THE EFFECT OF MIXING ATMOSPHERE AND FAT CRYSTAL SIZE ON BREAD QUALITY

by

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INTRODUCTION

One ingredient known to improve bread quality is fat (shortening). However, its role in breadmaking is complex. How fat works in bread systems to produce the desirable benefits is not known.

Many have speculated that addition of fat to a bread formula aids in air incorporaton, gas retention, and acts as a lubricant to soften the bread. The possible physical mechanisms by which fats produce an improving effect in breads have been reviewed by Bell _et al_. (1977).

Two areas of research that have not been throughly investigated are (a) the effects of different mixing atmospheres on the quality of breads containing fats. and (b) the effects of different fat polymorphs on bread characteristics.

The purpose of this investigation was to study the effects of different fat polymorphs and different mixing atmospheres on the following parameters: (a) dough density, (b) dough rheology, (c) dough and bread structure, and (d) loaf volume and crumb characteristics.

REVIEW OF LITERATURE

Numerous articles have been published on the importance of wheat flour lipids in bread quality (for review see Chung and Pomeranz, 1977). This review will deal only with the effects of added fat (shortenings) to a bread formula and its effect on dough rheology, gas incorporation and retention, and bread characteristics.

Lubricating Effects of Fat

The incorporation of triglycerides in bread dough results in improved bread quality by acting as a lubricant between starch granules and gluten strands (Platt and Fleming, 1923). However, it is not clear whether this lubricating action occurs during dough mixing or only during the baking stage or both. Information concerning the lubricating effects of fat on doughs can be provided, in part, by rheological measurements. However, the effects of fats on dough rheology have not been extensively studied.

Bohn and Bailey (1937) showed that farinograph mixing time increased with increasing levels of fat (0-6%). Moore and Helman (1942) found that water absorption decreased as fat was increased from 0 to 8%; this was true regardless of type of fat used. Conversely, Tao and Pomeranz (1968) found that water absorption was not altered when 2% vegetable shortening or corn oil was added to flour-water doughs.

Mixograph studies indicate that commercial shortenings or oils, do not significantly affect mixing time of flour-water doughs (Tao and Pomeranz, 1968) or doughs containing yeast, salt and sugar (Shellenberger, 1941). However, corn oils with high iodine values were found to increase dough mixing time (Tao and Pomeranz, 1968).

Extensibility and resistance to extension of flour-water doughs containing fats were studied by Merritt and Bailey (1945). They found that 3% vegetable shortening or cottonseed oil decreased extensibility and increased resistance to extension of doughs made with strong flours. On the other hand, both extensibility and resistance to extension increased when fats were present in doughs made from weak flours.

Little information is available on the effects of fats on the rheology of full formula doughs. Furthermore, few studies have correlated rheological measurements with bread quality. Much work is needed in this area if productive utilization of rheological data is to be realized.

Gas Incorporation and Retention in Doughs

Although a lubrication role for fat is possible, it does not explain why liquid oils do not produce as great an improving effect as solid shortenings in bread made by the rapid breadmaking process (Baker and Mize, 1942; Baldwin et al., 1963; 1965). Therefore, the improving effects of fats in dough may be related, instead, to air incorporation and/or gas retention.

Only one study has reported on the effects of fat on air incorporation in doughs. Baker and Mize (1942) showed that doughs containing fat were less dense than those without fat; differences in density were thought to be due to the emulsifying action of fat. No mention was made of the effect of fat crystal size on air incorporation or distribution.

Studies on gas retention in doughs containing fat are also limited. Elton and Fisher (1966) showed that, during baking, doughs containing fat expand more rapidly and for a longer time than doughs without fat. They suggested that this behavior might be related to a lower loss of CO_2 by doughs when fat was present.

Recently, works were reported on the effects of fats on gas retention in doughs (Daniels and Fisher, 1976 and Bell et al., 1974). The data indicate that fat exerts its beneficial effects on loaf volume by delaying the release of CO_2 during baking, resulting in an increase in dough expansion the first five min of baking. The delayed release of CO_2 may have been initiated during dough mixing when fat influences the organization of dough structural elements which later affect gas retention (Bell et al., 1974).

Other Aspects Relating to the Lubrication Hypothesis

The importance of fat solidity (% solids and melting point) in the improving action of fats has been extensively studied (Elton and Fisher, 1966; Baker and Mize, 1942, and many others). Early work by Baker and Mize (1942) showed that waxes improed loaf volume and texture similar to that of hydrogenated cottonseed oil.

Fat need not be plastic to produce high quality bread (Baldwin et al., 1963). Coconut oil or soy oil produced satisfactory bread when it contained small quantities of solid fat suspended in the liquid oil.

The melting point of the solid fat appears to be an important factor in the bread improving action of fat. Shortenings which have a proportion of fat that is solid at dough processing temperatures, yield better bread characteristics (Baldwin et al., 1963 and Chamberlain et al., 1965). Baldwin et al.(1963) have suggested that at dough temperatures during mixing, fermentation and proofing, solid fats acts only as a reservior. During baking the fat melts and was thought to coat gas cells to seal off leaks, resulting in improved gas retention. On the other hand, Bell et al.(1977) postulated that, although melting point is important, the orientation and mobility of hydrocarbon chains with respect to dough components may be the critical factor.

Neither fatty acid composition nor the degree of unsaturation were found to be essential to the effectiveness of shortening in bread (Baldwin et al., 1963; Chamberlian et al., 1965). On the other hand, Baldwin et al.,(1963) suggested that the crystalline structure of fat may affect bread quality. In a study of the continuous bread process, they briefly mentioned that smaller fat crystals produced better loaf volumes than large crystals. No explanation for these results was given. Perhaps fat crystal size in intricately related to the number of gas cells formed in the dough, with smaller crystals contributing numerous nucleation sites. On the other hand, fat crystal size may have an effect on the orientation of dough components, contributing to a strong or weak structure that determines gas retaining properties during baking. Much research is need in this area.

MATERIALS AND METHODS

Materials

Flour. Untreated flour (BCS 1977) was obtained from the USDA-Grain marketing Research Center, Manhattan, Kansas. The flour contained 12.2% protein, 12.5% moisture, and 0.4% ash.

Fat. Lard (Swift Edible Oil co.) was used in this study. The following analyses were received with the sample:

11% Fully Hydrogenated Lard

89% Bleached Lard with 0.05% Tenox 4 (BHA and BHT)

Peroxide Value 0.1 me/kg

Moisture 0.03%

Wiley melting point 116-1 ^{o}F

Active Oxygen Method 30 hr +

The fatty acid composition of the lard is shown in Figure 1.

Methods

Farinograph. A 300gm Brabender farinograph with temperature controlled at 27 ^{o}C was used to mix all doughs. The farinograph bowl was modified to run experimemts under different atmospheres as shown in Figure 2. Modifications included placement of rubber gasket around the farinograph bowl and positioning O-rings at the shaft of the blades. The metal cover for the bowl has vacuum and gas gauges and is fastened securely to the bowl by means of threaded bolt and hook clamps (see photo insert Fig. 2). A rubber gasket on the inside of the cover fits tightly to the top surface of the bowl when a vacuum is applied.

Extensograph. The Brabender extensograph was used to measure the rheological properties of full formula doughs after 45 min and 90 min of fermentation. Extensibility and resistance to extension were not measured after 135 min because, preliminary tests showed that these data did not produce more information than the 90 min extensogram.

Fig. 1. Fatty acid composition of lard.

