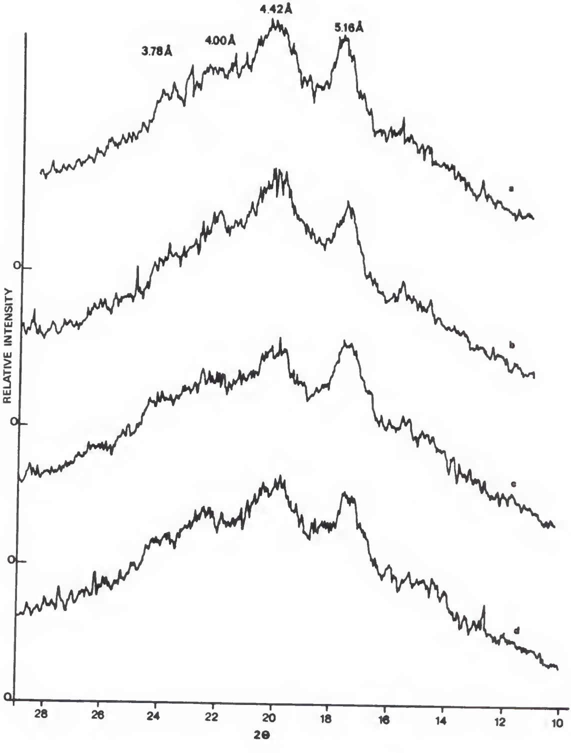
Fig. 13. X-Ray pattern of bread at day 14 storage (24°C).

a. White Pan Bread With SSL

b. Whole Wheat Bread With SSL

c. White Pan Bread Without SSL

d. Whole Wheat Bread Without SSL



4.42Å
5.16Å
4.00Å
3.78Å
a
b
c
d
0
0
0
0
RELATIVE INTENSITY
28
26
24
22
20
18
16
14
12
10
2θ

changes among samples.

By drawing reasonable background lines, an estimate can be made of the level of B-structure that develops by integrating the area under the 5.16 Å peak. Quantitatively, the data are expessed in Table 17.

From this table one can conclude that the fresh breads were generally less crystalline than the staled breads. Thus, crystallization definitely occurs during the storage period. Fresh whole wheat bread (less than 24 hours old) was more crystalline than fresh white pan bread. The difference diminished in one-day old bread. Afterwards, white pan breads were more crystalline than whole wheat breads. This indicates that the rate of starch retrogradation of white pan bread was much faster than that of whole wheat bread. This phenomenon held true for both cases, with and without SSL. This is in agreement with the time constant of the Avrami equation.

Both fresh and stale whole wheat and white pan breads containing SSL exhibited less starch crystallinity than those without SSL. Apparently, SSL interferes with starch crystallization in fresh and stale breads.

Table 17. Intensity of Crystallinity of Bread With and Without SSL

Storage temperature and time	Sample*	B Intensity at 5.16Å without SSL	B Intensity at 5.16Å with SSL
24°C, 0 day	100 WW	48	40
24°C, 0 day	100 SG	30	28
24°C, 1 day	100 WW	51	48
24°C, 1 day	100 SG	50	49
24°C, 7 days	100 WW	72	57
24°C, 7 days	100 SG	83	66
2°C, 14 days	100 WW	98	70
2°C, 14 days	100 SG	115	100

*WW = Whole wheat flour
SG = Straight grade flour

CONCLUSION

1. From compressibility measurements, one can obtain information on both crumb firmness at certain storage times and on the firmness rate of different bread samples. This compressibility test parallels the consumer squeeze test for bread staleness; however, the dependence on specific loaf volume complicated the interpretation of this test as an index of staling.

   X-ray measurements gave direct information on crystallization in the starch fraction during staling.
2. Sodium stearoyl-lactylate (and presumably other surfactants) will significantly lower the firmness, and starch crystallinity in baked bread as compared with unsupplemented control.
3. The firmness rate of whole wheat breads is apparently slower than that of white pan breads as based on the Instron compressibility test and X-ray diffraction measurements. This phenomenon holds true for breads with and without SSL.
4. The 75% WW + 25% SG blend shows a lower firmness rate than bread made from other flour samples. No one clear explanation can be offered for this observation on the basis of present evidence.

