TWO EFFECTS OF SURFACTANTS IN BREAD

I. AIR INCORPORATION IN BREAD DOUGH

II. A MECHANISM FOR SHORTENING IMPROVEMENT OF LOAF VOLUME

by

RICHARD C. JUNGE

B.S., Kansas State University, 1977

A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Grain Science and Industry

KANSAS STATE UNIVERSITY

Manhattan, Kansas

1980

Approved by: R Carl Hoseney

(Major Professor)

TABLE OF CONTENTS

CHAPTER 1: Incorporation of Air in Bread Dough.

INTRODUCTION

The use of surfactants in the bread baking industry is well established with essentially all bread produced in the United States containing one or more surfactants. Surface active agents are defined as materials that reduce the interfacial tensions between two phases in a system. In the bread baking industry the word surfactant is often used interchangable with the term dough conditioner. The terms do not have concise definitions and are used to cover the actions that surfactants have in doughs.

Surfactants in the bread baking process are used for the following effects or purposes: (a) to increase mixing stability, (b) to improve machinability and increase tolerance to mechanical abuse during high speed dough processing, (c) to improve the dough's ability to carry small amounts of foreign protein and still maintain loaf volume, (d) to improve loaf volume and crumb grain, (e) to replace or reduce the amount of shortening in the formula, and (f) to improve the shelf life of the product (antistaling). It appears obvious from the wide range of effects that surfactants have, that there is no single mechanism or reaction site in dough to explain all of the effects. The major objective of this work was to identify the basic mechanisms responsible for the several effects of surfactants in breadmaking. Certain surfactants improve the grain of bread. The improved grain is manifested as a large number of small cells giving the bread a fine grain. We reasoned that the fine grain originates from more air being incorporated in the dough or from the air being subdivided into smaller cells during dough mixing.

The amount of air occluded during mixing with and without certain surfactants could be determined by measuring the density of dough mixed to optimum. The effect of surfactant on the relative size and distribution of air cells in dough after mixing could be determined by viewing lyophilized, cryofractured dough with the scanning electron microscope.

Using these two methods we investigated the mechanism by which certain surfactants improve the crumb grain of bread.

LITERATURE REVIEW

Dough Density

Baker and Mize (1937, 1941) proposed that the grain of bread is controlled by the number of gas bubbles present in dough. They showed: (a) that yeast is incapable of originating gas cells in the dough, (b) entrained gasses in the endosperm or occluded in the flour or beaten in during an early stage of mixing are of little or no consequence as a source of gas cells, (c) the latter portion of the mixing period is capable of emulsifying all the gas required, and (d) punching and moulding do not introduce new gas cells into bread dough but create a greatly increased number of cells by subdividing those already present.

Baker and Mize (1946) later developed a simplified method for determining dough density whereby the occlusion of air in dough could be rapidly followed during the dough mixing period. The method was used to study the relationships between dough mobility, air occlusion, and baking quality. They also reported that the rate at which air is occluded varies widely during different stages of the mixing period. It is slow at first, rapidly increases when the dough offers it greatest resistance to mixing, and then declines after the normal mixing requirement has been exceeded.

Electron Microscopy of Dough

Light, transmission, and scanning electron microscopy have been used by many investigators as tools to observe the microstructure of cereal products.

Aranyi and Hawryleweiz (1968, 1969) were one of the first investigators to use scanning electron microscopy to study flour and doughs. With the scanning scope, the surface of the sample is scanned with an electron beam, and the image created by the secondary electrons emitted from the surface is observed. The image is produced on the screen of a cathode ray tube connected to the scentillator-photomultiplier system that detects the secondary electrons. Photomicrographs of the images observed can be recorded with a camera.

The advantage of using the scanning scope include (Aranyi and Hawryleweiz 1968, 1969):

a. Large depth of focus (three dimensional effect).
b. Large samples can be viewed.
c. Easy sample preparation.
d. Surface can be examined directly without any special treatment except for nonconductive materials and these have to be coated with a uniform layer of evaporated metal.

e. The sample can be viewed at an angle for a shadowing effect.

Aranyi and Hawryleweiz (1968, 1969) found scanning electron microscopy a useful technique for the examination for both wheat endosperm and wheat flour dough. The difference in the structure of flour as opposed to dough samples was clearly established. In dough, the starch granules are more evenly distributed and the protein matrix forms a smooth enveloping veil-like network that is stretched over the starch granules.

Khoo et. al. (1975) attempted to show the structural relationships between protein and starch in a good quality bread flour at various dough stages and in bread crumb. Their description agrees with Aranyi and Hawryleweiz (1969) however, they carried their SEM work through fermentation and proofing. After fermentation the protein lattice structure showed large air cells along with many small air cells enmeshed within the starch granules.

Varriano-Marston (1977) compared different preparation methods for SEM and rated them for spatial topographical relationships. One method that she has shown to give excellent results involves simply freezing a small portion of the dough in liquid nitrogen, cryofracturing, and freeze drying at -60°C for 48 hours in a Denton DFD-2 freeze dryer. Then normal sample preparation is used for viewing with the SEM.

The Functions of Surfactants in Bread Baking

The functions of surfactants in breadmaking has been the subject of number of recent reviews (Tenney, 1978, Knightly, 1977, Moncrieff, 1966, Birnbaum, 1963, Cole, 1973 and Birnbaum, 1977).

The views of many of the authors is summed up by Green (1975) who states surfactants are generally used for improvement in two areas: (a) modification of mixing properties of doughs to promote higher/or later arriving consistency peaks, increased mixing tolerance, increased tolerance to non-wheat proteins, and a tolerance to high speed mechanized production methods, and (b) improvement of bread quality through stabilization of higher loaf volumes, better crumb texture and cell structure, and greater resistance to staling.

Those are the major things surfactants are used for and many studies have been carried out to help understand their interactions in a dough system. One area that has not been investigated to a great extent is the effect of surfactants on the occlusion of air in bread dough. Our objective was to obtain a better understanding of that phenomena.

MATERIALS AND METHODS

Flour

A hard winter wheat flour (BCS-77) experimentally milled from a composite of many wheats harvested throughout the Great Plains was used. It contained 12.2% protein (N X 5.7) and 0.45% ash.

Surfactants

Sodium stearoyl-2-lactylate (SSL), and ethoxylated monoglycerides (EMG), were obtained from the C. J. Patterson Company, Kansas City, Missouri. Diacetyltartaric acid esters of monoglycerides (DATEM, V 35.851) were obtained from the Chemische Fabrik Crunau Gmbh, Jllertissen, West Germany. Pluronic polyol (F108) were obtained from the BASF Wyandotte Corporation, Wyandotte, Michigan. Distilled monoglycerides (Myverol 18-04) were obtained from the Eastman Chemical Products Inc., Kingsport, Tennessee. Propylene glycol esters (PGME) of palmitic and stearic acid (Promodan SP) were obtained from Grindsted Products, Overland Park, Kansas. Polyoxyethylene sorbitan monostearate (poly 60) were supplied by ICI America, Wilmington, Delaware.

Straight Dough Formula and Procedure

The formula given in Table 1 was used when full formulation was used for dough density measurements, scanning electron micrographs, or bread baking. The doughs were mixed in a 100 g National pin mixer (National Mfg. Co., Lincoln, Nebraska), and handled as described by Finney and Barmore (1943). In this procedure doughs are punched after 105 and 155 min. and panned after 180 min. fermentation.

Table 1. Formula used for Dough Density, Scanning Electron Microscope, and Baking.

Ingredients	%[a]
Flour	100.0
Sugar	6.0
Salt	1.5
Non-fat dry milk	4.0
Shortening (Crisco)	3.0
Yeast	2.0
Malt (60^oL)	Optimum
Potassium bromate	Optimum
Water	Optimum

[a] Ingredients, % based on flour weight.

Dough Density Procedure

Individual doughs were mixed in a 100 g National pin mixer (National Mfg. Co., Lincoln, Nebraska) and the density of the doughs determined immediately after mixing as descirbed by Baker and Mize (1946).

Scanning Electron Microscopy of Dough

Preparation of the mixed dough sample involved freezing a small portion in isopentane cooled with liquid nitrogen, cryofracturing, and freeze drying using a Denten tissue freeze dryer. Samples were freeze-dried at -100°C for 24 hours and -80°C for additional 24 hours. The dry dough samples were mounted on speciman stubs with silver paste and then coated under vacuum with approximately 60 Å of carbon and then with about 100 Å of gold-palladium. Samples were viewed with an ETEC U-1 Autoscan scanning electron microscope operating at an accelerating voltage of 5 KV. Images were photographed on Polaroid Type 55 film.

RESULTS AND DISCUSSION

Certain surfactants used in the baking industry impart a fine grain to bread. We assume this can be explained by one of the following conditions: (a) more air is being occluded during mixing with doughs containing the surfactant (b) the surfactants function by allowing smaller cells to form duirng mixing or (c) both an increased occlusion of air and a formation of smaller cells is occurring.

Baker and Mize (1946) followed the occlusion of air in dough throughout the period of dough mixing. They showed that air occlusion occurs slowly as the flour water dough hydrates and the proceeds rapidly as the protein matrix is developed. We confirmed those results in Figure 1. The dough mass starts with a density of 1.20 g/cc and occludes little air after the density reaches 1.10. The optimum development time for this flour water dough is 3 min. and 30 sec. at which time the dough density is 1.16. Thus, air is still occuled rapidly during the first phase of overmixing.