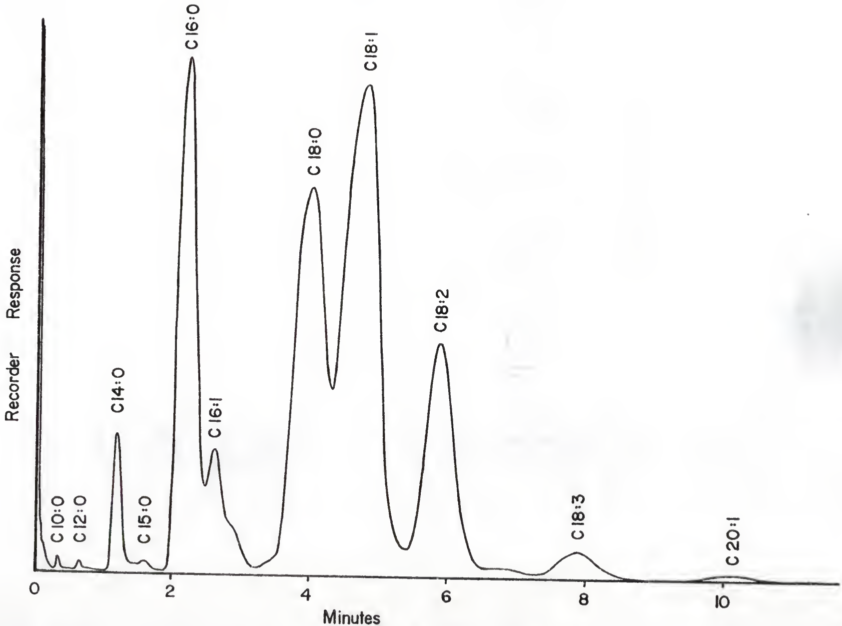
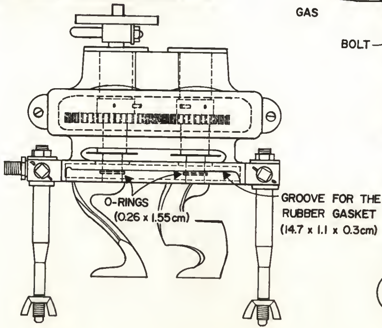
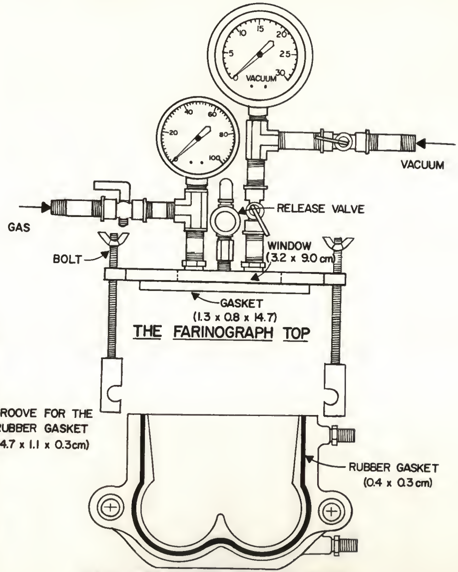

Recorder Response
C 10:0
C 12:0
C14:0
C 15:0
C 16:0
C 16:1
C 18:0
C18:1
C18:2
C 18:3
C 20:1
0
2
4
6
8
10
Minutes

Fig. 2. Detailed description of the modification made on the farinograph bowl.



BACK OF THE FARINOGRAPH
SHOWING THE O-RINGS



BACK VIEW OF FARINOGRAPH BOWL
SHOWING RUBBER GASKET

Formula. The formula in Table 1 was used for breadmaking and for farinograph and extensograph measurements and for the determination of dough densities as well as structural studies.

Lard was recystallized at different temperatures (see later section) before adding to the formula.

Baking Procedure. The straight dough method was used and the pup loaf procedure was followed. A flow diagram of the procedure, employing a 2 or 3 hr fermentation, is shown in Figure 3. After baking the loaves were weighed and volumes were determined by rapeseed displacement.

Fat crystallization. Different fat crystal sizes for microscopy were prepared from lard by weighing 2 mg of lard on a glass slide, melting on a hot plate and than recrystallizing by either plunging the slide in liquid nitrogen (LN_2) or allowing the slide to stand at room temperature (see flow digram in Fig. 4). Melting points were determined on a microscope hot stage. Preparation of fat crystal sizes for baking was done in the same manner as described above but 9 gm of lard was melted in an aluminum weighing dish and prior to recrystallization.

The fat crystals that were obtained by these procedures are shown in Figure 5. Fat crystal sizes in lard "as is" ranged from 5 to 20 μm. After recrystallization of melted lard at room temperature, fat crystal size increased. They ranged from 50 to 150 μm(β). These large crystals often clump together to form aggregates that give the lard a grainy appearance. The range of fat crystal sizes produced by rapid cooling in LN_2 was 0.5 to 1 μm and can be classified as β'.

The melting points of the three fat treatments were 49 $^{\circ}$C for lard "as is", 51.1 $^{\circ}$C for room temperature recrystallized lard, and 45.3 $^{\circ}$C for LN_2 recrystallized lard.

Microscopy. Samples of full formula doughs were taken after designated processing steps (after mixing, proofing, and baking) and frozen. Samples were sectioned on an American Optical freezing microtome operated at -25 $^{\circ}$C.

Table 1. Formula used in this study

Ingredient	%
Flour	100
Water	64
Sugar	6
Salt	1.5
Malt syrup	0.5
Yeast	2.4
Lard*	0 & 3
NFDM	4
$KBrO_3$	20ppm

* Includes lard "as is" (β'-I), recryst. at R.T. (β) and recryst. at LN_2 (β').

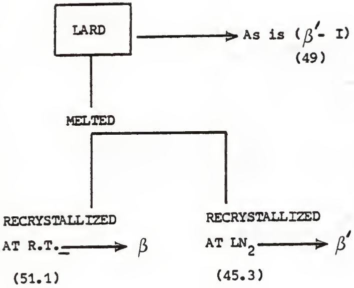
Figure 3. Pup loaf procedure employed in this study.

Steps in 2-hrs. fermentation	Steps in 3-hrs. fermentation
Mixing	Mixing
69 min.	105 min.
1st punch	1st punch
34 min.	50 min.
2nd punch	2nd punch
17 min.	25 min.
Panning	Panning

Proof to 7.8 cm. height

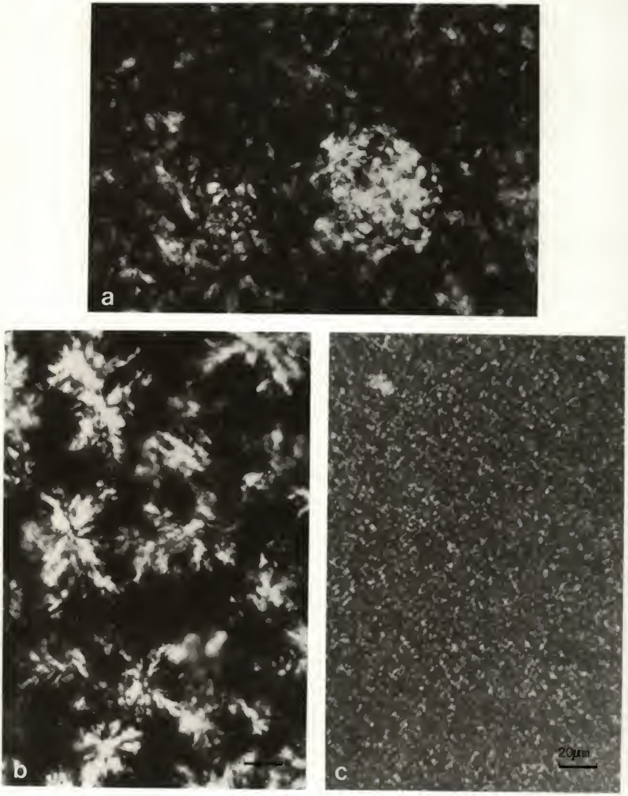
Bake For 24 min. at 218°C (425°F)

Figure 4.



THE MELTING POINTS ($^{\circ}$C) OF THE DIFFERENT FAT TREATMENTS ARE GIVEN IN PARENTHESES.

Fig. 5. Recrystallized Lard (a) Intermediate Fat Crystals (I)
(b) Beta Fat Crystals (β)
(c) Beta Prime Fat Crystals (β')


a
b
c
20µm

Sections (10 μm) were collected on glass slides previously coated with albumin fixative. Slides were then stained for protein and fat by methods of Flint _et al_. (1970). Light photomicrographs were taken on a Reichert (Austria) light microscpe.

RESULT AND DISCUSSION

Effects of Mixing Atmosphere on Bread Quality

Other researchers had reported that abnormal bread crumb characteristics were obtained when doughs were mixed under a vacuum of 28in Hg((Baker and Mize, 1941; Chamberlain and Collins, 1979). Both of the studies were with no-time bread processes. We wanted to study the effects of mixing under an excess vacuum on the bread produced by a pup loaf procedure employing a 2hr fermentation period with intermittent punching steps. In addition, the effect of different levels of fat on the characteristics of those breads was studied.

The effects of 0, 0.7% and 3% lard on the quality of breads made from doughs mixed under vacuum of 28 in Hg are shown in Figure 6. As the number of punching steps increased, the bread began to approach normal crumb characteristics and loaf volume. At all fat levels, when the dough was panned 20 min after mixing the bread showed large gas cells and a translucent appearance of the crumb. Similar results were reported by Baker and Mize (1941) for no-time breads.

