BREAD STALING: EFFECTS OF FATS, SURFACTANTS, STORAGE TIME AND STORAGE TEMPERATURE, AND THE INTERACTION BETWEEN THESE FACTORS

by

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LITERATURE REVIEW

Bread staling, like many problems or phenomena, must first be defined and understood before measures can be taken toward a permanent solution. A definition that has been used by many researchers is that of Bechtel et al. (1953) who defined staling as a "term which indicates decreasing consumer acceptance of bakery products by changes in the crumb other than those caused by spoilage organisms." Although this definition will suffice in a general sense, other more specific changes that occur in bread during storage should be noted. These include increases in the crumbliness of the crumb, increases in hardness of the crumb, changes in taste and aroma, increased opacity of the crumb, loss of crust crispness, decreased absorptive capacity of the crumb, decreased susceptibility to attack by alpha-amylase, and decreased soluble starch content (Herz, 1965).

The staling of bread has been a problem that has perplexed researchers for years. Although much research has been done concerning the staling phenomenon, a complete understanding of its exact nature has remained elusive. Since the quantity of bread returned for reason of staleness has been estimated at 8 percent of the bread produced in the U.S. (Maga, 1975), staling represents a problem of considerable magnitude. Therefore, a solution to the bread staling problem would benefit both the producer and the consumer.

Measurement of Crumb Compressibility

The most noticeable change occurring in the bread crumb when it stales is the development of a more rigid crumb structure. Therefore, crumb compressibility has been the measurement most commonly used to quantify staleness. Over the years many different methods have been developed for the determination of crumb compressibility (Bailey, 1930; Cornford et al., 1964; Crossland and Favor, 1950; Guy and Wren, 1968; Kilborn et al., 1983; Platt and Flemming, 1930; Platt and Powers, 1940).

Crumb compressibility is generally measured in one of two ways: by noting the force required to give a standard compression value (crumb firmness), or by measuring the compression obtained upon application of a standard force (crumb softness). Bice and Geddes (1949) attempted to distinguish between these two approaches. Crumb softness was shown to decrease in a curvilinear manner with time, taking the shape of an equilateral hyperbola. Measurements of crumb firmness, on the other hand, increased in a nearly linear fashion over the same storage period (three or four days). Bice and Geddes (1949) concluded that crumb firmness readings provided the only satisfactory measure for comparing staling rates from compressibility data because their slopes are simple, direct functions of the rate of change in firmness. They suggested that crumb softness slopes could not be readily interpolated as staling indices because they were complicated functions of both the rate of change with time and of the original softness of the crumb.

Somewhat later, Willhoft (1973) suggested that if the crumb softness curve was fit using a simple power-interpolation, the staling rate could be mathematically derived from the resulting empirical equation. Further, Willhoft contended that if compressibility measurements were performed under conditions where stress increases linearly with strain, then the distinction between crumb firmness and softness ceased to exist.

Bread Staling Theories

The first reported research on the cause of bread staling was by Boussingault (1852). It had been widely believed that bread staling was due to a loss of moisture, i.e. drying out. Boussingault proved that bread still became stale even though it was sealed in a glass tube so as to prevent moisture loss. Fifty years later, Lindet (1902) found that, compared to fresh bread, the amount of soluble starch decreased as the bread aged and staled. He gave the name "retrogradation" to this decrease in starch solubility.

By studying the x-ray diffraction patterns of starch pastes and bread crumb, Katz (1930, 1934) discovered that fresh bread contained starch in both the amorphous and crystalline forms. As the bread staled, the amount of crystalline starch increased. Katz concluded that bread staling was due to changes in starch, specifically retrogradation caused by an increase in starch crystallinity. Later work by Hellman et al. (1954) and Wright (1971) showed that the rate at which crystallinity developed in concentrated starch gels and bread crumb was similar to the rate at which the firming of bread crumb increased.

Zobel and Senti (1959), however, have shown that starch crystallinization and bread firming are not equivalent phenomena. They observed that, compared to control bread, the crumb from breads treated with alpha-amylase increases in x-ray crystallinity while exhibiting a decrease in crumb firmness. Their model proposed that alpha-amylase hydrolyzed linkages in the amorphous regions of the starch gel. This allowed the crystalline regions more freedom of movement, resulting in a softer crumb. The observed increase in crystallinity was due to the fact that more regions and chains were now able to align and associate with themselves. Similar results were obtained by Dragsdorf and Varriano-Marston (1980).

Schoch (1965), drawing on conclusions made in previous work (Schoch and French, 1947), offered a detailed explanation of the role of starch in bread staling. During baking, wheat starch granules undergo restricted swelling because the amount of water present is limited. While this swelling is taking place, a portion of the amylose in the granule dissolves and diffuses out of the granule into the surrounding aqueous medium. The concentration of the amylose increases in the interstitial water as granular swelling continues. Because amylose is prone to retrogradation, this interstitial carbohydrate will form an insoluble gel structure by the time the bread has cooled, and will undergo no further changes during subsequent storage. The increase in bread firmness observed as bread ages is primarily caused by retrogradation of the amylopectin. The branched amylopectin molecules unfold as the starch granule swells. A gradual alignment and association of their outer branches (A-chains) occurs with time, producing a rigid structure. By this model, fresh bread is considered to consist of soft deformable granules embedded in an already retrograded gel structure. Stale bread, conversely, has firm, rigid granules embedded in the same gel structure.

Minor modifications in Schoch's (1965) model have been made by Lineback (1984). Lineback proposed that portions of the amylose and amylopectin chains extend beyond the boundaries of the starch granules. The chains can associate and align with other carbohydrate chains in the interstices between granules or with other molecules protruding from granules in close proximity to each other. Therefore, intergranular as well as intragranular association of amylopectin chains accounts for the firming observed with staling. This model is similar to one proposed by Matsukura et al. (1983).

Migration of moisture from gluten to starch during storage has been suggested as an additional cause of bread firming (Alsberg, 1936; Breaden and Willhoft, 1971; Senti and Dimler, 1960; Willhoft, 1971a and 1971b). By this model, an irreversible modification in the water structure of the gluten occurs as bread is baked. The water that is freed by the gluten becomes available for absorption by the incompletely gelatinized starch. Since the gluten forms the continuous matrix of the crumb, its modification results in firming.

Ghiasi et al. (1984) measured the effect of reheating temperature on bread firming. They postulated that if amylopectin retrogradation was responsible for bread firming, then reheating to temperatures greater than 60°C should completely refresh bread. As the reheating temperature increased, the bread did become softer, but when bread firmness was plotted against the reheating temperature, the resultant curve was clearly biphasic, with a break occurring at 60°C. The researchers suggested that more than one phenomenon was responsible for refreshing and, presumably, for staling.