Rheological properties of dough can change when certain surfactants are added. The addition of 0.5% sodium stearoyl-2-lactylate (SSL) in a flour water dough mixed in a mixograph (Fig. 2) delayed optimum development from 3 min. 45 sec. (control) to 7 min. In addition, the mixing stability or mixing tolerance was also increased. Interestingly, part of the effect of SSL on the rheological properties is reversed when NaCl was added to the dough. Adding 1.5% sodium chloride with the 0.5% SSL shortened the mixing time back to 4 min. 45 sec.

Figure 1. Mixogram of a flour-water mixture, together with a curve showing change in dough density (g/cc) during mixing.

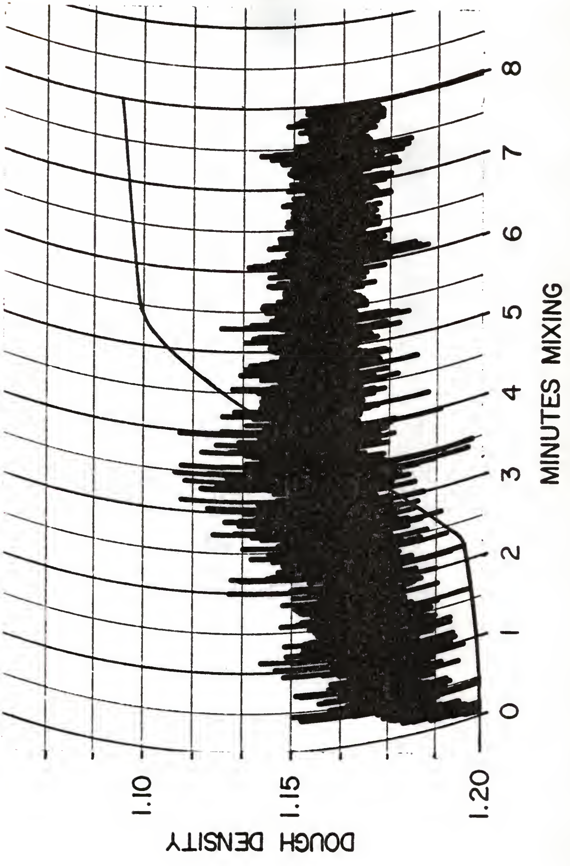
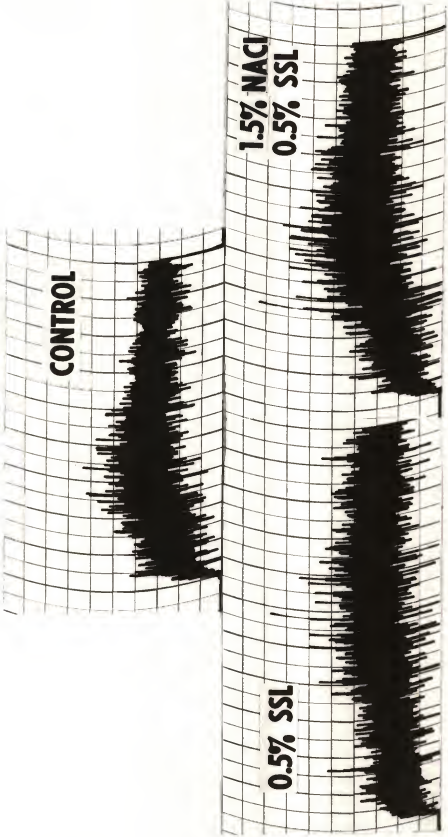

DOUGH DENSITY
1.10
1.15
1.20
MINUTES MIXING
0
1
2
3
4
5
6
7
8

Figure 2. Mixograms of flour-water dough, flour-water doughs containing 0.5% SSL, and 0.5% SSL and 1.5% NaCl.


CONTROL
1.5% NACl
0.5% SSL
0.5% SSL

The time at which dough starts to occlude air is changed when the rheological properties of the dough are changed (Fig. 3). When 0.5% SSL is added to a flour water dough 5 min. 30 sec. of mixing elapse before the dough starts to occlude air. Once the dough starts to occlude air, the rate of occlusion is the same as the control. Thus, the protein matrix which incorporates air is formed slower in the presence of SSL. Adding sodium chloride together with SSL, again changes the point where dough starts to occlude air. The dough density curves (Fig. 3) together with the mixograms (Fig. 2) suggest that air occlusion depends on the rheological properties of the dough. When SSL was added to dough the amount of air occluded at optimum development was not significantly different (1.15 vs. 1.16 g/cc) from the flour water control.

Next the rate of air occlusion in fully formulated doughs was studied. The density curves for three doughs containing (a) control, (b) control plus 0.25% EMG and 0.25% PGME, and (c) control with 0.5% SSL are shown in Figure 4. The dough densities at optimum development were 1.17, 1.16, 1.17, respectively. Again those surfactants did not effect the amount of air occluded at optimum mixing when compared with the control.

The obvious conclusion from the density data is that surfactants do not change the amount of air occluded at optimum mixing. Baking data for surfactant baked with no shortening are given in Table 2. Certain surfactants did replace shortening (SSL, EMG, polysorbate-60, F108, and DATE) while other did not (monoglycerides, PGME, and corn oil). There is also a wide difference in the crumb grain produced with the

Figure 3. Changes in dough density during mixing for flour-water dough, flour-water dough containing 0.5% SSL, and flour-water dough containing 0.5% SSL and 1.5% NaCl.

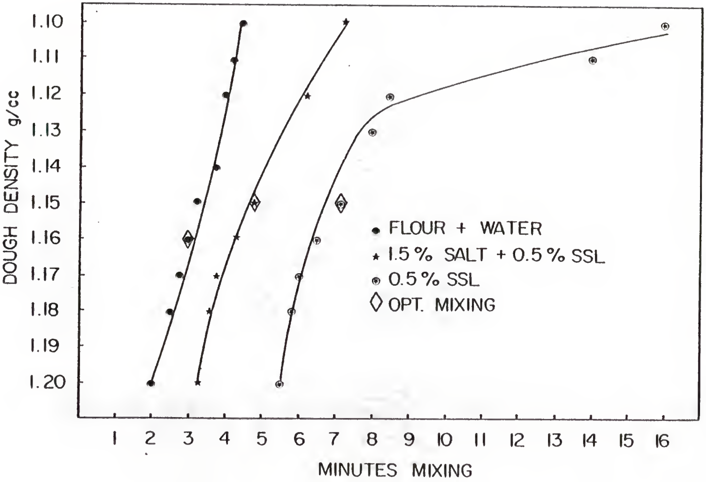

DOUGH DENSITY g/cc
1.10
1.11
1.12
1.13
1.14
1.15
1.16
1.17
1.18
1.19
1.20
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
MINUTES MIXING
● FLOUR + WATER
★ 1.5 % SALT + 0.5 % SSL
⊛ 0.5 % SSL
◊ OPT. MIXING

Figure 4. Changes in dough density during mixing for full formulation doughs: Control, 0.5% SSL but no shortening, and 0.25% EMG and 0.25% PGME but no shortening.

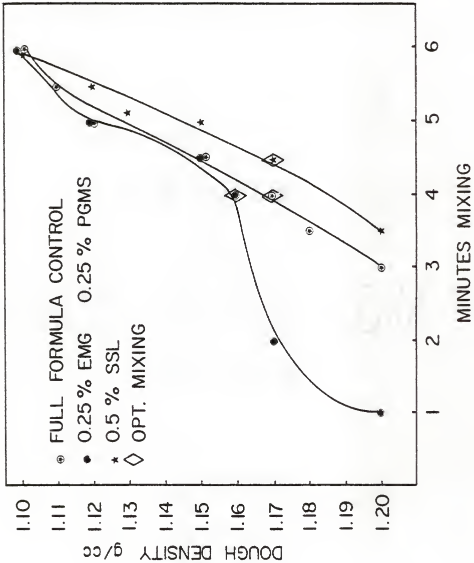

FULL FORMULA CONTROL
0.25 % EMG
0.25 % PGMS
0.5 % SSL
OPT. MIXING
DOUGH DENSITY g/cc
1.10
1.11
1.12
1.13
1.14
1.15
1.16
1.17
1.18
1.19
1.20
MINUTES MIXING
1
2
3
4
5
6

Table 2. Baking Data for Certain Surfactants.

Treatment	Proof Height cm	Loaf Volume cc	Crumb Grain
Control	7.6	950	medium
No shortening	7.5	855	open
No shortening 0.5% SSL	7.8	955	fine
No shortening 0.5% EMG	7.7	970	open
No shortening 0.5% Poly 60	7.7	960	medium
No shortening 0.5% PGME[a/]	7.6	790	very fine
No shortening 0.5% F108	7.9	990	open
No shortening 0.5% DATEM	7.8	945	slightly open
No shortening 0.5% Mono	7.5	860	open
No shortening PGME + EMG[b/]	7.6	925	fine
No shortening 3% Corn Oil	7.6	920	open

[a/] The PGME was ground for 60 sec in a Stein mill with the flour.

[b/] 0.25% of both PGME and EMG was ground for 60 sec. in a Stein Mill with the flour.

various surfactants. Because the surfactants do change the grain of bread we can assume that they change the grain by forming more but smaller air cells during mixing.