After a 69 min fermentation period step, improvements in cell distribution and crumb characteristics were noted as well as decreased translucency (Figure 6: a2, b2, & c2). Increasing the total fermentation time to 103 min with intermittent punching steps after 69 min and 103 min, resulted in a greater improvement in bread characteristics (Figure 6: a3, b3, & c3). A 3 hr fermentation gave further improvement in bread quality. Therefore, doughs mixed under vacuum of 28 in Hg can yield breads of satisfactory quality if both fermentation and punching steps are included in the bread process.

Vacuum of 28 in Hg mixed doughs had a yellow color which gradually decreased during dough processing. Therefore, a study was also conducted to determine if this was a major factor in the dough improving effects of the punching operations. Vacuum of 28 in Hg mixed doughs were further processed under a N_2 atmosphere or in air. Breads from these two treatments were found to be identical in loaf

Fig. 6. Effect of fat levels and punching steps on bread quality made from doughs mixed under 28 in. Hg and containing 0% fat (a, 1-3), 0.7% fat (b, 1-3), and 3% fat (c, 1-3).

1: indicates zero punch

2: indicates one punch

3: indicates two punches

a

b

c

volume and grain. However, the breads that were processed under N_2 had a thicker crust and a slightly yellow crumb compared to the air processed doughs. Therefore, incorporation of oxygen during punching appears to be mainly related to the bleaching of flour pigments and does not appreciably affect loaf volume.

The effect on bread quality of including lard in the formula depended on the level of fat used as well as the number of punching operations. Breads containing no lard or 0.7% lard (no punching step) were of poorer quality than comparable breads containing 3% lard (Figure 6: a1, b1, & c1). In addition, volumes of bread containing 0.7% lard were not different from no-lard counterparts at each punching step in the process (Table 2). Bread containing 3% lard, however, showed a marked improvement in loaf volume.

The differences in loaf volume (Table 2.) between the no-lard or 0.7% lard treatments and 3% lard with no punching were much greater than the volume differences observed between these treatments after 2 or 3 punching operations (140 cc vs. 80 cc, respectively). This would tend to suggest that the major improving effect of fat on loaf volume occurred during the mixing operation. It is possible as was suggested by Bell et al. (1977) that fat functions during mixing to produce oriented structures which favor gas retention during the early baking stages.

The above experiments were also conducted using poor quality flour; those result are presented in Figure 7. In general, similar effects of punching operations and fat levels on bread characteristics were observed with poor quality flour. Obviously, the improving effects of these treatments were considerably lessened by the inherent characteristics of the flour. Furthermore, it was also observed that low water levels in dough heightened the detrimental effects of vacuum of 28 in Hg on bread characteristics.

Fat and Dough Rheology

As mentioned above, fat may play an important role in dough mixing. Therefore, further studies were conducted to determine the effects of fat on dough

Table 2. Effect of dough processing steps on the loaf volume (cc) of bread obtained from doughs mixed under 28 in. Hg.

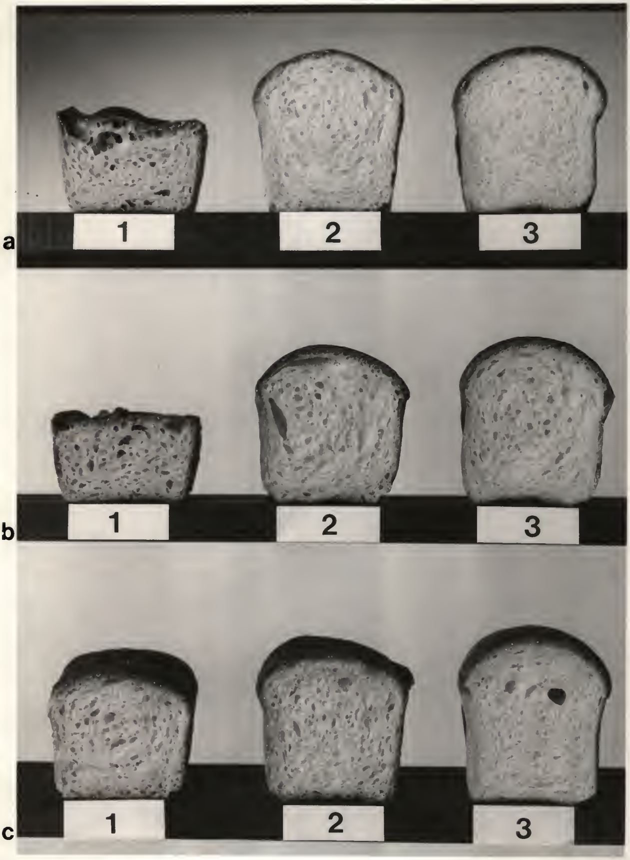
% lard	Number of punching steps			
	0	1	2	3
0	590	680	845	933
0.7	590	700	850	---
3.0	730	775	925	1010

Figure 7. Effect of fat levels and punching steps on bread quality made from doughs mixed under 28 in. Hg and containing 0% fat (a, 1-3), 0.7% fat (b, 1-3), and 3% fat (c, 1-3).

1: indicates zero punch

2: indicates one punch

3: indicates two punches


a
1
2
3
b
1
2
3
c
1
2
3

rheology as measured by the farinograph and extensograph.

Simple Doughs. The effects of different levels of lard (0 to 4%) on farinograph curve characteristics are presented in Figure 8. The addition of lard decreased dough consistency compared to the no-lard treatment. These data are in agreement with Moore et al. (1942), but Tao and Pomeranz (1968) showed that vegetable shortening and corn oil had no effect on dough consistency. Differences in dough strength (Merritt et al., 1945) as well as type of fat used may account for the discrepancies in the literature.

When 3% lard was added to the dough, decreasing the water absorption from 62% to 60.4% produced the same consistency and mixing time as the control. However, at the same consistency, dough containing lard had longer arrival times than the controls as can be seen by the depressed shape of the curve in the early mixing stage (Figure 8.)

Full formula dough. In preparation for breadmaking studies, we wanted to determine the effects of fat crystal size and mixing atmosphere on dough rheology. Farinograph curves of doughs mixed in different atmospheres and containing recrystallized lard are presented in Figure 9. Within each atmosphere, dough containing no lard had higher consistencies than doughs with lard; doughs mixed under vacuum of 28 in Hg showed the highest consistency. When doughs were mixed under vacuum of 28 in Hg a compact and probably, less elastic dough was produced. Carlson and Bohlin (1978) pointed out the essentiality of air cells in fostering dough elasticity. Therefore, the high consistency obtained with doughs mixed under vacuum of 28 in Hg may be due to the inelastic character of the dough rather than to the loss of moisture during mixing.

In general, farinograph curves showed that 3% lard decreased dough consistency in the same manner as described above for flour-water doughs. However, consistency was affected more by atmosphere than by fat crystal size (Table 3). For example, doughs mixed in air with lard "as is" had lower consistencies than

Figure 8. Effect of different fat levels (0-4%) on flour-water farinograms. Water absorption was maintained at 62% under otherwise stated.

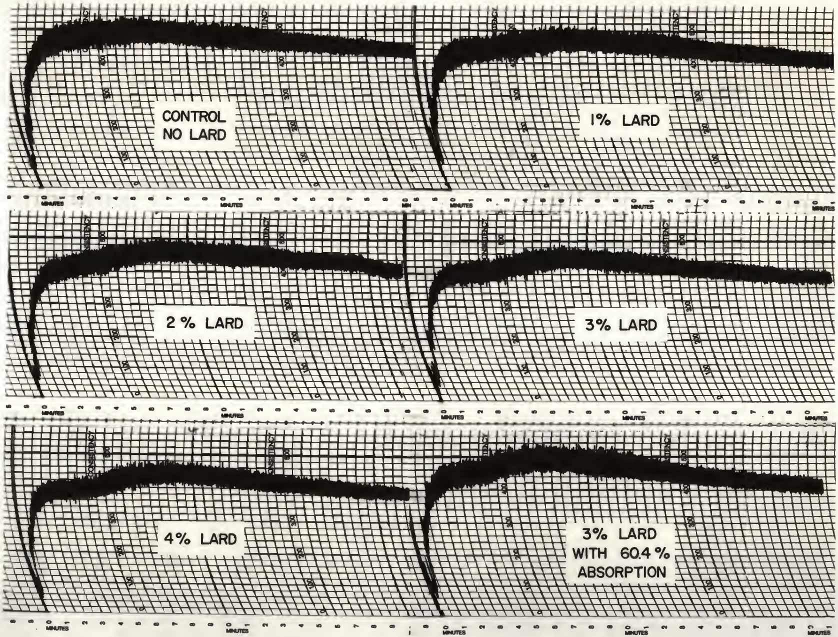

CONTROL
NO LARD
1% LARD
2 % LARD
3% LARD
4% LARD
3% LARD
WITH 60.4 %
ABSORPTION

Figure 9. Effect of different fat crystals and atmospheres on full formula dough farinograph curves mixed to the optimum.