Effect of Fat

Both flour components and dough additives have an effect on the staling of bread. Of these components and additives, lipids have received the most attention. The lipids associated with bread baking can be divided into those that occur naturally within the flour (i.e., free and bound lipids) and those that are added to the bread formula (i.e., fats and surfactants).

Animal and vegetable fats have a demonstrated anti-staling effect (Cornford et al., 1964; Ghiasi et al., 1984). Bread firmness and fat level have a negative correlation (Edelmann et al., 1950; Platt and Powers, 1940). It appears that extreme levels (e.g. ≃ 8 percent) of fat do not necessarily result in a further decrease in staling, i.e. firming (Carlin, 1947; Pelshenke and Hample, 1962).

Baldwin et al. (1965) examined the effect of hard fat, produced by hydrogenation of cottonseed oil, on the firmness of continuous-mix bread. Using a system of 3 percent lard containing hard fat flakes varying in amount from 0 to 40 percent, they found that hard fat levels between 10 and 20 percent produced bread with the softest crumb. At levels above and below this, hard fat produced increased firmness. Although it is generally agreed that fats improve the keeping quality of breads apparently by reducing the rate of firming, the mechanism by which they impart this effect is not well understood.

Effect of Surfactants

Surfactants are probably the most extensively studied group of lipids used in the baking industry. Most surfactants consist of one or more hydrophobic fatty acids esterified to a hydrophilic polar group.

Forty years ago Schoch and Williams (1944) reported that amylose formed a water-insoluble complex (clathrate) with fatty acids. Since that time, much work has been done on lipid-amylose complexes and their effect on bread staling. Mikus et al. (1946) suggested that amylose, in its helical configuration, will bind saturated fatty acids, while amylose in the extended chain configuration will not. They assumed, therefore, that the amylose-fatty acid complexes were similar in nature to the helical-amylose iodine complex described by Rundle and Baldwin (1944).

The ability of certain surface active agents (surfactants) to form complexes with starch is well documented (Krog, 1971; Osman et al., 1961). Additionally, many researchers (Coppock et al., 1954; Edelmann and Cathcart, 1949; Jongh, 1961; Ofelt et al., 1958a and 1958b; Riisom et al., 1984; Russell, 1983; Skovholt and Dowdle, 1950; Strandine et al., 1951) have shown that surfactants have the ability to soften bread crumb. However, this softening ability appears to be dependent on the ability of the surfactants, especially monoglycerides, to complex with amylose (Krog and Nybo Jensen, 1970; Lagendijk and Pennings, 1970; Osman and Dix, 1960). Lord (1950) postulated that the ability of surfactants to form complexes with amylose in bread was the cause of their crumb-softening action. The amylose complexing ability of monoglycerides is known to be influenced by their chemical structure (Krog, 1971; Lagendijk and Pennings, 1970; Osman et al., 1961; Riisom, 1984) and physical state (Krog and Nybo Jensen, 1970; Larsson, 1983; Riisom et al., 1984).

Several reports (DeStefanis et al., 1977; Krog, 1971; Lagendijk and Pennings, 1970) have shown that surfactants can interact with amylopectin. Whether or not this interaction influences the retrogradation of amylopectin is not yet clear.

A mechanism by which surfactants decrease the firmness of bread crumb has been postulated by Schoch (1965), who suggested that in bread dough without surfactants, amylose is leached out of starch granules during baking. Upon cooling, this interstitial starch solution retrogrades to form an insoluble gel structure which contributes to the initial firmness of the bread. When surfactants are added to bread dough, they immediately form a helical complex with amylose in the granule. This complexation "immobilizes" the amylose within the starch granules and prevents it from leaching and forming a gel structure. The starch granules are subsequently allowed more freedom of movement which, in turn, produces a softer crumb. Evidence to support Schoch's hypothesis has been reported by Ghiasi et al. (1982a and 1982b), whose work substantiated the assumption that complex formation between surfactants and amylose occurs within the starch granule before gelatinization takes place and that the surfactants effectively stopped the leaching of amylose from the swollen starch granules.

Effect of Native Flour Lipids

Native flour lipids can also act as anti-staling agents. As part of a study on the effects of free (petroleum ether-extractable) flour lipids on bread staling, Pomeranz et al. (1966) measured the compressibility of bread baked with shortening, polar, nonpolar, or total lipids. Adding 0.5 percent nonpolar lipids reduced crumb firmness only slightly. For retarding crumb firmness during storage, 3 percent shortening and 0.5 percent polar lipids were equally good and the most effective of all treatments. In a related study, Pomeranz et al. (1969) demonstrated the anti-staling effect of free polar lipids.

Effect of Storage Temperature and Loaf Specific Volume

Two other factors that affect bread staling are temperature and loaf specific volume. Katz (1928) published evidence that bread remained fresh if stored at temperatures above 60°C or below -10°C. The staling rate increased as temperature was lowered from 60°C, and reached a maximum at -2°C. The results showed that the staling process has a negative temperature coefficient. Cornford et al. (1964) investigated the relationship between the elastic modulus of the crumb and storage time at temperatures ranging from -1°C to 32°C. Their results confirmed the fact that temperature and the staling rate of bread are negatively related. These workers also observed that, independent of temperature, all the breads ultimately staled to the same firmness. The rate at which the breads staled, however, was dependent on storage temperature.

Loaf specific volume (cm^3/g) has also been shown to influence both the rate and the extent of bread staling (Axford et al., 1968; Maleki et al., 1980). As loaf volume increases, the rate and extent of bread staling decreases. This effect becomes more marked as storage temperature is lowered.

It is presently believed by some bakers that certain fats cause increases in bread firmness during the winter months due to exposure of the products to lower ambient temperatures (Jackel, 1982). This effect causes some bakers to reduce the usage levels of fats during that period of the year. There is, however, neither published evidence supporting this effect nor an explanation extant as to its mechanism.

With this in mind, the objectives of this study were to: (1) determine the effect of fat type and level on the firmness of white pan bread stored at varying temperatures, and (2) examine the effects of the addition of monoglycerides and sodium stearoyl-2-lactylate on bread firmness under the above conditions.

MATERIALS AND METHODS

Materials

Flours. Two commercially-milled hard wheat flours were obtained from Ross Industries, Inc. (Wichita, Kansas). Proximate analytical data for each are presented in Table 1. The first flour (Flour I) was used in the two experiments which examined the interactions between fat type, fat level, surfactant type, storage time and temperature, and their subsequent effect on bread staling. The second flour (Flour II) was used in the model-system experiment containing different hard fat/soy oil combinations.