These results suggest that probably some components are present in the whole wheat flour that retard starch retrogradation in bread (the number of factors may include dilution of starch, higher level of lipids and/or pentosans). This area needs more investigation for further clarification.

Appendix 1

Results of Slopes for Each Slice of Bread Obtained Through Instron Tracing (Six Slices of Each Bread) for 100% WW

A. No SSL

Temp (°C)	Time (day)	Scale*	S1	S2	S3	S4	S5	S6
2	14	2.50	4.3	3.5	3.3	4.5	5.0	5.5
24	0	0.25	5.0	4.0	6.0	5.0	4.0	5.0
24	1	0.50	5.0	5.5	5.5	5.5	6.0	6.0
24	3	1.00	5.0	4.5	4.7	4.7	4.7	5.0
24	5	1.00	6.5	6.0	6.0	6.0	5.7	5.5
24	7	1.00	6.5	5.5	6.7	7.5	7.0	8.0

B. With SSL

Temp (°C)	Time (day)	Scale*	S1	S2	S3	S4	S5	S6
2	14	2.50	4.0	3.5	3.4	4.3	4.8	4.3
24	0	0.25	3.6	4.0	3.5	4.0	4.0	4.0
24	1	0.50	4.0	5.0	5.0	5.0	5.0	4.3
24	3	1.00	2.3	4.0	4.0	3.5	3.7	3.3
24	5	1.00	4.5	4.0	4.0	4.0	4.5	5.5
24	7	1.00	4.8	4.5	5.0	4.7	5.5	6.5

*Represents the different scale setting of Instron

Appendix 2

Results of Slopes for Each Slice of Bread Obtained Through Instron Tracing (Six Slices of Each Bread) for 75% WW + 25% SG

A. No SSL

Temp (°C)	Time (day)	Scale*	S1	S2	S3	S4	S5	S6
2	14	2.50	4.0	3.5	3.0	4.0	4.0	4.0
24	0	0.25	3.3	4.0	4.0	4.0	4.0	4.0
24	1	0.50	5.0	4.0	5.0	4.0	4.5	4.0
24	3	1.00	5.0	5.0	5.0	4.0	5.0	4.0
24	5	1.00	6.0	6.0	5.5	5.5	6.0	6.0
24	7	1.00	8.0	7.0	6.0	5.5	5.7	5.5

B. With SSL

Temp (°C)	Time (day)	Scale*	S1	S2	S3	S4	S5	S6
2	14	2.50	3.5	2.3	2.3	4.0	4.0	4.5
24	0	0.25	3.5	3.9	4.3	4.0	4.0	3.7
24	1	0.50	3.0	4.0	4.5	4.3	5.0	4.5
24	3	1.00	2.5	3.0	3.0	3.0	3.0	3.0
24	5	1.00	3.3	3.0	3.5	4.0	3.7	3.5
24	7	1.00	4.5	3.5	3.8	4.5	4.5	5.0

*Represents the different scale setting of Instron

Appendix 3

Results of Slopes for Each Slice of Bread Obtained Through Instron Tracing (Six Slices of Each Bread) for 50% WW + 50% SG

A. No SSL

Temp (°C)	Time (day)	Scale*	S1	S2	S3	S4	S5	S6
2	14	2.50	4.0	4.0	5.0	5.0	5.0	4.5
24	0	0.25	3.0	3.3	3.7	3.7	4.0	3.0
24	1	0.50	5.0	6.0	6.0	6.0	5.0	4.0
24	3	1.00	4.0	5.0	5.0	5.0	5.0	5.0
24	5	1.00	6.0	5.0	5.5	7.0	7.0	7.0
24	7	1.00	8.0	6.0	6.3	7.5	8.0	8.0

B. With SSL

Temp (°C)	Time (day)	Scale*	S1	S2	S3	S4	S5	S6
2	14	2.50	3.7	2.7	3.3	4.0	4.0	5.0
24	0	0.25	2.7	3.2	3.5	3.3	3.3	2.7
24	1	0.50	3.5	4.0	4.5	4.0	4.5	4.7
24	3	1.00	2.8	3.5	3.0	3.5	3.5	3.5
24	5	1.00	3.3	3.3	3.0	4.0	3.3	4.0
24	7	1.00	4.0	3.8	4.0	5.0	4.0	4.3