MIXING ATMOSPHERES

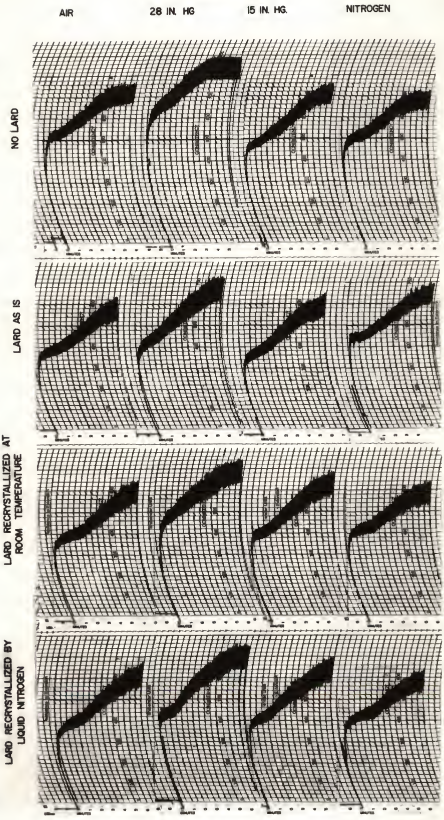


Table 3. Effect of different fat crystal size and mixing atmosphere on the farinogram consistency (B.U.) of full formula dough

Fat treatment	Mixing atmosphere			
	Air	28"Hg	15"Hg	N_2
No lard	720^a	820^a	705^a	690^a
Lard "as is" (β'-I)	575^b	670^b	580^b	640^b
Lard recryt. at R.T. (β)	585^b	675^b	636^c	580^c
Lard recryst. in LN_2 (β')	613^b	695^b	613^{bc}	560^c

LSD: Across atmospheres =40 B.U.

comparable doughs mixed under nitrogen. Some differences in consistency did, however, appear to be related to fat crystal size.

The effect of fat on farinograph consistency has never been fully explained. The decrease in consistency when lard is incorporated either in flour-water or full formula doughs may be related to the effect of fat on flour hydration or to the lubrication action of fat. When fully developed doughs (with and without fat) were allowed to rest for 10 min , 2 hr, and 3 hr, and remixed in the farinograph, the consistency of dough containing lard was lower than of doughs containing no fat (Figure 10). Because differences in hydration should be lessened during long rest periods, these data may suggest that fat functions more as a lubricant than as a deterant to flour hydration. Water activity measurments would be useful here.

Extensograph. Extensograph studies were also conducted on full formula doughs (containing all ingredients including yeast) to obtain more information on the possible lubricating action of fat. The effects of different fat crystal sizes on extensograph curves were also investigated.

Statistical analysis showed that the extensibility of doughs after 45 min and 90 min fermentation was not affected by mixing atmosphere (Table 1 appendix). However, within each atmosphere, doughs without lard were significantly ($P<0.05$) less extensible than doughs containing lard (Fig. 11 and 12). For doughs containing lard , no differences were observed in extensibility due to different fat crystal sizes.

Mixing atmosphere and fat crystal size were found to affect dough resistance to extension at 45 min fermentation (Table 4). In general, doughs mixed under vacuum of 28 in Hg showed the highest resistance to extension. However, this resistance was not affected by the addition of lard to the formula or by crystal size. On the other hand, when doughs were mixed under vacuum of 15 in Hg, lard significantly lowered the resistance with no differences by the various fat

Figure 10. Effect of fat treatment on dough consistency after 10 min., 2 hr. and 3 hr. fermentation.

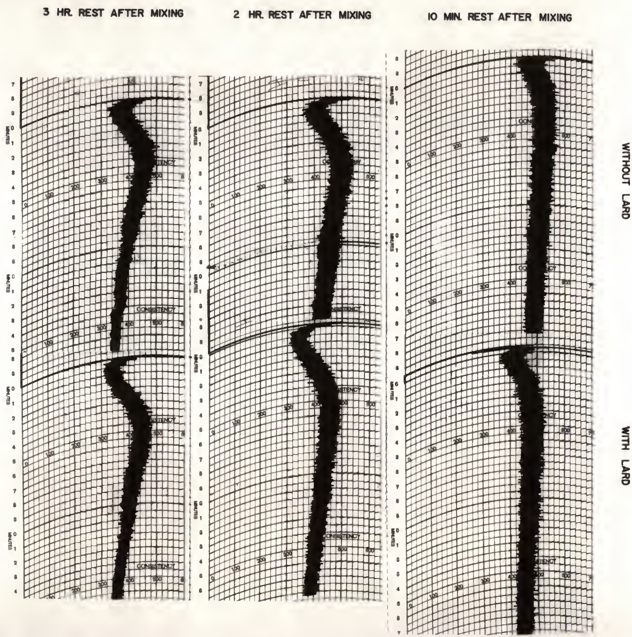

3 HR. REST AFTER MIXING
2 HR. REST AFTER MIXING
10 MIN. REST AFTER MIXING
WITHOUT LARD
WITH LARD

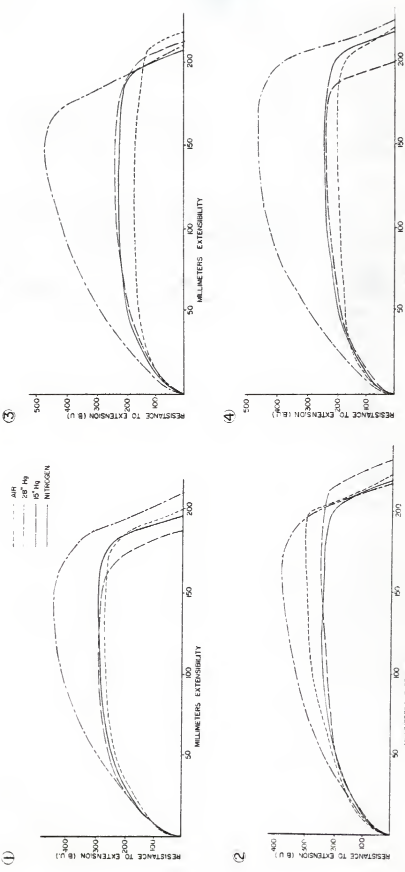
Figure 11. The effect of different atmospheres and fat crystal sizes on extensibility, resistance to extension, and area of full formula doughs after 45 min fermentation:

(1) No lard

(2) with lard "as is"

(3) with β fat crystals

(4) with β' fat crystals



AIR
28" Hg
15" Hg
NITROGEN
RESISTANCE TO EXTENSION (B.U.)
MILLIMETERS EXTENSIBILITY

Figure 11. The effect of different atmospheres and fat crystal sizes on extensibility, resistance to extention, and area of full formula doughs after 90 min fermentation:

(1) No lard

(2) with lard "as is" (β'-I)

(3) with β fat crystals

(4) with β' fat crystals

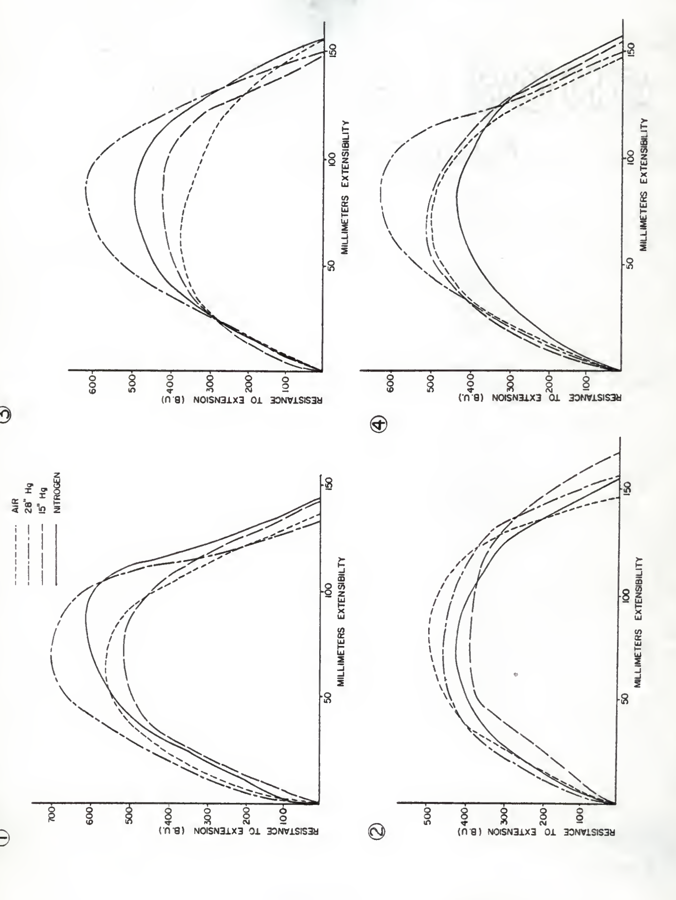

1
2
3
4
AIR
28" Hg
15" Hg
NITROGEN
RESISTANCE TO EXTENSION (B.U.)
MILLIMETERS EXTENSIBILTY
MILLIMETERS EXTENSIBILITY
100
200
300
400
500
600
700
50
100
150