Fats. Lard, partially-hydrogenated soy oil, hydrogenated soy-oil shortening, and hard fat flakes were donated by Humko Products (Memphis, Tennessee). Analytical data are presented in Table 5.

Surfactants. Sodium stearoyl-2-lactylate (Emplex) and distilled monoglycerides (Starplex) were obtained from the C.J. Patterson Co. (Kansas City, Missouri).

Methods

Bread. All breads were prepared using the sponge and dough process (Figure 1). The baking formula based on flour weight is listed in Table 2.

Fats and Surfactants. Breads were produced which contained either lard, soybean oil, or soy-oil shortening at levels of 1.5 and 3 percent flour weight basis (Table 3, numbers 2-7). A control loaf was also produced containing no fat (Table 3, number 1). Subsequent tests involved the combination of either 0.375 percent sodium stearoyl-2-lactylate or 0.25 percent distilled monoglycerides with each of the above levels of soybean oil and soy-oil shortening (Table 3, numbers 8-11). A model system prepared with different hard fat/soy oil combinations was also examined. The hard

Table 1. Proximate analyses of flours

Proximate Analysis	Flour I	Flour II
Moisture, %	12.00	13.20
Protein, % (N x 5.7)	11.60	11.70
Ash, %	0.50	0.48

Figure 1. Flow diagram for the sponge and dough process used for baking all breads

MIX SPONGE
(3 min with Hobart M-802 mixer)

↓

SPONGE FERMENTATION
(4 hrs at 85°F and 85% R.H.)

↓

MIX DOUGH
(Optimum mixing time determined by farinograph and test bakes)

↓

FLOOR TIME
(20-min relaxation period)

↓

DIVIDE
(Dough pieces scaled to 539 g)

↓

INTERMEDIATE PROOF
(Dough pieces allowed 10-min relaxation period)

↓

MOULD
(Oshikiri model MS moulder)

↓

PROOF
(60 min at 110°F and 90% R.H.)

↓

BAKE
(20 min at 425°F)

Table 2. Sponge and dough formula

Ingredient	Percent (Flour Weight Basis)	
	Sponge	Dough
Flour	70.00	30.00
Water[a]	41.00	21.00
Yeast (instant active dry)	1.00	-
Mineral yeast food	0.25	-
Salt	-	2.00
Sucrose	-	6.00
NFDM	-	3.00
Fat	-	(b)
Surfactant	-	(b)

[a]Water added to optimum as determined by bake tests.

[b]Variable by experiment; refer to Table 3.

Table 3. Fat and surfactant levels used in breads

Test No.	Lipid Source (as a percent of flour weight)				
	Lard	Oil	Shortening	SSL	MG
1	0	0	0	0	0
2	1.5	0	0	0	0
3	0	0	0	0	0
4	0	0	1.5	0	0
5	3.0	0	0	0	0
6	0	3.0	0	0	0
7	0	0	3.0	0	0
8	0	1.5	0	0.375	0
9	0	0	1.5	0	0.25
10	0	3.0	0	0.375	0
11	0	0	3.0	0	0.25

fat/soy oil combinations were as follows: (1) 100 percent soy oil, (2) 90 percent soy oil and 10 percent hard fat flakes, (3) 80 percent soy oil and 20 percent hard fat flakes, and (4) 60 percent soy oil and 40 percent hard fat flakes. Each soy oil/hard fat combination was added at the 3 percent level.

Preparations of Hard Fat/Soy Oil Combinations. The soy oil and hard fat combinations were prepared following the method of Bayfield and Young (1964).

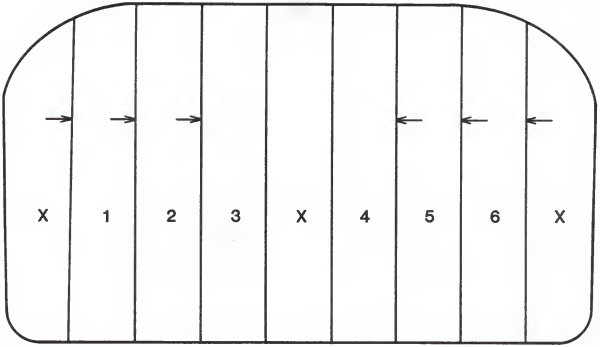
Storage Conditions. All loaves were allowed to cool for 2 hr after baking and were then double-wrapped in polyethylene bags. The storage temperatures were 7.5, 15, and 25°C. The storage times were 1, 3, and 5 days. Loaves containing a given fat treatment were stored for study at all time-temperature combinations.

Firmness Determination. Firmness values were obtained by measuring compressibility with an LFRA Texture Analyzer (Voland Stevens, Hawthorne, New York) fitted with a solid Plexiglass™ cylinder (diameter 1.5 cm). The texture analyzer was adjusted so as to compress the bread crumb 4 mm at a rate of 2 mm/sec.

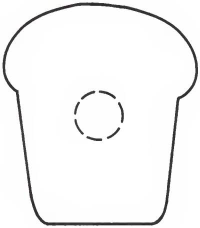
Loaves were prepared by sectioning into nine, 1-in thick slices (Figure 2). The center and both end slices were discarded. Readings were taken from the center of the remaining six slices. Thus, the firmness value for each loaf was the mean of six readings.

Statistical Analysis. Experiments using fat independently were replicated four times and average firmness values were based on 24 observations. When surfactants were added to the formula, the experiments were repeated twice and average firmness values were based on 12 observations. The hard fat/soy oil model system experiment was replicated four times and average

Figure 2. Diagram illustrating how loaves were sectioned and where individual slices were compressed. Arrows (⟶) indicate in what direction each slice was compressed. Firmness measurements were taken only on numbered (1-6) slices, while those containing an X were discarded.



LOAF



SLICE

firmness values were based on 24 observations. Differences in firmness were determined by analysis of variance (Snedecor and Cochran, 1980), using alpha-levels of 0.05 and 0.10.

RESULTS AND DISCUSSION

Effect of Storage Time and Storage Temperature

The results of storing breads at 25, 15 and 7.5°C demonstrated that bread firmness and storage temperature were inversely related. This relationship was in agreement with the findings of Cornford et al (1964) and Katz (1928). Breads stored for 1, 3 and 5 days increased in firmness as the storage time increased. Analysis of variance showed that both storage time and storage temperature were significant in increasing bread firmness at the 0.05 alpha level.