Baker and Mize (1946) found that the grain of bread originates from those operations which apply work to the dough, namely mixing, punching, and moulding. We used the scanning electron microscope (SEM) to study how the grain originates during mixing and the effects of subsequent punching steps on the grain. Doughs were studied with and without addition of certain surfactants.

SEMs of three flour-water doughs mixed to optimum and containing (a) no shortening, (b) 3.0% shortening and (c) no shortening plus 0.5% SSL are shown in Figure 5. The dough containing SSL has more and smaller air cells. Care must be taken in interpreting the SEMs. Air cells can appear in the photomicrographs as large and tunnel-like or they can be small light areas that appear as depressions on the surface of the dough. The depressions should not be confused with starch granules at the surface which appear as light elliptical areas with smooth or regular outlines.

SEMs of three fully formulated doughs that had been mixed to optimum are shown in Figure 6. The dough containing EMG has large air cells, while the dough containing PGME and the dough containing a mixture of PGME and EMG have more and smaller air cells. These results are in agreement with what we found baking bread with these surfactants. The EMG improved loaf volume, but gave an open, undesirable grain (Table 2).

Figure 5. Scanning electron micrographs of cryofractured freeze-dried, flour-water doughs. Top dough contains 0.5% SSL, lower left dough flour-water control, and lower right dough contains 3% shortening.

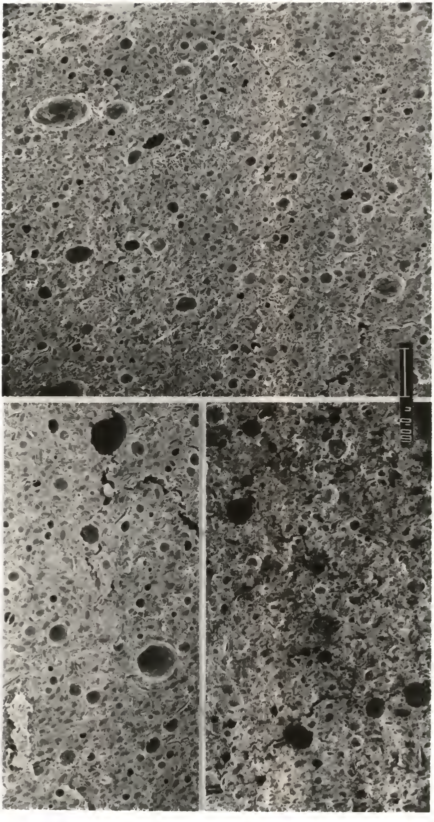
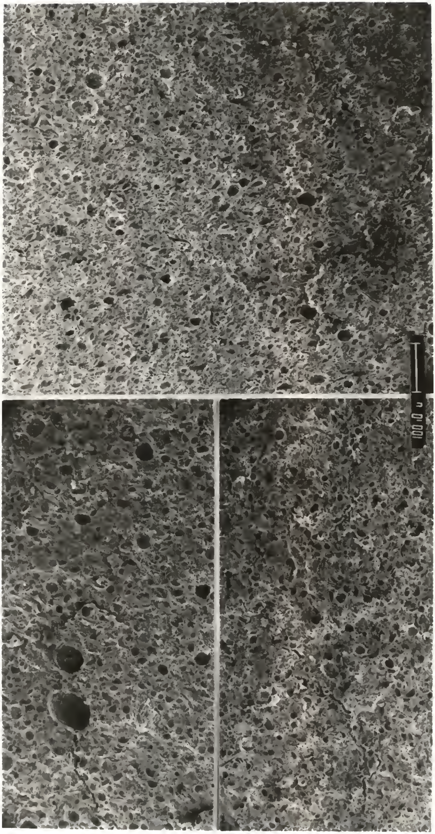

100 µ

Figure 6. Scanning electron micrographs of full formulation dough that were cryofractured and freeze dried. The doughs contained no shortening. Top dough contained 0.25% EMG and 0.25% PGME, lower left dough contains 0.25% EMG, and lower right dough contains 0.25% PGME.


100.0 μ

PGME gives a fine grain, but it depresses loaf volume. When both EMG and PGME are added to the dough, bread with an improved volume and grain is obtained.

The effect of punching on crumb grain was studied by SEMs of dough after second punching (Fig. 7) and after third punch, just before moulding (Fig. 8). Clearly the effect of SSL upon air incorporation is shown in both the figures. Formation of more air cells during mixing followed by greater subdivision of the cells during punching are all important to produce a fine grain in the finished product.

CONCLUSIONS

The density of optimum mixed doughs with and without added surfactants did not appear to be significantly different. Thus, surfactants do not alter the amount of air occluded during mixing.

Certain surfactants change dough rheology (greatly extended mixing time) as shown by the mixograph, however, the dough density curves showed that air was occluded only as the dough developed.

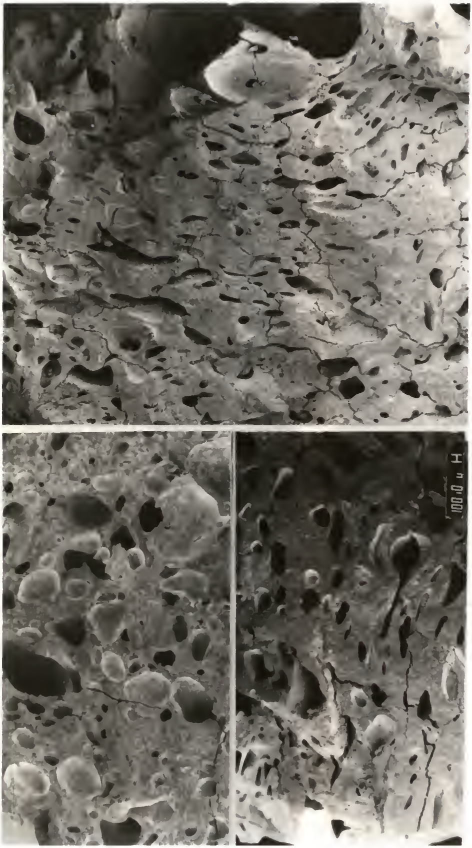
The SEM results showed that surfactants that impart a fine grain in the finished product do so by forming more and smaller air cells during mixing. The larger number and smaller cells were maintained throughout punching and thus was present in the finished products and responsible for the fine grain in the bread.

Figure 7. Scanning electron micrographs of full formulated doughs that were cryofractured and freeze dried. The doughs were punched for the second time after 155 min. of fermentation. The dough at the top contains 0.5% SSL but no shortening and the dough at the bottom contains 3% shortening.


01-1 10.0 17 E03 010
100.0 u H


01-1 10.0 18 E03 009
100.0 u H

Figure 8. Scanning electron micrographs of full formula dough that were cyrofractured and freeze dried after 180 min. fermentation and after the third punch. The dough at the top contained 0.5% SSL but no shortening, the dough on the lower left no shortening, control, and the dough on the lower right contained 3% shortening.


100.0 μ

LITERATURE CITED

Aranyi, C. and Hawryleweiz, E. J., 1968. A Note on Scanning Electron Microscopy of Flour and Dough. Cereal Chem. 45:500.

Aranyi, C. and Hawryleweiz, E. J., 1969. Application of Scanning Electron Microscopy of Cereal Specimens. Cereal Sci. Today 14:230.

Baker, J. C. and Mize, M. D., 1937. Mixing Doughs in Vacuum and In the Presenct of Various Gases. Cereal Chem. 14:721.

Baker, J. C. and Mize, M. D., 1941. The Origin of the Gas Cell in Bread Dough. Cereal Chem. 19:19.

Baker, J. C. and Mize, M. D., 1946. Gas Occlusion During Dough Mixing. Cereal Chem. 23:39.

Birnbaum, H., 1963. Some Newer Concepts of the Relation of Emulsifier Structure to Functionality. Baker's Digest 37(6):44.

Birnbaum, H., 1977. Interaction of Surfactants in Breadmaking. Baker's Digest 51(3):16.

Cole, M. S., 1973. An Overview of Modern Dough Conditioners. 47(6):21.

Finney, K. F., and Barmore, M. A., 1943. Yeast Variability in Wheat Variety Test Baking. Cereal Chem. 20:194.

Green, F. C., 1975. Surfactant Dough Conditioners. Baker's Digest 49(3):16.

Knightly, W. H., 1977. The Staling of Bread, a Review. Baker's Digest 51(3):16.

Moncrieff, James, 1966. Emulsifiers in Food Products. Baker's Digest 40(6):54.

Tenney, R. J., 1978. Dough Conditioners/Bread Softeners - the Surfactants used in Breadmaking. Baker's Digest 52(4):24.

Varriano-Marston, E., 1977. A Comparison of Dough Preparation Procedures for Scanning Electron Microscopy. Food Tech. 31(10):32.

CHAPTER II. A Mechanism for Shortening Improvement of Loaf Volume.

INTRODUCTION

Shortening is a term that was coined for fats used in the baking industry. Fat from vegetable or animal origins or a mixture of the two can be used. Fats made by hydrogenation of vegetable oils are used extensively in the industry, however, it is generally recognized that animal fats, particularly lards, have higher "shortening" effects in breadmaking. There are many kinds of vegetable shortenings available today. Most have emulsifiers or hardened flakes blended with the fat to make them more effective "shortenings."