Table 4. Effect of fat crystal size and mixing atmosphere on dough resistance to extension.*

Fat treatment	Mixing atmosphere			
	Air	28"Hg	15"Hg	N_2
Resistance at 45 min				
No lard	200^{a}	240^{a}	230^{a}	220^{a}
Lard "as is" (β'-I)	180^{ab}	230^{a}	190^{b}	190^{ac}
Lard recryst. at R.T. (β)	160^{bc}	240^{a}	170^{b}	180^{ac}
Lard recryst. in LN_2 (β')	170^{bc}	240^{a}	175^{b}	175^{bc}
Resistance at 90 min				
No lard	450^{a}	510^{a}	400^{a}	425^{a}
Lard "as is" (β'-I)	350^{b}	380^{b}	275^{b}	340^{b}
Lard recryst. at R.T. (β)	320^{b}	355^{b}	330^{c}	310^{b}
Lard recryst. in LN_2 (β')	400^{c}	400^{b}	400^{a}	310^{b}

*All values in the table are in Braberder Units (B.U.).

Within each atmosphere and time period, numbers not superscriped by the same letter are significantly different at P= 0.05.

crystal sizes. Fat crystal size did, however, affect the 45 min resistance of of doughs mixed in air or N_2. For example, doughs mixed in air and containing β or β' crystals were significantly less resistant than doughs containing no lard the addition of lard "as is" to the doughs did not reduce resistance compared to the no lard treatment.

Allowing the dough to ferment for 90 min, brought about a greater differentiation among treatments (Table 4). In all atmospheres, doughs containing lard were less resistant than the no-lard control. Furthermore, when doughs were mixed in air or vacuum of 15 in Hg and containing lard, the β' crystals produced the highest resistance. No effect of fat crystal size was observed for doughs mixed under vacuum of 28 in Hg or in N_2.

The area under an extensograph curve is supposed to be related to the total force required to stretch a dough and therefore, should supply some information concerning the elasticity of a dough (Brabender Corp., 1968). The area (under the extensograph curve) of doughs mixed under vacuum was not affected by addition of lard or fat crystal size (Table 5). However, doughs mixed in air or in N_2 required less forces to stretch when β or β' fat crystals were present than the doughs contained no lard or a mixture of intermediate crystals (lard "as is").

The Effect of Mixing Atmosphere and Fat Crystal Size on Bread Quality

The data presented above, indicated that mixing atmosphere and fat crystal size had a definite effect on dough rheology. We wanted to determine if these rheological measurements would be reflected in bread quality. Therefore, the effect of mixing atmosphere and fat crystal size on bread quality was determined.

Doughs were mixed in the 300 gm farinograph under various atmospheres at 90 r.p.m. to optimum development, which was determined by sheeting the dough after mixing. An excess of 1.5% water was added to doughs mixed under vacuum of 28 in Hg to counteract the loss of water during evacuation.

Gross Characteristics of Mixed Doughs. Inspection of the doughs mixed under

Table 5. Effect of fat crystal size and mixing atmosphere on the extensogram area (in^2) after 90 min fermentation

Fat treatment	Mixing atmosphere			
	Air	28" Hg	15" Hg	N_2
No lard	14.7^a	16.3^a	14.0^a	15.5^a
Lard "as is" (β'-I)	14.6^a	15.8^a	13.4^a	14.7^a
Lard recryst. at R.T. (β)	11.8^b	16.1^a	12.4^a	11.4^b
Lard recryst. in LN_2 (β')	12.8^b	17.6^a	12.2^a	12.2^b

Numbers not with a common superscript letter are not different $P < 0.05$.

vacuum of 28 in Hg showed that the doughs had a slight yellow color which may be due to the lack of bleaching of flour pigments by lipoxygenase; yellow color also may be related to the compactness of the dough. In addition, these doughs felt dense compared to doughs mixed in air or nitrogen atmospheres. This was true for doughs with and without lard.

Doughs mixed under N_2 (2 psi) had a sponge-like character to them and appeared to contain high levels of gas. However, dough color was normal (i.e. creamy white). Conversely, no differences were observed between doughs mixed under vacuum of 15 in Hg or air.

Dough characteristics were altered after 1st and 2nd punches, particularly when doughs were mixed under a vacuum of 28 in Hg. For these latter doughs, the fermentation height before the 1st punch was less than that observed for doughs mixed in air, N_2, or vacuum of 15 in Hg (Figure 13). However, after the 2nd punch, the heights of vacuum mixed doughs were considerably greater than that for doughs mixed in other atmospheres (Figure 13). In addition, the yellowish color lessened with increased fermentation time.

At 1st punch, doughs that were mixed under a vacuum of 28 in Hg did not show a uniform distribution of gas cells (Figure 13). Large gas bubble were concentrated at the surface of the dough piece, and there was little evidence of gas cells in the center of the dough. However, small gas bubbles were present on the bottom surface of the dough piece.

The depressed heights of vacuum mixed doughs prior to 1st punch suggested that fermentation rate was decreased. Since nucleation sites were not created during mixing, carbon dioxide and metabolic substances produced by yeast may accumulate around the yeast cells because, these substances can not diffuse readily through the dense dough. The end result would be depression of yeast activity.

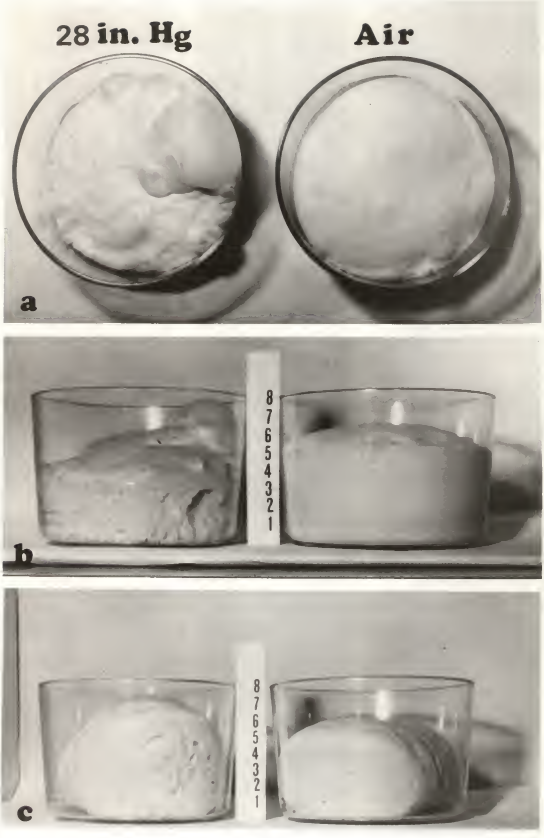
The appearance of large gas bubbles at the surface of the dough mass, rather

Fig. 13. Dough heights before 1st and 2nd punch when doughs were mixed in 28 in. Hg or air.

(a) Top view of dough before 1st punch.

(b) Side view of dough before 1st punch.

(c) Side view of dough before 2nd punch.


28 in. Hg
Air
a
8
7
6
5
4
3
2
1
b
8
7
6
5
4
3
2
1
c

than a uniform distribution of gas cells throughout the compact structure was produced when doughs were mixed under a vacuum of 28 in Hg. This would suggest that few nucleation sites were produced when doughs were mixed under a vacuum of 28 in Hg and that most of the Co_2 diffused to these sites.