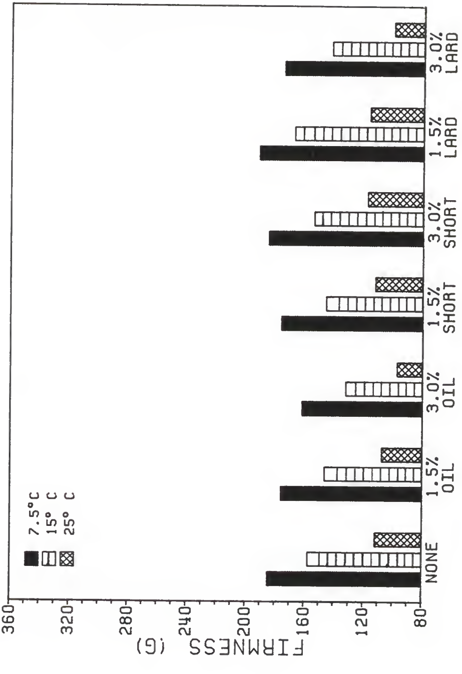
Effect of Fat Type and Level

Previous studies (Carlin, 1947; Edelmann et al., 1950; Pelshenke and Hample, 1962; Platt and Powers, 1940) concluded that increasing the level of fat present in the formula generally decreased bread firmness. Additions of soybean oil and lard, in this study, behaved in such a manner. The plastic soy-oil shortening, on the other hand, did not.

The crumb firmness readings obtained when fats were independently added to bread at levels of 1.5 and 3.0 percent (flour weight basis) are presented in Figures 3, 4 and 5. Both soybean oil and lard decreased bread firmness as their usage levels were increased from 1.5 to 3.0 percent. In contrast, when the amount of plastic shortening in the formula was increased from 1.5 to 3.0 percent, an increase in bread firmness resulted. These results were the same at the end of 1, 3 and 5 days of storage (Figures 3, 4 and 5, respectively). A more detailed examination of Figures 3, 4 and 5 indicates that the previously described firming patterns caused by each fat were not affected by storage temperature.

Loaf specific volume is known to affect firmness values (Axford et al., 1968). Specifically, lower volumes result in higher firmness. If a decrease

Figure 3. Effect of fat type and level on the firmness of breads stored for 1 day at 7.5°C (■), 15°C (⊟), and 25°C (⊠)



FIRMNESS (G)
360
320
280
240
200
160
120
80
7.5°C
15° C
25° C
NONE
1.5%
OIL
3.0%
OIL
1.5%
SHORT
3.0%
SHORT
1.5%
LARD
3.0%
LARD

Figure 4. Effect of fat type and level on the firmness of breads stored for 3 days at 7.5°C (■), 15°C (⊟), and 25°C (▩)

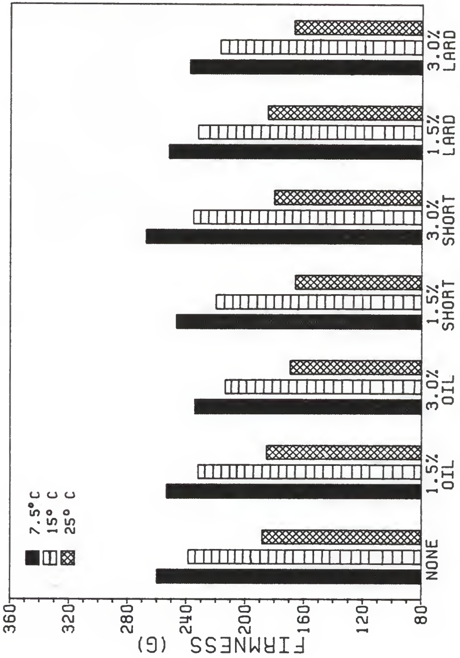
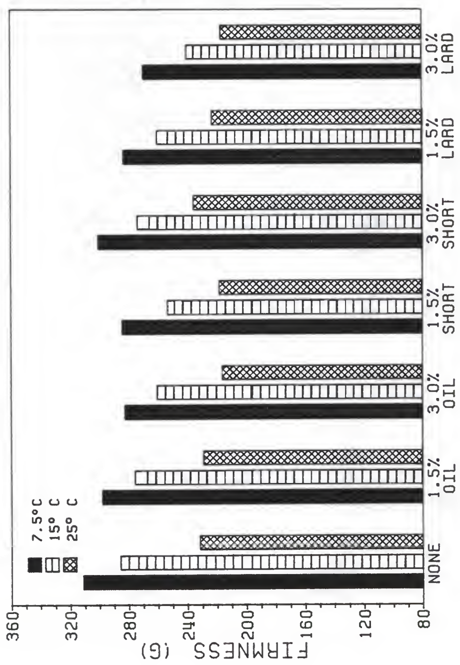

FIRMNESS (G)
360
320
280
240
200
160
120
80
NONE
1.5% OIL
3.0% OIL
1.5% SHORT
3.0% SHORT
1.5% LARD
3.0% LARD
7.5° C
15° C
25° C

Figure 5. Effect of fat type and level on the firmness of breads stored for 5 days at 7.5°C (■), 15°C (⊟), and 25°C (⊠)


FIRMNESS (G)
360
320
280
240
200
160
120
80
7.5°C
15° C
25° C
NONE
1.5% OIL
3.0% OIL
1.5% SHORT
3.0% SHORT
1.5% LARD
3.0% LARD

in loaf specific volume were occurring with the addition of the higher (3.0 percent) plastic shortening level, then this could explain the observed increase in bread firmness. Table 4 lists the loaf specific volume obtained for each individual fat treatment. Three percent plastic shortening produced bread with the largest loaf specific volume. Therefore, a decrease in loaf specific volume is not the cause of increased crumb firmness exhibited by the bread containing 3.0 percent plastic shortening.

The physical and chemical nature of the fats used in this study provide a possible explanation as to the cause of the increased firmness in the breads containing 3.0 percent plastic shortening. Table 5 gives the analyses of the different fats. The most noticeable difference between the lard, soybean oil and plastic shortening is their solid fat index (SFI). The SFI of a particular fat is an expression of its percent solids at the testing temperature. Soybean oil contains no solid fat at the temperatures at which the SFI is commonly measured. Lard and plastic shortening, on the other hand, are composed of liquid (oil) and solid (crystalline) fractions. The relative proportions of solid fat (crystalline) to liquid fat (oil) vary as the temperature changes. The plastic shortening, compared with both lard and soybean oil, has a higher SFI at all measurement temperatures (Table 5). The data, therefore, tend to suggest that the amount of solid fat present in bread somehow affects the firmness. Evidence in the literature also seems to support this model. Baker and Mize (1942) reported that the bread-improving effects of a fat are largely determined by whether it is solid or liquid at the temperatures of dough mixing and proofing. Baldwin et al. (1965) have shown that the addition of 12 percent hard-fat flakes to lard produced the softest continuous mix bread. Percentages above and below the 12 percent hard-fat level were reported to increase bread firmness.