Shortening is used for a number of reasons in the production of bread. One of the major effects os shortening is to increase the volume of the loaf. The mechanism by which shortening improves the loaf volume has been explained as a delayed release of carbon dioxide during baking. Daniels and Fisher (1976) showed, using the short time Chorleywood formula, that retention of carbon dioxide for a few minutes longer during the early stages of baking results in bread with higher loaf volume. The goal of our study was to determine if shortening delayed CO_2 loss using our formulation and procedure for bread baking and to determine if surfactants that replace shortening also delay CO_2 loss.

LITERATURE REVIEW

For two centuries bakers have realized that the addition of a fat would make their products more tender. To the baker the word tender (soft) and short were synonomous. Thus, we have today an all inclusive word, shortening, that has been used to describe the following functions in bread baking: (a) tenderizing (antistaling), (b) lubrication of dough constituents so they may easily slide by each other (a rheological effect), (c) slicing aid, and (d) to give bread with higher loaf volume.

Release of Carbon Dioxide from Dough During Bread Baking

Daniels and Fisher (1976) reported using a short-time Charleywood process (CBP) that doughs containing shortening retained carbon dioxide longer during the early stages of baking than dough without shortening. Graphs of cumulative carbon dioxide release versus time in the oven were sigmoid in shape and showed an induction period averaging 4 min. 30 sec. for mechanically developed (CBP) doughs mixed with fat, and 2 min. 30 sec. without fat. The induction period is the time before carbon dioxide starts to come off.

The course of dough expansion in the oven was also investigated by means of time-lapse cinematography. The results showed doughs containing fat started to rise more rapidly after entering the oven, and continued to rise longer than doughs made without added fat (Daniels and Fisher, 1976).

The Effect of Temperature on Dough Properties

In the standard method of baking bread, a crust is quickly formed which interferes with the study of the properties of the interior of dough during baking. The change in the properties of dough, while baking, progress in sequence from the exterior to the interior. This is caused by the temperature gradient developed when a cool dough is placed in a hot oven. This produces problems in interpreting temperature related changes; no two zones in the dough are under the same condition at the same time. To obviate these difficulties Baker (1939) developed a method of baking bread electrically in which no crust was formed, and in which the entire mass rises uniformly in temperature. In this method, dough is placed between electrodes carrying alternating current and the resistance of the dough to current flow results in heating of the dough.

Baker and Mize (1939) used the method for producing crustless bread to determine the following: (a) the temperature of dough as a function of time during baking, (b) the voltage necessary to maintain a predetermined wattage between the electrodes, (c) the distance a plunger falls through the dough during baking (a measure of dough rheology as a function of temperature), (d) the gas pressure generated within the dough, and (e) the oven spring (change in dough height as a function of time). These values were obtained simultaneously so that their relationship to each other could be readily noted.

Although much useful information was collected from the parameters these authors studies, our primary interest in the data was the effects of shortening on oven spring or dough height. Baker and Mize (1939) used the resistance oven to cook dough containing no shortening, oil, and hydrogenated shortening. The expansion of the dough as measured by oven spring, during heating was the same for all doughs until a certain temperature was reached, at that point the nonshortening and oil containing doughs stopped expanding while the dough containing hydrogenated shortening continued to expand. The data was explained by assuming that the doughs containing no shortening or oil lost their ability to retain gas at a lower temperature than did doughs containing hydrogenated shortening. This explaination has been widely accepted among cereal scientists.

Starch Gelatinization During Baking

Many workers have used microscopic techniques to study dough and bread and thus supplement the chemical findings of other investigators. Strandine et. al. (1951), showed photomicrographs of heated 4% aqueous wheat starch slurries containing monoglyceride, lard and no lard. They found monoglycerides inhibited the swelling of starch but found no difference between lard and no shortening slurries. They also examined slurries of bread crumb made with and without monoglyceride containing shortenings. The results showed starch granules swell and lose their birefringence during baking. However, little collapse of starch granules occurs because of the small amount of moisture present in dough. Preliminary size-frequency studies of starch granules isolated from bread indicated that the starch granules swell to a larger size in breads made without shortenings or with lard than in the breads made with monoglyceride shortenings. The difference shown was small, and more work was judged necessary to make that finding conclusive.

Little work has been reported on the degree of starch gelatinization occurring during breadmaking. Bechtel (1959), has described the relationships between starch gelatinization and protein during bread making. Although he presents no evidence he stated that proteins in bread dough are highly hydrated, whereas starch absorbs little water. However, as the temperature of the dough increases, the protein becomes denatured and loses its water-binding capacity. At a slightly higher temperature, the starch begins to gelatinize (swell) and water originally bound by the protein becomes available for starch gelatinization.

It has been shown by Hoseney et. al. (1971) the temperature of starch gelatinization was different for a flour water dough as opposed to a fully formulated bread dough. The flour water dough showed starch starting to gelatinize at $54^{o}C$ as opposed to the bread dough in which starch gelatinization was delayed to $65^{o}C$.

The problems encountered and methods used to study starch gelatinization in baked foods was discussed by Varriano-Marston et al (1980). It was concluded that new quantitative methods need to be developed to determine the condition of starch in bakery foods <u>in situ</u>. Until that time, a combination of crystallographic (polarized light, X-ray diffraction) and enzymatic methods can provide a good indication of the extent of starch gelatinization and swelling in bakery foods.

MATERIALS AND METHODS

Flour

A hard winter wheat flour (BCS-78) experimentally milled from a composite of many wheats harvested throughout the Great Plains was used in all experiments unless mentioned otherwise. It contained 12.2% protein (N X 5.7) and 0.45% ash.

Two other flours, one strong (Eagle) and the other weak (Omaha) were selected to represent differences in protein quality. They contained 12.8 and 12.6% protein respectively (N X 5.7) and 0.45% ash.

Straight Dough Formula and Procedure

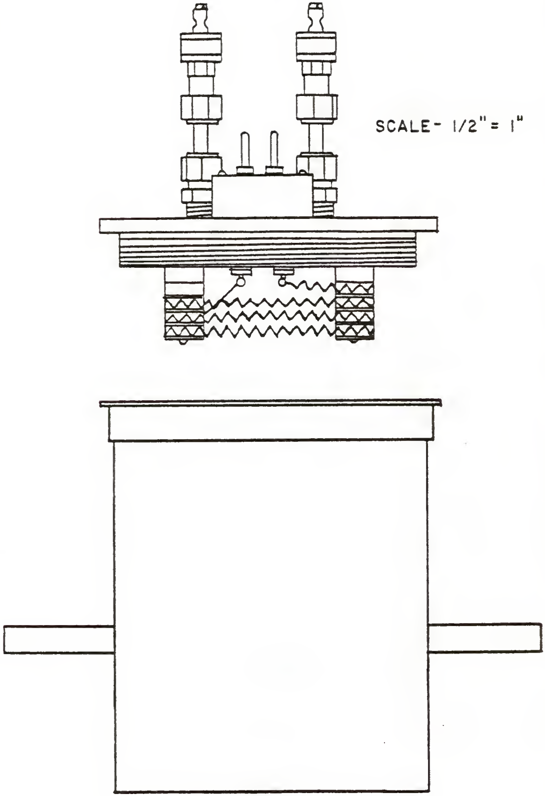
The formula given in Table 1 was used for all experiments in bread baking. The doughs were mixed with a 100 g National pin mixer (National Mfg. Co., Lincoln, Nebraska), and handled as described by Finney and Barmore (1943). In this procedure doughs are punched after 105 and 155 minutes and panned after 180 min. fermentation.

Carbon Dioxide Collection

Bread was baked in the container shown in Figure 9. The baking container is made of 5/16" thick steel tubing with a diameter of 5 1/4". A permanent seal is mounted on the lip to insure an air tight environment. The seal is made by applying a thin coat of silicone rubber ring gasket.

The lid of the container is made from 1" solid steel and is threaded to screw into the body. The heating element is constructed from "nichrome" wire (121 alloy nickel and chrome, 175 ohms/ft.) wound around "lavelite" posts. The "lavelite" serves as an insulator plus it withstands the high temperature. Vacuum tight feed throughs are used to

Figure 9. Scale drawing of the baking container.



SCALE- 1/2" = 1"

insulate and feed the electrical wire to the outside. The external male plug, mounted in "lavelite", is fixed to the top of the lip and is a permanent connection point. The female electrical connections are also mounted in "lavelite" and asbestos wire is used to bring current to the baking container.

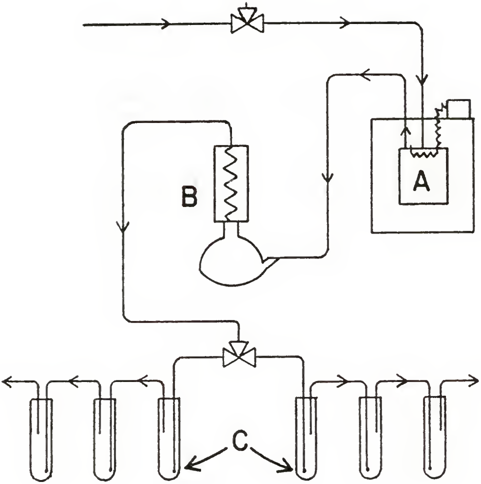
The schematic diagram of the apparatus used for collecting carbon dioxide during baking is shown in Figure 10. Arrows indicate the flow of nitrogen gas (85 ml/min). Nitrogen gas passes through baking container (A) and carries carbon dioxide through a double surface condensor (B) to gas dispersion tubes immersed in 2 N NaOH in collecting tubes (C) the oven temperature was set at 450°F and the internal heater mounted in the lid of the baking chamber was adjusted to give optimum baking using a variable transformer.