*Represents the different scale setting of Instron

Appendix 4

Results of Slopes for Each Slice of Bread Obtained Through Instron Tracing (Six Slices of Each Bread) for 25% WW + 75% SG

A. No SSL

Temp (^{o}C)	Time (day)	Scale*	S1	S2	S3	S4	S5	S6
2	14	2.50	4.0	4.0	3.5	4.0	3.5	3.5
24	0	0.25	3.0	3.5	4.0	4.0	3.7	3.0
24	1	0.50	5.0	5.5	6.0	6.0	4.5	4.5
24	3	1.00	4.0	5.0	5.0	5.0	5.0	5.0
24	5	1.00	7.0	6.0	6.0	7.0	6.5	5.5
24	7	1.00	6.0	7.0	7.0	7.0	8.0	6.5

B. With SSL

Temp (^{o}C)	Time (day)	Scale*	S1	S2	S3	S4	S5	S6
2	14	2.50	3.0	2.5	2.3	4.0	3.8	3.5
24	0	0.25	2.7	3.3	3.0	3.3	3.0	2.7
24	1	0.50	3.0	2.5	3.0	3.5	3.5	3.5
24	3	1.00	3.0	2.5	3.0	3.5	3.5	3.5
24	5	1.00	4.0	4.0	4.0	4.0	4.0	4.7
24	7	1.00	4.7	4.3	4.5	5.0	4.5	5.0

*Represents the different scale setting of Instron

Appendix 5

Results of Slopes for Each Slice of Bread Obtained Through Instron Tracing (Six Slices of Each Bread) for 100% SG

A. No SSL

Temp (^{o}C)	Time (day)	Scale*	S1	S2	S3	S4	S5	S6
2	14	2.50	4.0	4.0	3.5	3.7	3.7	4.0
24	0	0.25	2.7	3.0	3.5	3.5	3.3	3.3
24	1	0.50	6.0	5.0	6.0	5.0	4.5	3.5
24	3	1.00	5.0	5.0	6.0	6.0	5.0	5.0
24	5	1.00	7.0	7.0	8.0	7.0	8.0	9.0
24	7	1.00	9.0	7.0	9.0	8.0	9.0	9.0

B. With SSL

Temp (^{o}C)	Time (day)	Scale*	S1	S2	S3	S4	S5	S6
2	14	2.50	3.0	2.3	3.0	4.0	5.0	3.8
24	0	0.25	2.3	2.7	3.5	3.3	3.5	3.0
24	1	0.50	3.7	4.0	4.5	5.0	5.0	3.3
24	3	1.00	4.0	3.5	4.5	5.0	4.5	4.0
24	5	1.00	5.0	5.0	4.5	5.5	4.5	5.0
24	7	1.00	6.0	5.0	5.5	6.8	5.5	6.0

*Represents the different scale setting of Instron

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FIRMING COMPARISON OF WHITE PAN AND WHOLE WHEAT BREADS

by

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AN ABSTRACT OF A MASTER'S THESIS

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ABSTRACT

Work on bread staling has primarily been directed at white pan bread. The present study was concerned with comparing staling properties of white vs. whole wheat-type breads.

Wheat (Plainsman V) was milled on a pilot flour mill to produce 2 flours: straight grade flour and whole wheat flour. Three blends of whole wheat and stright grade flours were also prepared (75% whole wheat + 25% stright grade; 50% whole wheat + 50% straight grade; 25% whole wheat + 75% straight grade).

Bread made with these flours were stored at 24°C, and were tested over a period of seven days on the Instron Universal Testing Machine and were also examined by x-ray diffraction. At day 1, the white pan bread was softer than the wheat breads, but after day 3, the wheat breads were found to firm less rapidly. One of the flour blends (75% whole wheat + 25% straight grade) produced bread that firmed substantially less than that of the other flours.

Bread firming trends were substantiated by x-ray diffraction data. Possible reasons for aging differences among the breads are disclosed.