Table 4. Average loaf specific volume for breads that contained lard, soybean oil and plastic soy-oil shortening

Fat Level and Type	Mean Loaf Specific Volume[a] (cm^3/g)
Control	5.80 A
1.5% soybean oil	5.81 A
3.0% soybean oil	5.88 B
1.5% lard	5.92 C
3.0% lard	6.02 E
1.5% shortening	5.97 D
3.0% shortening	6.05 E

[a]Means followed by the same letter are not significantly different at an alpha-level of 0.05.

Table 5. Fat analyses

Analysis	Fat			
	Oil	Shortening	Lard	Hard Fat[a]
SFI[b] at 10.0°C (50°F)	-	51.5	30.1	11.6
at 21.1°C (70°F)	-	36.8	20.6	12.3
at 26.7°C (80°F)	-	18.0	14.1	12.1
at 33.3°C (92°F)	-	14.1	5.0	12.2
at 37.8°C (100°F)	-	5.6	3.2	11.6
at 40.0°C (104°F)	-	2.2	2.5	11.6
Wiley Melting Point, °F	-	105 ± 1	104.5	145 ± 5
Iodine Value	117	70	62.7	7.5 ± 2.5

[a]For the 90 percent soy oil, 10 percent hard fat blend.

[b]Percent solid fat present at a given temperature.

Interaction of Fats with Storage Temperature

It is a common, though unsubstantiated, belief that certain fats (most noticeably plastic shortening) cause increases in bread firmness during winter months due to exposure of the products to lower ambient temperatures (Jackel, 1982). This results in a reduction of the usage levels of plastic shortenings during this period of the year. Since this belief is for all intents and purposes unproven, the interaction between storage temperature, fat type, and fat level are of interest.

The mean firmness values of breads prepared with 0, 1.5 or 3.0 percent plastic shortening are presented in Table 6. After 1 day of storage, the breads containing the 1.5 percent plastic soy-oil shortening were less firm than those containing either the 0 or 3.0 percent levels. Analysis of variance showed that these differences in firmness between the three fat levels were not significant within a given storage temperature. At the end of 3 days of storage, the breads containing 1.5 percent plastic shortening were, again, less firm. Here the only significant difference in firmness between the 1.5 and 3.0 percent shortening levels was measured at 7.5°C. No significant differences in firmness were found between these two levels at the 15 and 25°C storage temperatures. After 5 days of storage, significant differences in bread firmness between the two shortening levels existed at all three storage temperatures. Therefore, increasing the shortening level from 1.5 to 3.0 percent tended to significantly increase bread firmness. In addition, storage at a lower temperature made this difference manifest at shorter periods of storage time. These phenomena are consistent with the previously-discussed assertion that higher levels of plastic shortening produced breads that were firmer in the cold winter months.

Table 6. Firmness of breads made with plastic soy-oil shortening and stored for 1, 3 and 5 days at 7.5, 15 and 25°C

Shortening (%)	Storage Time (days)	Mean Firmness[a] (g)		
		7.5°C	15°C	25°C
0.0	1	184.8 E	157.4 BC	111.7 A
	3	260.0 IJK	238.6 HI	188.3 E
	5	311.3 N	285.7 LN	231.7 FGH
1.5	1	175.7 DE	145.3 B	112.1 A
	3	246.9 HI	220.0 FG	166.2 CD
	5	284.1 L	253.3 IJ	218.0 F
3.0	1	184.8 E	153.8 BC	117.6 A
	3	267.7 JK	235.3 GH	180.6 DE
	5	300.4 MN	273.7 KL	235.4 H

[a]Means followed by the same letter are not significantly different at an alpha-level of 0.05.

Table 7 presents the mean firmness values for breads that contained 0, 1.5 or 3.0 percent soybean oil and identifies those differences that were significant. Compared to its control (0 percent), 1.5 percent soybean oil did not significantly reduce bread firmness. The inclusion of 3.0 percent soybean oil, however, did significantly reduce bread firmness. The differences in mean bread firmness became more significant as storage time increased. The same trend occurred at reduced storage temperatures. Again, lower temperatures produced significant differences at shorter storage times.

The mean firmness of breads containing 0, 1.5 or 3.0 percent lard are given in Table 8. Lard at 1.5 percent significantly decreased bread firmness, compared to the control (0 percent), only at the lower storage temperatures and higher storage times. At higher temperatures and shorter times, differences in firmness were not significant. The addition of 3.0 percent lard resulted in further reductions in the bread firmness (Table 8). As was true for the 1.5 percent level, significant differences were, again, only manifested at lower storage temperatures and longer storage times.

Results of the Hard Fat/Soy Oil Model

In order to test the hypothesis that the SFI of fats has an effect on bread firmness, a model fat system was developed. It was theorized that, by combining hard-fat flakes at different percentages with a soybean oil, fats having a desired SFI could be produced. In this model, 20 percent hard-fat flakes combined with 80 percent soybean oil would result in a fat having an SFI of 20. Hard fat/soy oil ratios of 0:100, 10:90, 20:80 and 40:60 were prepared for this experiment. As a test of the physical properties of the model fat, one combination (10:90) was analyzed for its SFI. Table 5 gives the SFI values for this particular blend. It can be seen

Table 7. Firmness of breads made with soybean oil and stored for 1, 3 and 5 days at 7.5, 15 and 25°C

Soybean Oil (%)	Storage Time (days)	Mean Firmness[a] (g)		
		7.5°C	15°C	25°C
0.0	1	184.8 FG	157.4 CD	111.7 A
	3	260.0 L	238.6 K	188.3 G
	5	311.3 P	285.7 NO	231.7 IJK
1.5	1	175.7 EFG	146.1 BC	107.3 A
	3	253.4 L	231.9 IJK	185.5 G
	5	298.1 OP	275.8 MN	229.1 HIJ
3.0	1	161.6 DE	132.0 B	97.1 A
	3	234.3 JK	213.7 H	169.6 DEF
	5	282.6 N	260.6 LM	216.1 HI

[a]Means followed by the same letter are not significantly different at an alpha-level of 0.05.