Punching steps probably assist in the creation of "normal" doughs from vacuum mixed doughs by subdividing already existing gas cells as well as creating new nucleation sites for later CO_2 diffusion and gas cell expansion. In addition, the metabolic products of yeast fermentation are also distributed throughout the dough, some of which may lead to a mellowing of the protein network to result in increased gas retention.

Dough Density. Many authors have suggested that fat aids in air incorporation (Baker and Mize, 1937). While extensive work has been published on the effects of fats or fat crystal size on air incorporation in cakes, no information has been published on the effects of fat or fat crystal size on air incorporation in bread dough. Therefore, we wanted to determine the effects of mixing atmosphere and fat crystal size on air incorporation.

The densities of doughs mixed under atmosphere of air, a vacuum of 28 in Hg, a vacuum of 15 in Hg, and N_2 are presented in Table 6. The density of doughs mixed in air was affected by both fat addition and fat crystal size. Doughs without lard had a high density (ρ=1.22), suggesting that little gas was incorporated during mixing. However, large fat crystal sizes (β) produced the same dough densities as the no-lard control. Conversely, doughs containing fats with (β') or (I) fat crystals (lard "as is") resulted in greater air incorporation (ρ= 1.18). The greater air incorporation by small fat crystals may be due to a more uniform distribution of fat throughout the dough piece.

When doughs were mixed under a vacuum of 15 or 28 in Hg, the densities were high (1.24 and 1.28, respectively). In addition, the presence or absence of fat did not alter dough density.

Table 6. Effect of fat crystal size and mixing atmosphere on dough density.

Fat treatment	Mixing atmosphere			
	Air	28"Hg	15"Hg	N_2
No lard	1.22	1.28	1.24	1.14
Lard "as is" (β'-I)	1.18	1.28	1.24	1.14
Lard recryst. at R.T. (β)	1.22	1.28	1.24	1.14
Lard recryst. in LN_2 (β')	1.18	1.28	1.24	1.14

Dough mixed in N_2 had a lower density than doughs mixed in other atmospheres (ρ=1.14). In this instance, N_2 was probably incorporated into the doughs when they were mixed at a constant pressure of 2 psi.

Bread quality. It can be concluded from density studies that fat crystal size has an effect on dough density only when doughs are mixed in air. It is possible that dough density is, therefore, not related to bread quality (loaf volume) when doughs are mixed in atmospheres other than air. To investigate this further, the relationship among crystal size, dough density and bread characteristics (volume and crumb) were determined.

The data presented in Table 7. shows the effects of fat addition and fat crystal size on loaf volume. For each atmosphere no lard doughs had the lowest loaf volume.

Fat crystal size was found to,be related to loaf volume (Table 7). When doughs were mixed in air, the highest loaf volumes were obtained when doughs contained small (LN_2) or intermediate (lard "as is") fat crystal sizes. On the other hand, when doughs were mixed in the other three atmospheres, (vacuum of 28 in Hg, and 15 in Hg, and N_2), lard "as is" produced the highest loaf volumes. It should be noted that a comparison of mixing atmospheres showed that the highest loaf volumes were always obtained from doughs mixed under a vacuum of 28 in Hg.

Loaf volume and dough density appear to be related only when doughs were mixed in air. For example, doughs containing β' crystals (LN_2) or intermediate(I) size crystals (lard "as is") had the same dough density (Table 6) and the same loaf volume (Table 7). However, these relationships did not always hold true. The no lard doughs and doughs containing β crystals (recrystallized at room tempt.) had the same dough density but different loaf volumes. The differences in loaf volumes between these latter two treatments may be related to the increased gas retention of dough containing fat (lard)rather than to the amount of air incorporated during mixing.

Table 7. Effect of fat crystal size and mixing atmosphere on loaf volume (CC).

Fat treatment	Mixing atmosphere			
	Air	28"Hg	15"Hg	N_2
No lard	858^a	932^a	814^a	831^a
Lard "as is" (β'-I)	990^b	1072^b	1010^b	1031^b
Lard recryst. at R.T. (β)	955^c	1019^c	994^c	970^c
Lard recryst. in LN_2 (β')	1000^b	1015^c	981^c	954^c

L.S.D. Across atmospheres =22 cc.

Doughs mixed under vacuum or N_2, in many cases produced higher loaf volume than doughs mixed in air; this was particularly true when doughs contained fat crystals intermediate in size. Bell et al. (1977), in a study of the Chorlywood process, also found that doughs (with $KBrO_3$) mixed in N_2 produced higher loaf volumes than doughs mixed in air. These data may suggest that oxygen has a detrmental effect on bread quality..

Fat crystal size was also found to affect bread crumb characteristics (Figure 14, and Table 8). In general, doughs without lard or containing (β) produced bread with an open grain. Conversely, doughs containing (β') crystals produced bread with a close grain. Hoerr (1960) has suggested that during agitation fat crystals chop off pieces of air as they push through the air-fat interface, smaller crystals produced smaller air bubbles. This analogy could also be applied to the effects of fat crystal size on bread grain. However, it would not explain the production of fine grain in breads mixed under a vacuum of 28 in Hg.

Figure 14. Effects of fat crystal size and mixing atmospheres on bread grain: breads 1-4 contain no lard, 5-8 contain lard "as is", 9-12 contain lard recrystallized at room temperature, and 13-16 contain lard recrystallized in LN_2.

FARINOBREAD; MIXED:

IN AIR | IN 28 MM. Hg | IN 15 MM Hg | IN NITROGEN

Table 8. Effect of fat treatment and mixing atmosphere on bread crumb characteristics.

Fat treatment		Mixing atmosphere			
		Air	28"Hg	15"Hg	N_2
No lard	Open			++	
Lard "as is" (β'-I)	Close		••		
Lard recryst. at R.T. (β)	Open	xx			
Lard recryst. at LN_2 (β')	Close				xx

•• Highest loaf volumes (of doughs containing fat)

xx Lowest loaf volumes (of doughs containing lard)

++ Lowest loaf volume (of doughs with no lard)

Microscopy Studies

Light and scanning electron microscopy were used in this study to determine if variations in structural characteristics could help to explain the observed differences in bread quality obtained from doughs mixed with and without lard and in different atmospheres. Dough structure was studied after mixing and before and after 1st and 2nd punching steps as well as after baking.

Light microscopy indicated that the distribution of lard in dough was affected by fat crystal size but not by the mixing atmosphere. In all cases, when lard was present as large crystals it resulted in poor distribution within the dough, i.e. it remained as large masses (Figure 15-b). Conversely, small fat crystals produced well-distributed fat particles within the doughs (Figure 15-a and c). Similar effects have been noted in cake batters (Lee, 1979). In all instances, the fat appeared to be associated mainly with starch granules (Figure 16-a), appearing as irregular masses smeared over the starch granules as described by Standing (1973) and Burlans and Clapp (1942). After baking the fat coalesced into droplets at the edges of the gelatinized starch granules (Figure 16-b).

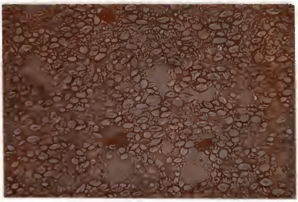
The addition of fat (lard) to the doughs also affected the size and number of gas cell present in the dough. The general effect of fat on gas incorporation in doughs is shown in Figure 17. Doughs containing lard and mixed in air (Figure 17-a) exhibited more gas cells than those without added lard (Figure 17-b). In addition, doughs containing small (β')(Fig. 18-c) or (I)(Fig. 18-a) fat crystals showed smaller gas cells than doughs containing large (β) fat crystal (Fig. 18-b). This was true for doughs mixed in air, a vacuum of 15 in Hg, and N_2 . Fat crystal size had no affect on the cells in doughs mixed in high vacuum (28 in Hg). The microscope results agreed with the density data for doughs mixed in air but not for doughs mixed in the other atmospheres.

Since we had shown that it was possible to produce good quality bread from doughs mixed under high vacuum if punching steps were included, we decided to

Figure 15. Distribution of fat in doughs containing (a) intermediate fat crystals, (b) crystals, and (c) crystals. Orange particles are fat.

a

200μm



200μm

b

c

200μm

Figure 16. Distribution of fat (orange coloration) in dough (a) and in bread (b).