Carbon dioxide was collected in the first tube of each of the two, three-tube sets. The other two tubes were used to collect any carbon dioxide not trapped in the first tube. No significant amounts of carbon dioxide was found in the overflow tubes in our experiments. After each minute the gas stream was redirected to the second set of collection tubes, and the first tube removed for carbon dioxide quantification.

Carbon Dioxide Quantification

Carbon dioxide was quantified by back titrating the NaOH in collection tubes with 1 N HCl. Indigo carmine was used as an end-point indicator. This indicator allowed us to titrate NaOH in the presence of Na_2CO_3.

Figure 10. Schematic drawing of the apparatus used to collect carbon dioxide.


A
B
C

Resistance Baking Oven

The baking chamber was constructed from 1/4" plexiglas (Fig. 11). The electrical connections (A) bring current to the stainless steel electrodes plates (B) the carrier gas flows into the upper inlets (C) passes over the dough and out through the lower outlet (D).

The voltage was adjusted to the desired rate of heating using a variable transformer. An alcoholic solution of quinhydrone (Vogel 1959) was used to coat the electrode surfaces. The quinhydrone decrease surface effects between the dough and the electrode (Baker and Mize 1939). Carbon dioxide was collected and quantified using the method previously described.

To prevent drying of the dough surface the nitrogen stream was passed through carbon dioxide free water with a gas dispersion tube.

Photomicrographs

Light photomicrographs of bread crumb, 15 g dispersed in 100 ml water, showing the same field under normal and polarized light, were all at the same magnification. Pictures were taken on a Reichert (Austria) light microscope using Kodak high contrast copy film 5069.

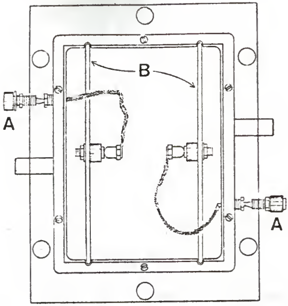
Pressure Measurements

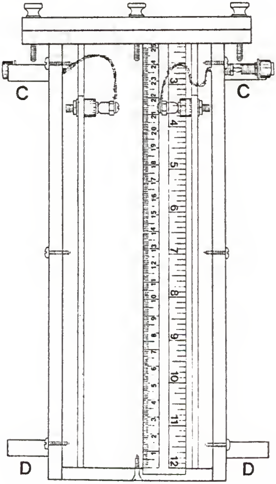
Pressure was determined using a S shaped capillary tube (2.5 mm I.D.). The tube was filled with methanol and immersed in the dough just before baking.

Flour Defatting

Free lipids were extracted from flour in a soxhlet with petroleum ether. The extraction was carried out 24 hours on a 400 gram sample. Heating was adjusted to insure a complete change of solvent in 25 - 30 minutes. The defatted flour was dried at room temperature until no trace of solvent odor remained.

Figure 11. Scale drawing of the resistance baking oven.


B
A
A


C
C
D
D

RESULTS AND DISCUSSION

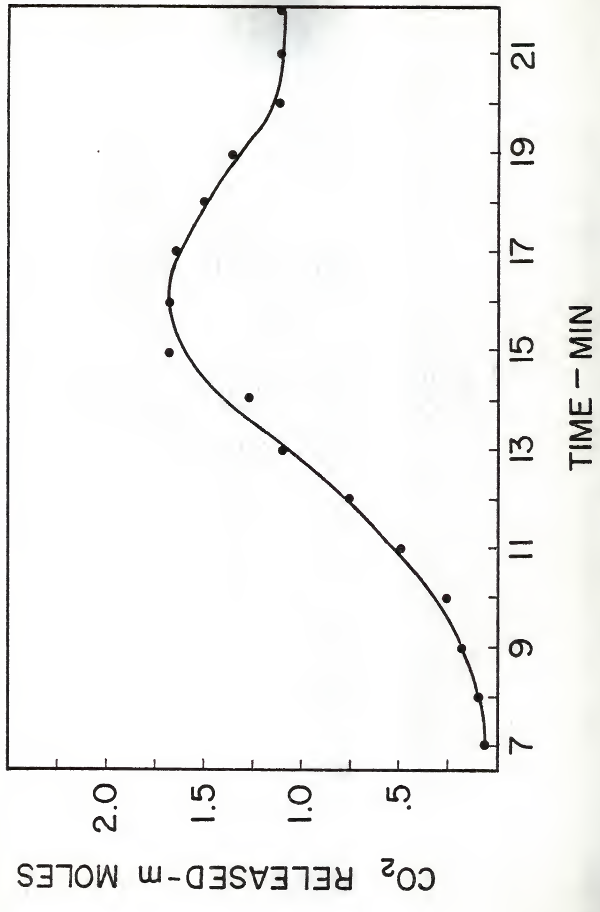
None of the numerous hypothesis discussed in the literature provide a clear explanation for the mechanism of fat improving the loaf volume of bread. Daniels and Fisher (1976) have shown the release of carbon dioxide is delayed by the addition of shortening to the formula in a short-time Chorleywood procedure. We found this data interesting and undertook to confirm their data using our own baking procedure.

Oven Baking

Our method of collecting and determining carbon dioxide during baking gave good reproducibility. Using a known amount of a heat triggered leavening acid with sodium bicarbonate, we could calculate a theoretical value for the carbon dioxide that should evolve upon heating. Results showed a recovery of 96%, when the mixture was put in the baking chamber and heated as if a dough was present.

With our straight dough procedure and three hour fermentation we found no apparent difference in the time of or amount of carbon dioxide lost from dough formulated with and without shortening. A typical curve for carbon dioxide evolved during baking from dough made with or without shortening is shown in Figure 12. These results appear to be in direct contrast to those reported by Daniels and Fisher (1976). However, when using their formulation and procedure we obtained results similar to those they reported. Doughs containing shortening gave slightly delayed evolution of carbon dioxide.

Figure 12. Release of CO_2 (m moles) as a function of time in the oven baking procedure.


CO$_2$ RELEASED-m MOLES
2.0
1.5
1.0
.5
7
9
11
13
15
17
19
21
TIME - MIN

Electric Resistance Oven

Baker (1939) developed a method to bake dough by heating it internally. In that way the entire mass rises in temperature uniformly. The electric resistance oven does not produce a crust. In commercial baking of bread the temperature rise in the dough is progressive from the outside to the inside. However, each portion of the dough must go through a similar cycle of heating (or temperature regime) as does the dough in the electric resistance oven. Thus, the reactions which are observed in the resistance oven also occur in a commercial loaf. The main difference between the two baking methods is that in the resistance oven the temperature triggered reactions all occur at the same time rather than over the course of the baking as found with a hot air oven.

Effect of Shortening

We used the resistance oven to study the release of carbon dioxide during baking. Because the dough is heated uniformly, if the dough becomes permeable to carbon dioxide at a certain temperature and shortening alters that temperature, then this method should clearly differentiate the effect.

Profiles of height (oven spring) and temperature curves plotted versus time for doughs with and without shortening (Figs. 13 and 14) showed that the dough containing shortening expands longer and to a greater height than does the nonshortening dough. The presence or absence of shortening in the dough does not affect the rate at which the temperature rises in the dough. The results are essentially the

Figure 13. Dough height as a function of baking time in the electric resistance oven (★) with shortening (●) no shortening.

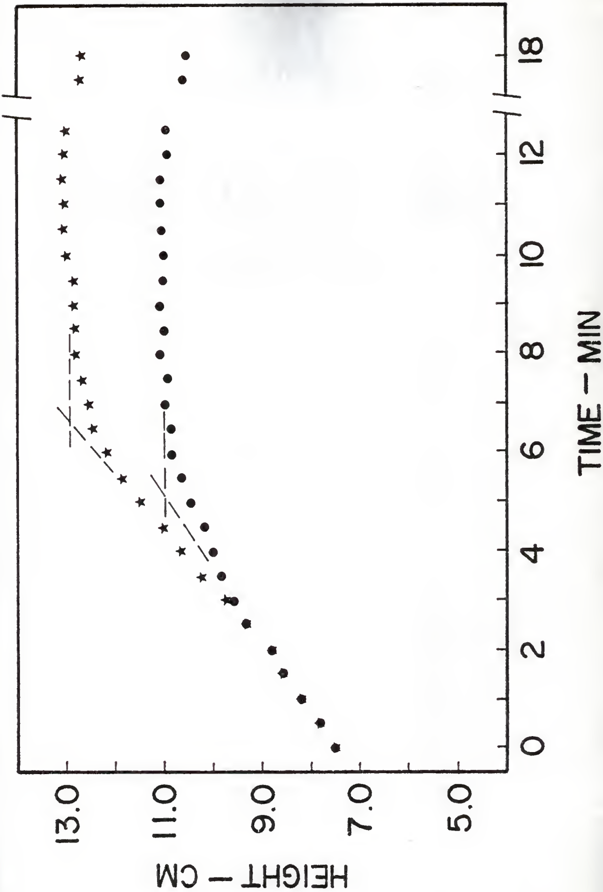
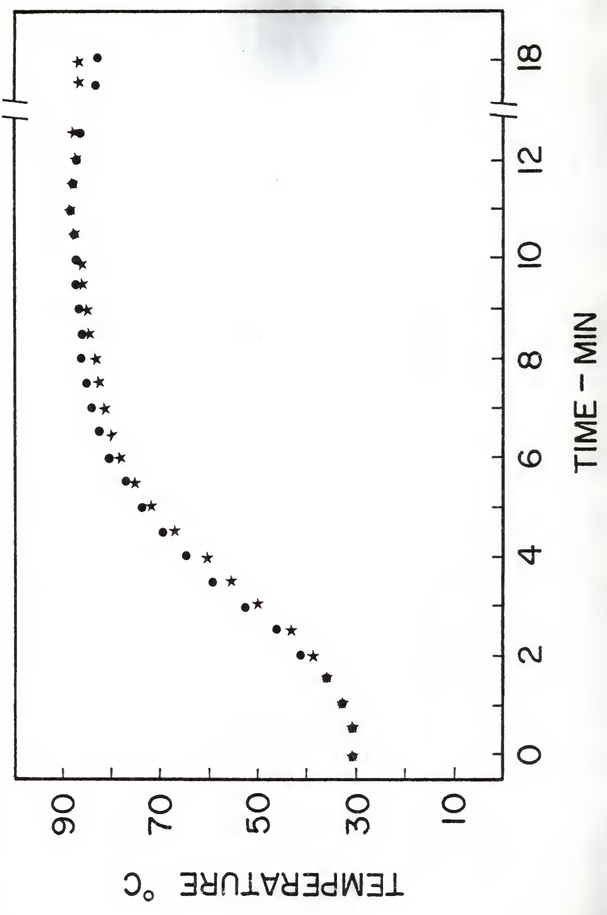