Table 8. Firmness of breads made with lard and stored for 1, 3 and 5 days at 7.5, 15 and 25°C

Lard (%)	Storage Time (days)	Mean Firmness[a] (g)		
		7.5°C	15°C	25°C
0.0	1	184.8 FG	157.4 CD	111.7 AB
	3	260.0 MN	238.6 JKL	188.3 FG
	5	311.3 Q	285.7 P	231.7 HIJK
1.5	1	191.4 G	167.3 DE	116.3 B
	3	252.2 L	232.2 IJK	185.0 FG
	5	283.1 OP	260.2 MN	222.7 HIJ
3.0	1	174.5 EF	147.2 C	100.3 A
	3	237.9 JKL	217.3 HI	167.2 DE
	5	269.5 NO	240.1 KL	216.7 H

[a]Means followed by the same letter are not significantly different at an alpha-level of 0.05.

that the SFI was similar in value to the percentage of hard fat that was present in the blend. Therefore, it appears that the model developed for this part of the study was capable of producing fats having the desired SFI's.

The results of including the model fats in breads are illustrated in Figures 6, 7 and 8. After 1 day of storage, the breads containing the 0:100 and 40:60 hard fat/soy oil ratios were the firmest. The hard fat/soy oil combinations (10:90 and 20:80) between these two ratios were less firm (Figure 6). The same relationship existed at the end of 3 days (Figure 7) and 5 days (Figure 8) of storage.

Analysis of variance, using an alpha-level of 0.10, showed that after 1 day of storage a significant difference in the mean firmness between the 40:60 and 20:80 hard-fat blends was measured at 7.5°C (Table 9). No significant differences in mean firmness were found between the four blends at the 15 and 25°C storage temperatures. At the end of 3 days of storage, significant differences in firmness between the 40:60 and 20:80 blends were, again, only measured at 7.5°C (Table 10). After 5 days of storage, significant differences in bread firmness between the 40:60 and 20:80 blends were found at both the 15 and 7.5°C storage temperatures (Table 11).

From the data reported above, it appears that the presence of hard fat in conjunction with oil decreases bread firmness over time. However, if the hard-fat level exceeds 20 percent of the total added lipid, bread firmness will increase. Further, this mechanism appears to be enhanced with lower storage temperatures and longer storage times. The data form this part of the experiment were in concurrence with the results obtained earlier with plastic shortening. Therefore, it appears that this model helps support the previous hypothesis that the SFI of fats has an effect on bread firmness.

Figure 6. Effect of different ratios of hard-fat flakes and soybean oil on the firmness of breads stored for 1 day at 7.5°C (■), 15°C (□), and 25°C (⊠)

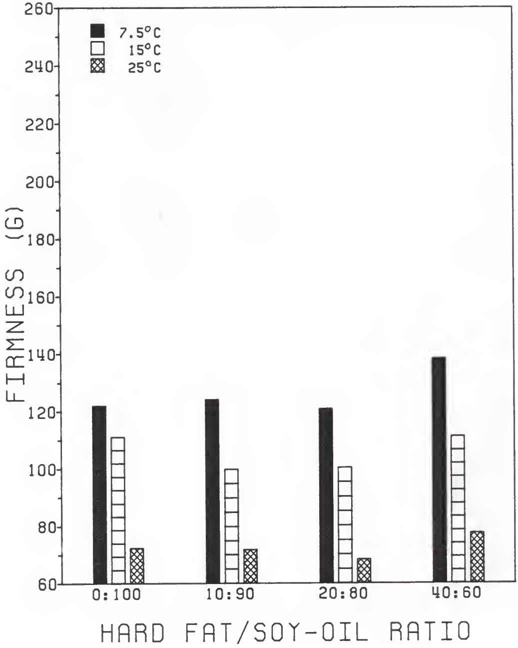

7.5°C
15°C
25°C
FIRMNESS (G)
260
240
220
200
180
160
140
120
100
80
60
0:100
10:90
20:80
40:60
HARD FAT/SOY-OIL RATIO

Figure 7. Effect of different ratios of hard-fat flakes and soybean oil on the firmness of breads stored for 3 days at 7.5°C (■), 15°C (□), and 25°C (▩)

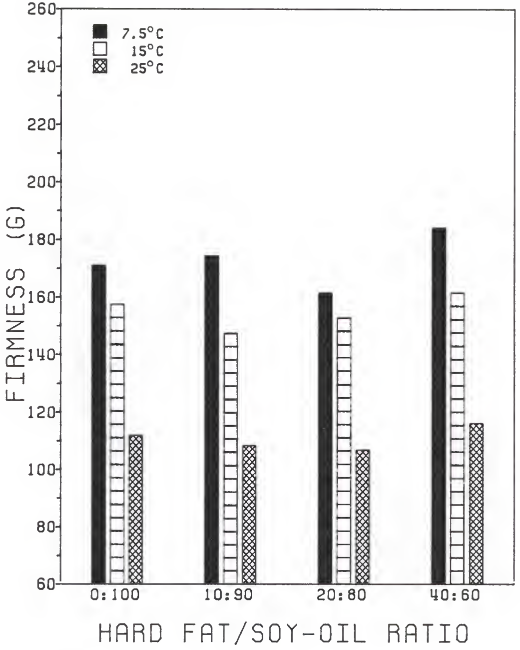
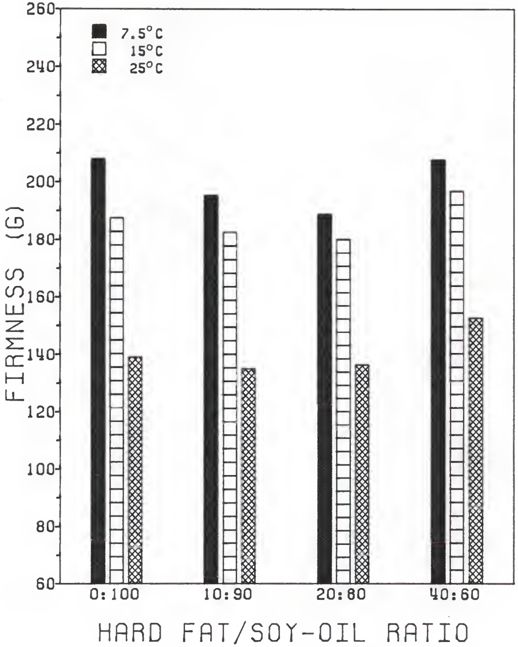

7.5°C
15°C
25°C
260
240
220
200
180
160
140
120
100
80
60
FIRMNESS (G)
0:100
10:90
20:80
40:60
HARD FAT/SOY-OIL RATIO

Figure 8. Effect of different ratios of hard-fat flakes and soybean oil on the firmness of breads stored for 5 days at 7.5°C (■), 15°C (□), and 25°C (▩)



260
240
220
200
180
160
140
120
100
80
60
FIRMNESS (G)
7.5°C
15°C
25°C
0:100
10:90
20:80
40:60
HARD FAT/SOY-OIL RATIO

Table 9. Effect of hard fat/soy oil ratio on the firmness of breads stored for 1 day at 7.5, 15 and 25°C

Hard Fat/Soy Oil Ratio	Mean Firmness[a] (g)		
	7.5°C	15°C	25°C
0:100	122.0 AB	111.1 A	72.4 A
10:90	124.0 AB	99.7 A	71.7 A
20:80	120.7 A	100.3 A	68.3 A
40:60	138.1 B	111.0 A	77.4 A

[a]Means followed by the same letter within a single column are not significantly different at an alpha-level of 0.10.