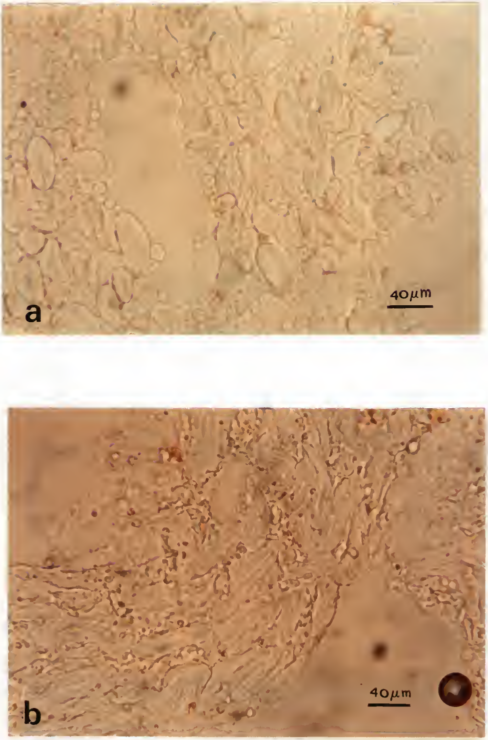
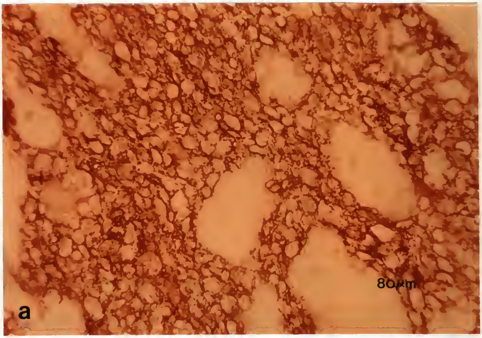

a
40µm
b
40µm

Figure 17. Doughs mixed in air with 3% lard (a) and without lard (b).


80µm
a

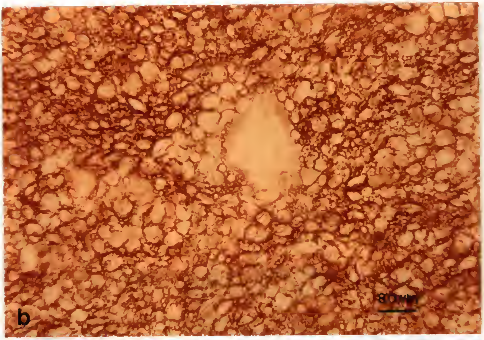
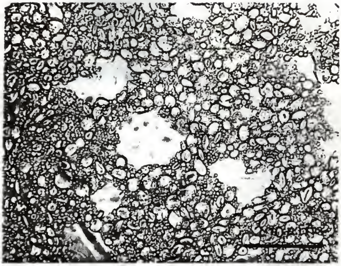
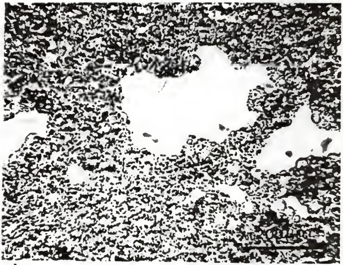

80µm
b

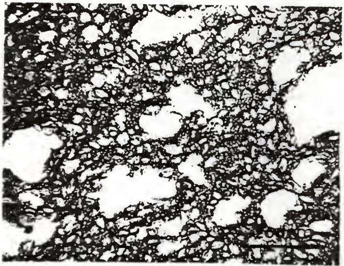
Figure 18. Effect of fat crystals on the size of air cell in the dough after mixing (a) with lard "as is" (β'-I), (b) with β crystals, (c) with β' crstals.



a



b



c

Figure 19. SEM micrographs of dough showing gas cell number and distribution after (a) mixing under 28 in Hg, (b) before first punching step, (c) after first punch, and (d) before second punch.

AI: gas cell

AC: gas cell wall

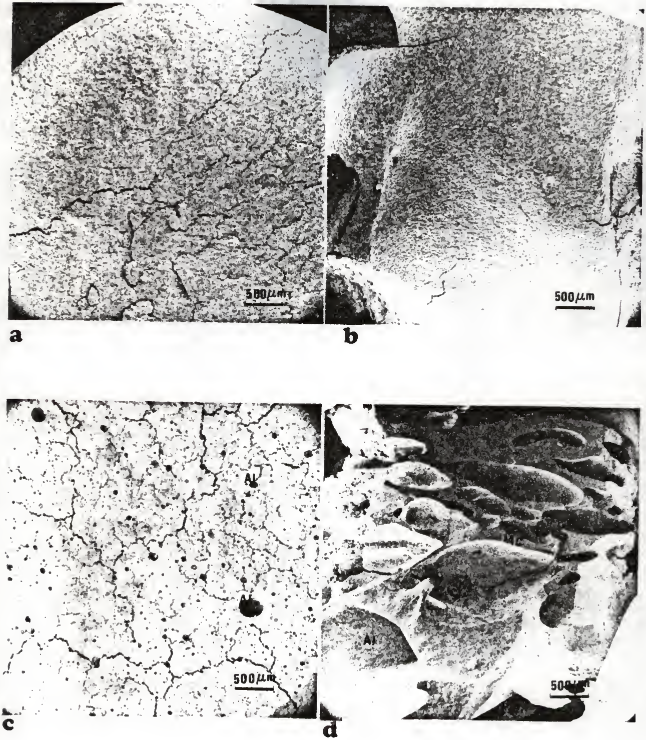
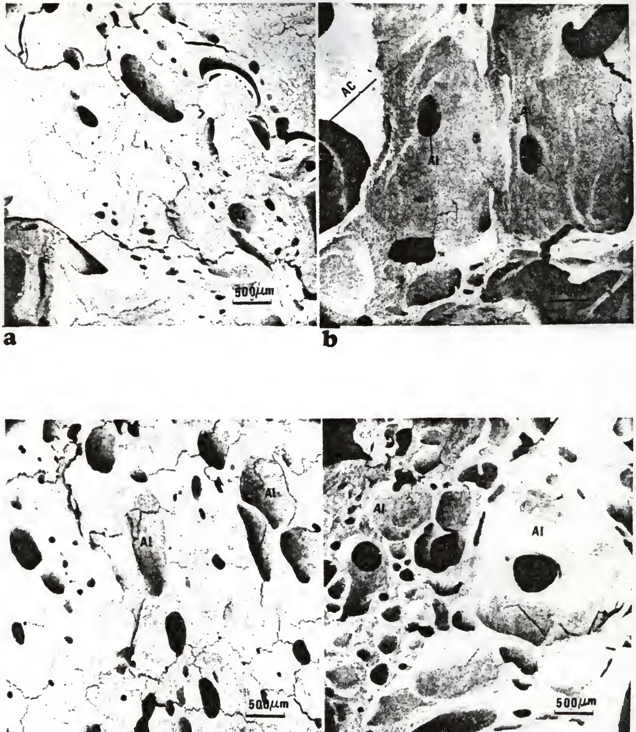

500μm
500μm
a
b
Al
Al
500μm
Al
500μm
c
d

Figure 20. SEM micrographs of dough showing gas cell number and distribution after (a) mixing in air, (b) before first punching step, (c) after first punch, and (d) before second punch.

AI: gas cell

AC: gas cell wall


500μm
AC
Al
Al
Al
Al
500μm
Al
Al
500μm
a
b
c
d

study the doughs at various stages in the bread process. SEM may allow us to determine at which point the nucleation of gas cells occurred in the processing of vacuum (28 in Hg) mixed doughs.

Doughs mixed in vacuum of 28 in Hg were dense and essentially free of gas cells (Figure 19-a) when compared to the air-mixed counterpart (Figure 20-a). When vacuum (28 in Hg) mixed doughs were fermented for 105 min, they showed large gas cells at the surface of the dough mass (Fig. 19-b) as also was seen in Figure 11-a.. In addition, there were fewer gas cells than in the comparable air mixed doughs (Figure 20-b).

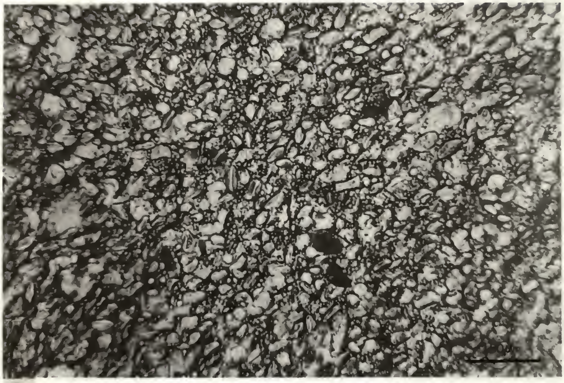
Vacuum mixed doughs, 10 min after the 1st punch (Fig. 19-c), exhibited many small gas cells. Obviously, the 1st punching step resulted in the production of numerous nucleation sites in the vacuum doughs and subdivided the already existing cells in the air mixed doughs (Figure 20-c).