HEIGHT — CM
13.0
11.0
9.0
7.0
5.0
0
2
4
6
8
10
12
18
TIME — MIN

Figure 14. Dough temperature as a function of baking time in the electric resistance oven (★) with shortening (●) no shortening.


TEMPERATURE °C
90
70
50
30
10
TIME – MIN
0
2
4
6
8
10
12
18

same as reported by Baker and Mize (1939). They explained the height difference between loaves containing shortening and no shortening by assuming that the shortening prolonged the retention of carbon dioxide.

We measured the carbon dioxide evolved during baking with the resistance oven. The results were surprising because only small amounts of carbon dioxide were evolved during baking. In addition, there was no difference between doughs made with and without shortening. The total CO_2 lost was very small (2 m moles) in relation to that lost from bread baked in the oven (20 m moles).

Carbon dioxide loss in the electrically heated dough was measured at one minute intervals during baking, and showed the loss of CO_2 was erratic. Most of the CO_2 was released after 7 min. of baking, which is after the loaf had set. This suggested that retention of CO_2 has little to do with the loaf improving effect of shortening. The large amount of CO_2 evolved when bread is baked in an oven, is because the heat at the surface of the loaf vaporizes water and the CO_2 dissolved in the water. A moisture gradient then developes and more water with it's dissolved CO_2, diffuses to the surface of the loaf and is vaporized. Thus, CO_2 loss is a measure of water lost from the loaf.

Studying the temperature and height profiles (Figs. 13 and 14) of the shortening and no shortening doughs baked by resistance heating clearly shows that the temperature at which dough containing shortening stops expanding was higher than the temperature at which dough with no shortening stopped expanding. This data indicated that the gelatinization temperature of starch in the dough containing shortening was delayed. This possibility had been suggested, but not tested by Daniels and Fisher (1976). The resistance oven gave two advantages in studying starch gelatinization in bread dough (1) the dough could be raised essentially to any temperature desired up to 100°C and (2) once that temperature was obtained the power could be turned off and the temperature would immediately stop rising.

Doughs prepared with and without shortening were heated to 60°, 64°, and 68°C. After heating to the desired temperature, a sample of dough was removed from the resistance oven and dispersed in water. Photomicrographs (Figs. 15, 16, and 17) clearly show that starch gelatinization (loss of birefringence) was delayed in doughs containing shortening. Thus, the "shortening effect" on loaf volume is explained by starch gelatinization being delayed and the dough remaining expandable for a longer time as shown in the oven spring (height) curves.

Effect of Surfactants

Certain surfactants (monoglycerides) and corn oil do not give a "shortening effect." Height in the resistance oven (Fig. 18) is similar to that obtained with no shortening in the formula. Other surfactants which are known to replace shortening (SSL, DATEM, Poly 60, F108, and EMG) give a similar curve, particularly the temperature at which the dough no longer expands, as does shortening

Figure 15. Photomicrographs both bright field and polarized light of the same field. Doughs were heated to 60°C in the electric resistance oven. Dough (15 g) containing shortening (left) and no shortening (right) was dispersed in water (100 ml).

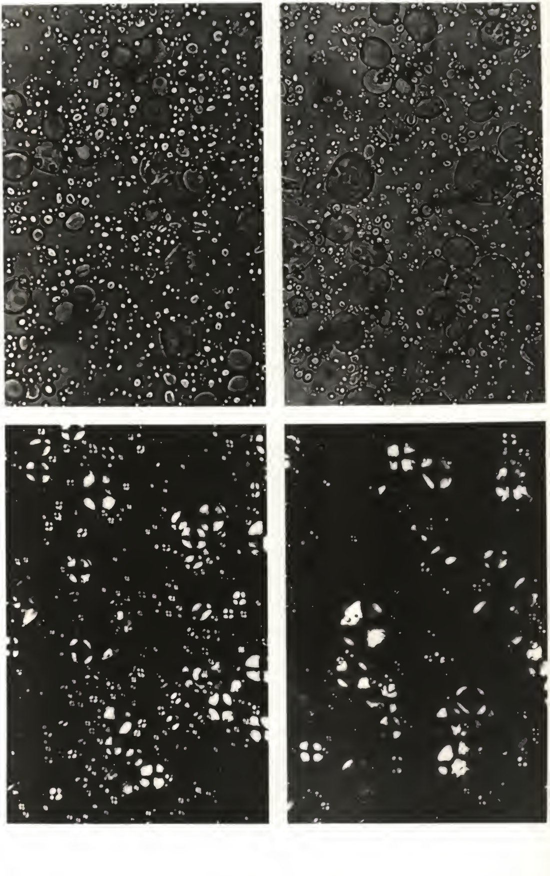


Figure 16. Photomicrographs both bright field and polarized light of the same field. Doughs were heated to 64°C in the electric resistance oven. Dough (15 g) containing shortening (left) and no shortening (right) was dispersed in water (100 ml).

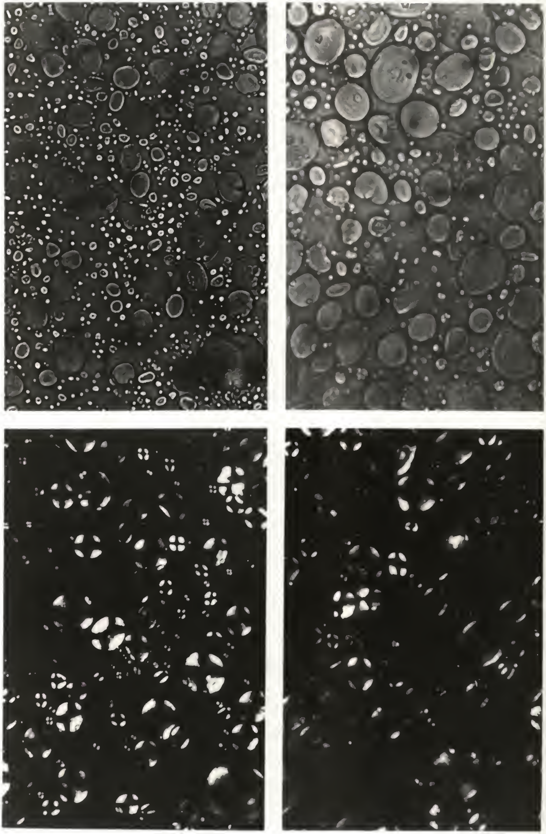


Figure 17. Photomicrographs both bright field and polarized light of the same field. Doughs were heated to 68°C in the electric resistance oven. Doughs (15 g) containing shortening (left) and no shortening (right) were dispersed in water (100 ml).