Table 10. Effect of hard fat/soy oil ratio on the firmness of breads stored for 3 days at 7.5, 15 and 25°C

Hard Fat/Soy Oil Ratio	Mean Firmness[a] (g)		
	7.5°C	15°C	25°C
0:100	171.0 AB	157.5 A	111.8 A
10:90	174.3 AB	147.4 A	108.3 A
20:80	161.4 A	152.8 A	106.7 A
40:60	184.0 B	161.4 A	116.0 A

[a]Means followed by the same letter within a single column are not significantly different at an alpha-level of 0.10.

Table 11. Effect of hard fat/soy oil ratio on the firmness of breads stored for 5 days at 7.5, 15 and 25°C

Hard Fat/Soy Oil Ratio	Mean Firmness[a] (g)		
	7.5°C	15°C	25°C
0:100	208.0 B	187.5 AB	139.0 AB
10:90	195.3 AB	182.4 AB	135.0 A
20:80	188.7 A	179.9 A	136.3 AB
40:60	207.7 B	196.8 B	152.5 B

[a]Means followed by the same letter within a single column are not significantly different at an alpha-level of 0.10.

Effect of the Inclusion of Surfactants

Most commercially-produced breads contain one or more surfactants (Dubois, 1984). Therefore, it was of interest to examine the effects of surfactants on the firming patterns that were produced by the lard, soybean oil and plastic shortening (Figures 6, 7 and 8). Because lard and soybean oil produced breads that firmed in a similar fashion (i.e. decreases in bread firmness as usage levels increased from 1.5 to 3.0 percent), it was decided, for simplification, to omit lard from this part of the study. Therefore, only results for soybean oil and plastic shortening are given below.

Analysis of variance showed that at all storage times and storage temperatures, sodium stearoyl-2-lactylate (SSL) was significantly more effective at reducing bread firmness than were the distilled monoglycerides (Tables 12, 13 and 14). Distilled monoglycerides (DMG), however, were used at a lower level than SSL. In addition, DMG was in its unhydrated form when added to the dough. This could explain its poor performance.

The bread firmness, recorded after 1 day of storage, is presented in Table 12. Both SSL and DMG effectively eliminated the differences in firmness that were occurring between the 1.5 and 3.0 percent levels of the soybean oil and plastic shortening. This effect was independent of storage temperature. The same results were obtained after 3 days (Table 13) and 5 days (Table 14) of storage.

Pattern of Firmness Within the Loaves of Bread

The least significant difference (LSD) value for comparison of mean firmness between breads containing different hard fat/soy oil ratios was equal to 16.5 at the 0.10 alpha-level. This indicates that a large amount of variation in crumb firmness was measured among individual slices within

Table 12. Effects of the inclusion of distilled monoglycerides (DMG) or sodium stearoyl-2-lactylate (SSL) on the firmness of breads stored for 1 day at 7.5, 15 and 25°C

Fat Type	Fat Level (%)	Surfactant	Mean Firmness[a] (g)		
			7.5°C	15°C	25°C
Shortening	1.5	Control	135.5 CD	109.8 CD	75.7 BC
		DMG	127.4 CD	105.3 CDE	75.4 BC
		SSL	104.5 E	86.5 FG	61.0 C
	3.0	Control	155.9 AB	127.5 AB	83.3 AB
		DMG	130.1 CD	110.4 CD	75.1 BC
		SSL	103.4 E	89.4 FG	68.9 BC
Soybean Oil	1.5	Control	163.6 A	131.4 A	95.1 A
		DMG	127.6 CD	101.5 CDEF	81.8 AB
		SSL	99.5 E	80.6 G	62.2 C
	3.0	Control	141.4 BC	115.5 BC	76.5 ABC
		DMG	119.1 DE	96.5 EF	84.8 AB
		SSL	106.2 E	93.5 EFG	70.2 BC

[a]Means followed by the same letter within a single column are not significantly different at an alpha-level of 0.05.

Table 13. Effects of the inclusion of distilled monoglycerides (DMG) or sodium stearoyl-2-lactylate (SSL) on the firmness of breads stored for 3 days at 7.5, 15 and 25°C

Fat Type	Fat Level (%)	Surfactant	Mean Firmness[a] (g)					
			7.5°C		15°C		25°C	
Shortening	1.5	Control	186.8	BC	168.3	BC	124.3	ABC
		DMG	176.3	CD	159.6	BCD	115.7	ABCDE
		SSL	141.8	E	123.4	F	94.8	DE
	3.0	Control	201.9	B	175.5	AB	132.8	AB
		DMG	172.7	CD	151.1	CDE	117.3	ABCD
		SSL	143.0	E	130.8	EF	93.8	DE
Soybean Oil	1.5	Control	232.8	A	191.9	A	139.2	A
		DMG	190.3	BC	163.3	BC	164.8	BC
		SSL	144.6	E	120.2	F	90.5	E
	3.0	Control	194.5	BC	169.1	ABC	128.4	ABC
		DMG	173.9	CD	164.8	BC	106.4	CDE
		SSL	153.9	DE	138.6	DEF	112.2	BCDE

[a]Means followed by the same letter within a single column are not significantly different at an alpha-level of 0.05.