After 155 min of fermentation (before 2nd punch),both vacuum mixed (Figure 19-d) and air-mixed doughs (Figure 20-d) containing numerous gas cells of varying sizes. However, vacuum-mixed doughs had thicker cell walls than the air-mixed counterpart. The second punching step and proofing produced many gas cells with thin cell walls.

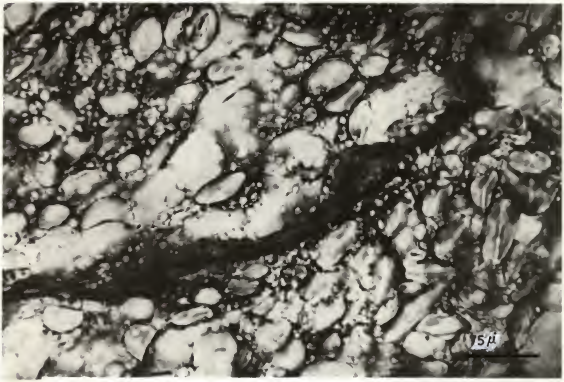
In conclusion, the microscope study appears to indicate that the critical step in the nucleation of gas cells in vacuum-mixed doughs is at the 1st punching step. Subsequent fermentation and punching steps result in greater numbers of gas cells which are more uniformly distributed throughout the dough mass.

Further studies were conducted to determine the affect of excess vacuum on dough structure. Micrographs of doughs mixed in vacuum of 28 in Hg indicated that much of the protein had not formed into thin sheets during mixing. Instead, it remained in large masses (Figure 21-a) or as thick sheets (Figure 21-b). These thick sheets probably are responsible for the thickened cell walls that were observed in Figure 19-d. The differences between air-mixed and vacuum-mixed

Figure 21. Light micrographs showing the protein as large masses (a), or thick sheets when doughs were mixed under 28 in Hg.



a

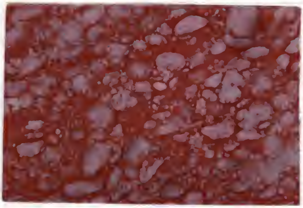


b

doughs can be more clearly seen with protein stains and colored photography (Figure 22).

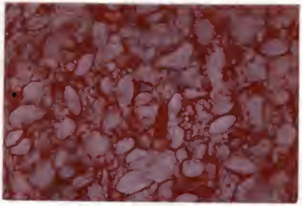
It was also observed (Figure 22-b) that starch granules in vacuum (28 in Hg) mixed doughs were aggregated than in air-mixed doughs (Figure 22-a). We wanted to determine if this affected the gelatinization of the starch during baking. Therefore, X-ray diffraction patterns were run on starch washed from air-mixed and and vacuum-mixed doughs. No differences were observed in the relative crystallinity of starches from the two breads. In other words, the degree of starch gelatinization in the bread was essentially the same. This was also verified by SEM studies. The major effect of vacuum on bread quality, therefore, must be related to its affect on dough proteins.

Figure 22. Organization of protein (red) in air-mixed dough (a), and vacuume of 28 in Hg mixed dough (b).



a

75 μm



b

75 μm

SUMMARY AND CONCLUSIONS

1. Modifications in the farinograph bowl were made so that doughs could be mixed under different atmospheres.
2. Farinograph and extensograph data suggested that lard 3% level acted as a lubricant and that fat crystal size had little effect on dough rheology. Some differences in dough rheology were observed due to different mixing atmosphere.
3. Dough densities were affected by fat crystal size only when doughs were mixed in an air atmosphere. Furtheremore, loaf volume was correlated to dough density only when doughs were mixed in air.
4. Doughs mixed under a vacuum of 28 in Hg produced the highest loaf volume regardless of whether lard was present or absent in the formula. This suggested that air was not necessary during mixing to produce good quality bread.
5. Fat crystal size was found to affect crumb grain, i.e. small crystals gaive a close grain while larg crystals gave an open grain.
6. SEM studies and fermentation heights showed that the critical stage in the nucleation of gas cells in doughs mixed under a vacuum of 28 in Hg was at the first punching step. Light microscopy showed that large protein aggrigates were obtained when doughs were mixed in excess vacuum.
7. Light microscopy studies showed that fat crystal size affect fat distribution and air incorporation. Small fat crystals distributed themself as small particles throughout the dough; large fat crystals remained as large particles.

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APPENDIX

Table 1. Effect of fat crystal size and mixing atmosphere on dough extensibility after 45 and 90 min. fermentation.

Fat Treatment	Mixing Atmosphere			
	Air	28 in Hg	15 in Hg	N_2
Extensibility at 45 min.				
No lard	201^a	211^a	189^a	197^a
Lard "as is" (β'-I)	221^b	216^a	231^b	218^a
Lard Recryst. at R.T. (β)	218^b	211^a	212^{bc}	208^a
Lard Recryst. in LN_2 (β')	221^a	225^a	200^{ac}	219^a
Extensibility at 90 min.				
No lard	137^a	134^a	143^a	144^a
Lard "as is" (β'-I)	148^a	158^b	168^b	155^a
Lard Recryst. at R.T. (β)	157^b	151^b	150^b	158^b
Lard recryst. in LN_2 (β')	148^a	149^b	154^b	157^b

* All values in the table are in mm.

Within each atmosphere and time period, numbers not superscripted by the same letter are significantly different at P= 0.05.

DEFINITIONS

Pup loaf: is a baking procedure where 100gm of flour is used and two punching steps are included in the process.

Sheeting: a procedure for determining the optimum mixing by hand stretching the dough to form a thin sheet.

The optimum mixing is evident when the dough can be stretched to a thin translucent sheet without tearing.

No-time bread procedure: the dough is paned immediately after mixing.

Full formula dough: a dough that contains all the ingredient in a normal bread formula including yeast.

THE EFFECT OF MIXING ATMOSPHERE
AND FAT CRYSTAL SIZE ON BREAD QUALITY

by

JASSEM GHALIB MAHDI

B. S., Mosul University, 1974

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

in

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Department of Grain Science and Industry

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1979

The farinograph was modified to study the effects of fat on dough mixed in air,vacuum and nitrogen atmospheres. Contrary to recent literature (Chamberlain and Collins, 1979), we found that good quality bread could be produced from doughs mixed in high vacuum. The processing steps after mixing were critical for the formation of nucleation sites. Scanning electron microscope indicated that the critical stage in the nucleation of gas cells in doughs mixed under vacuum of 28 in Hg was at the first punching step. Subsequent fermentation and punching operations resulted in a great number of gas cells which were more uniformly distributed throughout the dough.

The modified farinograph was used to determine the effect of fat crystal type on dough density and rheology as well as bread characteristics. Lard decreased the consistency of the dough but increased extensibility of full formula doughs compared to the no lard control. In addition, the effects of lard on dough rheology were dependent on mixing atmosphere and fat crystal size. At constant water absorption, doughs mixed under vacuum of 28 in Hg showed the highest consistency and resistence to extension. The lowest consistency and resistence to extension were obtained when doughs contained β' or intermediate fat crystal sizes and were mixed under vacuum of 15 in Hg. On the other hand, β and β' fat crystal sizes produced the lowest consistencies in doughs mixed under N_2. Doughs with β crystals showed the lowest resistence to extension.

Only the densities of doughs mixed in air were affected by fat addition and fat crystal size. High densities (ρ =1.22) were produced by doughs without lard or when β crystals were present in the dough. Conversely, doughs containing lard with β' and $\underline{I}$ fat crystal sizes had low densities (ρ=1.18) indicating great greater air incorporation. The greater air incorporation by fat crystal sizes may be related to the more uniform distribution of fat throughout the dough piece that was observed with the light microscope.

Fat crystal size did affect loaf volume but its affect was dependent on mixing atmosphere. When doughs were mixed in air, the highest volumes were obtained with β' or I fat crystals. On the other hand, I fat crystals produced the highest loaf volumes when doughs were mixed under vacuum of 15 in Hg or N_2 atmosphere. The highest loaf volumes were always obtained from doughs mixed under vacuum of 28 in Hg. This suggests that oxygen may have a determental effect on loaf volume.

Fat crystal size also affected bread crumb characteristics. In general, doughs without lard or containing β crystals produced bread with an open grain. Conversely, doughs containing β' or I fat crystals produced breads with a close grain. Light microscope studies showed that the small fat crystals produced more finely divided gas cells in the doughs thandid the large crystals. This may expalin the observed differences in crumb characteristics.