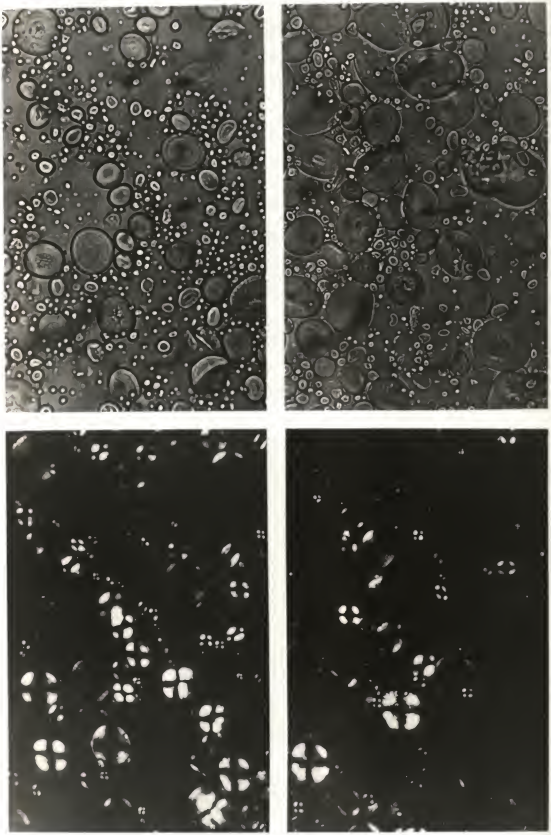
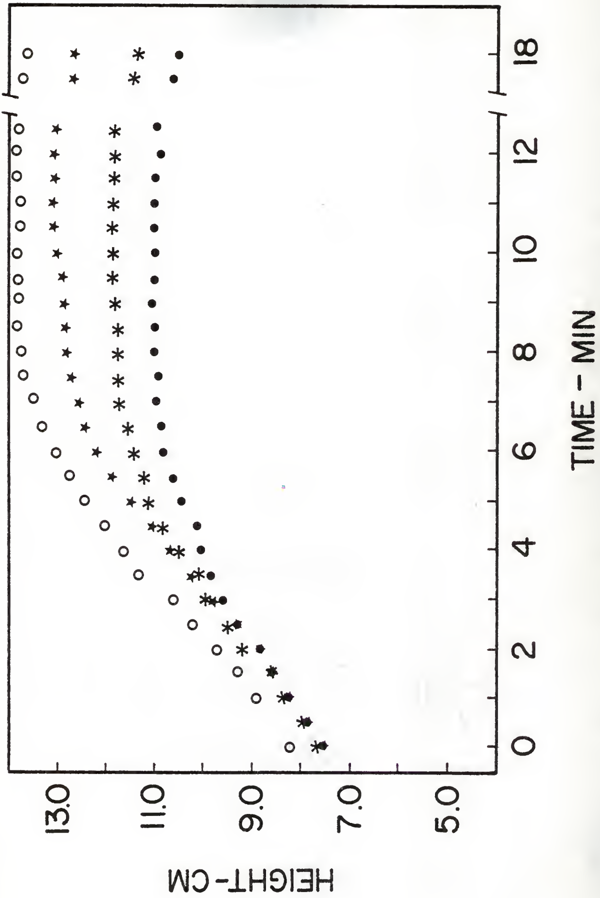


Figure 18. Dough height as a function of baking time in the electric resistance oven. (○) No shortening but, SSL, DATEM, Poly 60, F108, and EMG, (★) shortening, (✱) no shortening but monoglycerides or corn oil, and (●) no shortening.


HEIGHT-CM
13.0
11.0
9.0
7.0
5.0
TIME - MIN
0
2
4
6
8
10
12
18

doughs. Thus surfactants that delay starch gelatinization in a dough system (limited water) will give the shortening effect while those surfactants and oils that do not delay starch gelatinization do not replace shortening. The surfactant PGME (Fig. 19) appears to be unique in that it causes the dough to set at a lower temperature than does a no shortening dough.

Defatted Flours

Doughs prepared with and without shortening from petroleum ether extracted flour were baked in the resistance oven (Fig. 20). The addition of 3% shortening to the defatted flour dough gave essentially no shortening response. With no shortening, doughs from defatted flour gave a greater height than did doughs from nondefatted flour. In general, these results are in agreement with those reported by Pomeranz et al (1967) on the baking responses of defatted flours.

Effect of Protein Quality

One explanation often given for differences in protein quality between wheat varieties is that good quality flours retain CO_2 better than do poor quality flours. The finding in this work that dough does not become permeable to CO_2 during baking raises a question about that explanation. Therefore, two flours of nearly equal protein content but varying widely in loaf volume (different quality) were studied (Table 3). Height curves of the good quality Eagle and poor quality Omaha baked in the resistance oven are shown in Figure 21.

Figure 19. Dough height as a function of baking time in the electric resistance oven (★) shortening, (✱) PGME, and (●) no shortening.

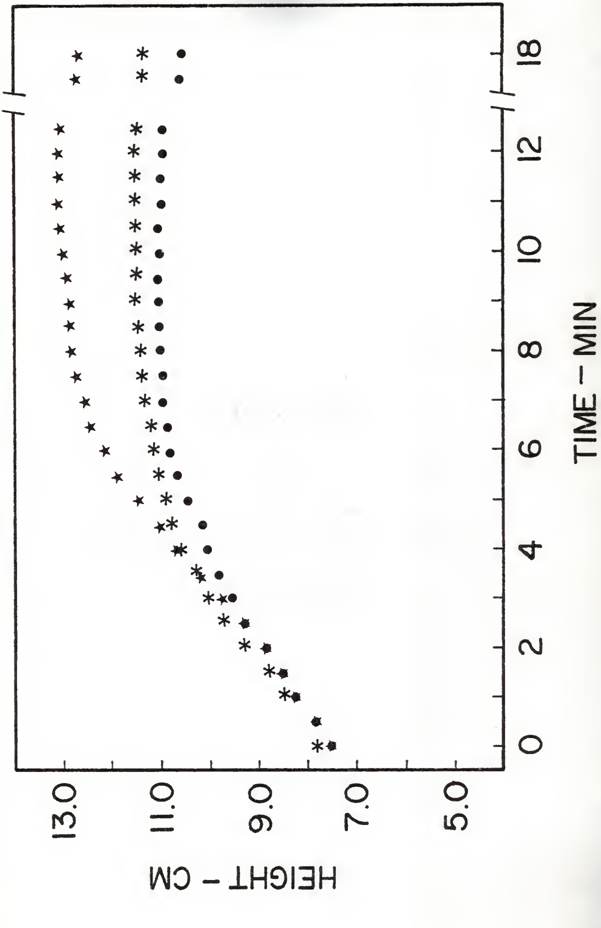

HEIGHT - CM
13.0
11.0
9.0
7.0
5.0
0
2
4
6
8
10
12
18
TIME - MIN

Figure 20. Dough height as a function of baking time in the electric resistance oven. (★) shortening regular flour, (○) defatted flour, no shortening (✱) defatted flour, with shortening, and (●) regular flour, no shortening.

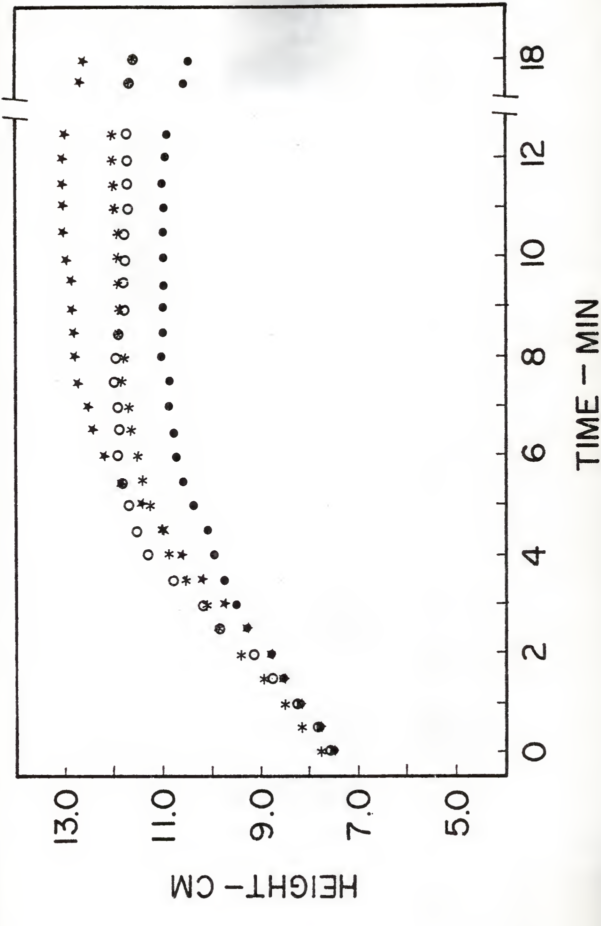

HEIGHT – CM
13.0
11.0
9.0
7.0
5.0
TIME – MIN
0
2
4
6
8
10
12
18

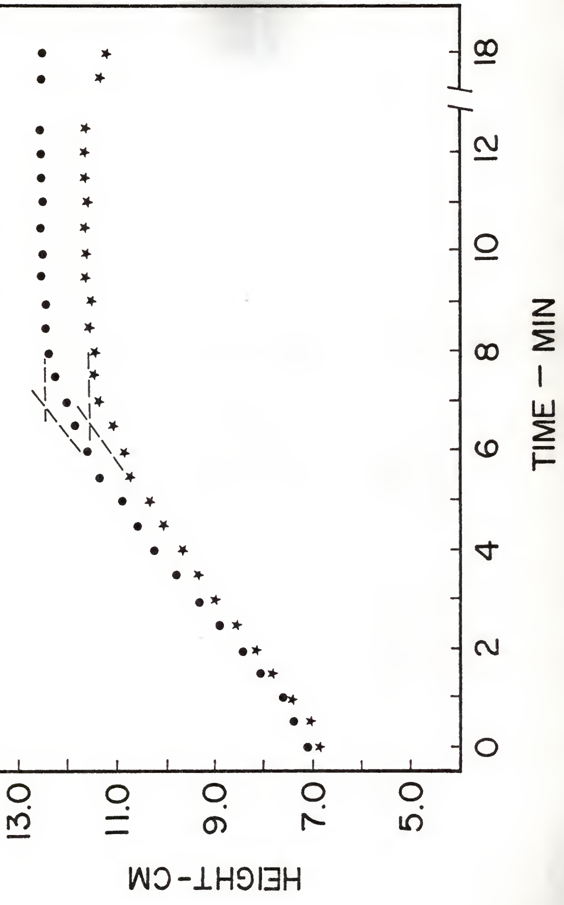
Table 3. Baking Data and Carbon Dioxide Evolved for Doughs from Good and Poor Quality Flours.