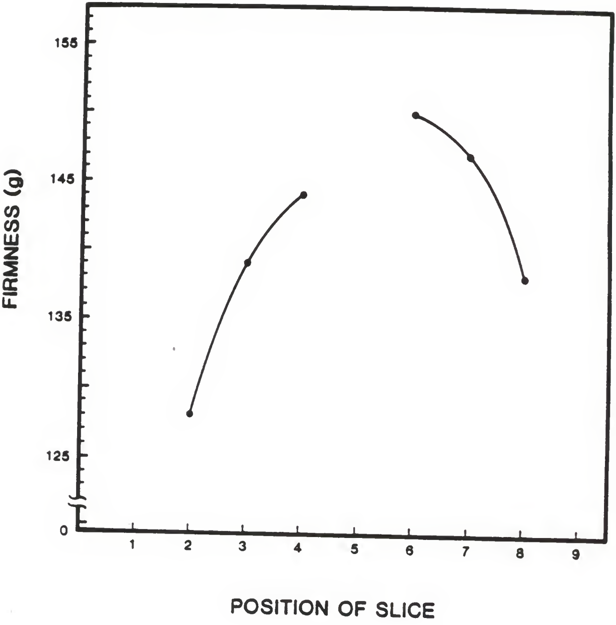
Table 14. Effects of the inclusion of distilled monoglycerides (DMG) or sodium stearoyl-2-lactylate (SSL) on the firmness of breads stored for 5 days at 7.5, 15 and 25°C

Fat Type	Fat Level (%)	Surfactant	Mean Firmness[a] (g)					
			7.5°C		15°C		25°C	
Shortening	1.5	Control	206.7	D	200.5	BCD	151.2	BCDE
		DMG	216.1	BCD	177.5	DEF	162.1	BC
		SSL	169.0	F	153.8	G	122.6	F
	3.0	Control	209.0	CD	203.0	BC	157.9	BCD
		DMG	201.8	DE	178.6	DEF	151.0	BCDE
		SSL	172.7	F	158.3	FG	137.5	DEF
Soybean Oil	1.5	Control	255.0	A	238.5	A	188.8	A
		DMG	231.2	B	207.3	B	173.0	AB
		SSL	179.8	F	152.9	G	169.4	EFG
	3.0	Control	225.6	BC	183.4	CDE	148.6	CDE
		DMG	204.9	D	195.1	BCD	147.5	CDE
		SSL	183.2	EF	169.4	EFG	138.1	CDEF

[a]Means followed by the same letter within a single column are not significantly different at an alpha-level of 0.05.

the same loaf. When the crumb firmness of each slice was plotted against its position within the loaf, a definite pattern appeared (Figure 9). The center slices were firmer than the end slices. Ponte et al. (1962) reported the occurrence of a similar pattern in their studies and proved that the center slices had a lower specific volume, which explained why they were firmer than the end slices. Similar results were also obtained by Al-Madani (1980).

Figure 9. Pattern of firmness within the loaves. Mean firmness values for each slice were obtained by averaging over all storage times, storage temperatures, and replications. The curve is discontinuous because the firmness of the center slice (position 5) was not measured.


155
145
135
125
0
FIRMNESS (g)
1
2
3
4
5
6
7
8
9
POSITION OF SLICE

CONCLUSIONS

It is believed at present that higher levels of certain fats (particularly plastic shortening) cause increased firmness in breads produced during the cold winter months. This effect causes some bakers to reduce the usage levels of plastic shortenings during that period of the year. The work reported above demonstrates that the beliefs and practices of these bakers were not unwarranted.

When soybean oil or lard were added to breads, they both decreased bread firmness as their usage levels were increased from 1.5 to 3.0 percent. In contrast, when the usage level of plastic shortening was increased from 1.5 to 3.0 percent, an increase in bread firmness resulted. Analysis of variance showed that the differences in firmness measured between the two levels of plastic shortening became significant at lower storage temperatures and higher storage times. These phenomena are consistent with the bakers' previously discussed assertion that higher levels of plastic shortening produced breads that were firmer in the cold winter months.

The plastic shortening, compared to the soybean oil and lard, has a higher SFI at all measurement temperatures. Therefore, this tends to suggest that the amount of solid fat present in bread somehow affects the firmness. In order to test this hypothesis, a model fat system composed of different hard fat/soy oil ratios was constructed. It was theorized that by combining hard-fat flakes at different percentages with a soybean oil, fats having a desired SFI could be produced. This was found to be true and the results of this study appear to show that the presence of hard fat in conjunction with oil decreases bread firmness. However, if the hard fat level exceeds 20 percent of the total added lipid, bread firmness will increase. Further, this mechanism appears to be enhanced with lower storage temperatures and longer storage times. The data from this part of the experiment were in concurrence with the results obtained earlier using plastic shortening. Therefore, it appears that this model helped support the previous hypothesis that the SFI of fats has an effect on bread firmness. However, more work needs to be done to elucidate the actual mechanism by which high percentages of solid fat increase the firmness of breads and why storage at lower temperature enhances this firmness.

The inclusion of either 0.375 percent sodium stearoyl-2-lactylate (SSL) or 0.25 percent distilled monoglycerides (DMG) with the soybean oil or plastic shortening effectively eliminated the differences that were occurring between the 1.5 and 3.0 percent usage levels of these two fats. This effect was similar at all storage times and storage temperatures. Therefore, if bakers include surfactant in their formulation they need not worry about higher shortening levels causing an increase in bread firmness during the cold winter months.

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BREAD STALING: EFFECTS OF FATS, SURFACTANTS, STORAGE TIME AND STORAGE TEMPERATURE, AND THE INTERACTION BETWEEN THESE FACTORS

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ABSTRACT

Lard, soybean oil, and plastic soy-oil shortening were independently added to breads at usage levels of 0, 1.5 and 3.0 percent. The breads were then stored for 1, 3 and 5 days at 7.5, 15 and $25^{\circ}C$. Bread firmness was determined by crumb compressibility with a Voland Stevens Texture Analyzer. Both soybean oil and lard decreased bread firmness as their usage levels were increased from 1.5 to 3.0 percent. In contrast, when the usage level of plastic shortening was increased from 1.5 to 3.0 percent, an increase in bread firmness resulted. This pattern of staling was the same at all storage times and storage temperatures. Analysis of variance showed that the differences in bread firmness measured between the 1.5 and 3.0 percent fat levels were significant only at the longer storage times and lower storage temperatures. The amount of solid fat present could possibly be a factor affecting the bread firmness.

The inclusion of either 0.375 percent sodium stearoyl-2-lactylate (SSL) or 0.25 percent distilled monoglycerides (DMG) with the soybean oil or plastic shortening effectively eliminated the differences in bread firmness that were occurring between the 1.5 and 3.0 percent usage levels of these two fats. The SSL was significantly more effective at reducing bread firmness than was the DMG. These effects were similar at all storage times and storage temperatures.

A model fat system composed of hard-fat flakes and soybean oil in ratios of 0:100, 10:90, 20:80, and 40:60 was developed to relate the percent solids in a fat to bread firmness. The amount of hard fat present appeared to affect bread firmness. Breads that contained hard fat/soy oil ratios of 0:100 and 40:60 were more firm than those that contained the 10:90 and 20:80 ratios.