		Pup Baking		Resistance Baking			
					CO_2 Evolved (m moles)		
Flour	Protein %	Volume cc	Height cm	Height cm	55 min Proof	7 min[a] Bake	11 min [b] Bake
Eagle	12.8	950	11.9	12.5	1.17	0.51	1.83
Omaha	12.6	830	11.3	11.6	1.22	0.53	2.64

[a] First 7 min. of baking, oven spring stage.

[b] Last 11 min. of baking, final baking stage.

Figure 21. Dough height as a function of baking time in the electric resistance oven. (●) Eagle flour, and (★) Omaha flour.

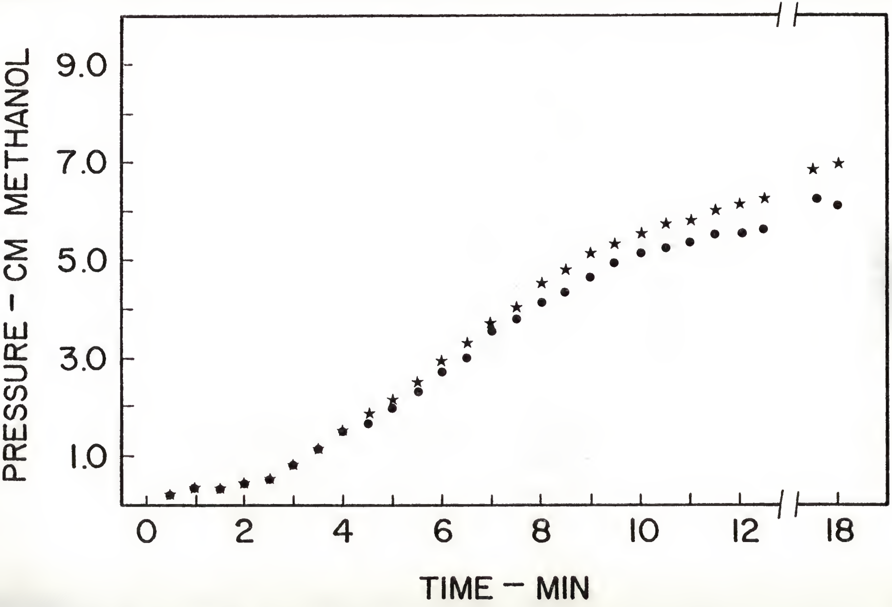

HEIGHT-CM
13.0
11.0
9.0
7.0
5.0
TIME — MIN
0
2
4
6
8
10
12
18

The height curves shows both doughs stop expanding at the same time. Thus, there is no difference in the temperature of starch gelatinization between a good and poor quality flour. The difference in final height between the two flours is largely manifested during the oven spring stage of baking. The amount of carbon dioxide evolved during proofing, the oven spring stage, and final stage of baking are much too small to explain the differences in height. Thus, an explanation for the differences in volume between good and poor quality flours remains obscure.

Measurement of Pressure in Dough

The data shows, (1) only small amounts of carbon dioxide are evolved when doughs were heated between electrodes, and (2) shortening produces higher volume in bread because starch gelatinization is delayed in dough containing shortening. Those conclusions indicate that dough does not become permeable to carbon dioxide during the early stage of bread baking. If the above is true, the pressure within a dough should rise with the temperature of the dough. If the dough becomes permeable, the pressure should fall at the temperature at which the dough becomes permeable. A method to measure pressure within a dough was developed. Pressure measurements were taken during baking in the resistance oven on doughs made with and without shortening (Fig. 22). The plot of pressure versus time shows no loss of pressure when the dough sets. Thus, no significant amount of gas is lost from the system during the oven spring stage of baking. The preliminary data with pressure supports our previous conclusions.

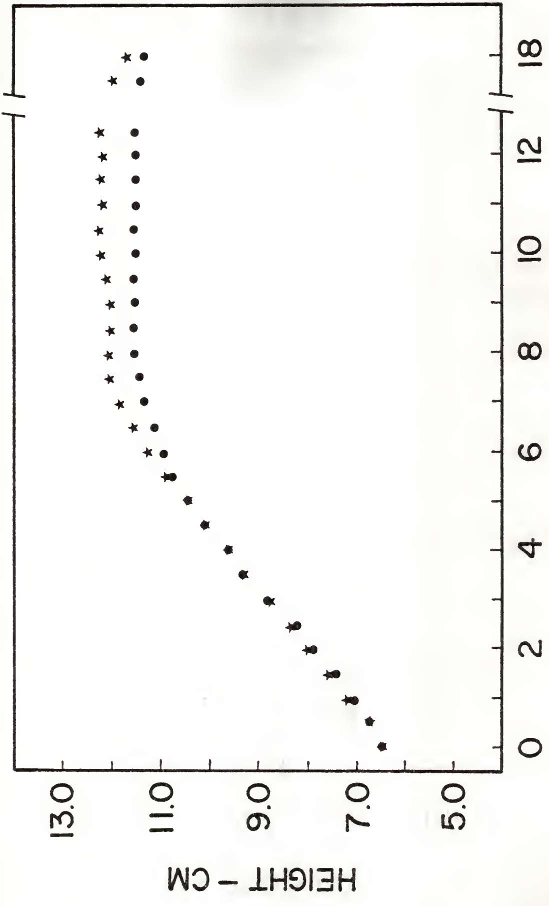
Figure 22. Pressure within dough as a function of baking time in the electric resistance oven, (★) shortening containing dough, and (●) no shortening containing dough.


PRESSURE - CM METHANOL
9.0
7.0
5.0
3.0
1.0
0
2
4
6
8
10
12
18
TIME — MIN

Effect of Oxidants

Height measurements of dough made with and without oxidants and baked in the resistance oven are shown in Figure 23. A higher height is found with the oxidized dough as would be expected. Oxidized doughs give a larger loaf volume in normal bread baking. The temperature at which the dough sets is not affected by the oxidant. There is no apparent explanation for the higher height for the doughs containing oxidants.

Figure 23. Dough height as a function of baking time in the electric resistance oven. Dough contains (★) 20 ppm $KBrO_3$ and (●) dough contains no oxidant.


13.0
11.0
9.0
7.0
5.0
HEIGHT – CM
0
2
4
6
8
10
12
18
TIME – MIN

LITERATURE CITED

Baker, J. C., 1939. A Method and Apparatus for Testing Dough. Cereal Chem. 16:513.

Baker, J. C. and Mize, M. C., 1939, Effect of Temperature of Dough Properties, I. Cereal Chem. 16:517.

Baker, J. C. and Mize, M. C., 1939. Effect of Temperature on Dough Properties, II. Cereal Chem. 6:682.

Bechtel, W. G., 1959. Gelatinization of Starch During Baking. Baker's Digest, 33(6):74.

Daniels, G. H. and Fisher, N., 1976. Release of Carbon Dioxide from Dough During Baking. J. Sci. Fd. Agric. 27:351.

Pomeranz, Y., Shogren, M., and Finney, K. F. 1968. Functional Bread-Making Properties of Lipids. I. Resonstitution Studies and Properties of Defatted Flours Milled from Wheats Varying Widely in Bread-Making Potentialities. Food Tech. 22(3):76.

Strandine, E. J., Carlin, G. T., Werner, G. A., and Hopper, R. P., 1951. Effect of Monoglycerides on Starch, Flour, and Bread: A Microscopic and Chemical Study. Cereal Chem. 28:449.

Vogel, A. I. 1978. Practical Organic Chemistry. 4th Ed. p. 788. Longman. London and New York.

Hoseney, R. C., Finney, K. F., Pomeranz, Y., and Shogren, M. D. 1971. Functional (Breadmaking) and Biochemical Properties of Wheat Flour Components. VIII. Starch. Cereal Chem. 48:191.

Varriano-Marston, E., Ke, Victor, Huang, Grace, and Ponte, J. G. Jr. 1980. Comparison of Methods to Determine Starch Gelatinization in Baking Foods. Cereal Chem. Submitted.

ACKNOWLEDGEMENTS

Grateful acknowledgement is expressed by the author to his major professor, Dr. R. Carl Hoseney, for his numerous suggestions, advice, and encouragement throughout the course of this investigation and preparation of this thesis.

The author is deeply grateful to Dr. P. E. Seib, Dr. E. Varriano-Marston and J. G. Ponte Jr. for their advice, help, and service on the advisory committee.

Appreciation and thanks are directed to his colleagues for their friendship and encouragement throughout the course of this study. A special appreciation is extended to Don W. Lillard for all his assistance and support during the authors graduate studies.

Deep appreciation is extended to the authors parents for their encouragement and support throughout his term in school.

Finally, but not least the author acknowledges with deepest gratitude the patience and understanding of his wife, Roxanna and daughters, Candice Elaine and Miranda Kaye, for being a loving and giving family throughout the authors studies at Kansas State University.

TWO EFFECTS OF SURFACTANTS IN BREAD

I. AIR INCORPORATION IN BREAD DOUGH

II. A MECHANISM FOR SHORTENING IMPROVEMENT OF LOAF VOLUME

by

RICHARD C. JUNGE

B.S., Kansas State University, 1977

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Grain Science and Industry

KANSAS STATE UNIVERSITY

Manhattan, Kansas

1980

ABSTRACT

One role of certain surfactants in yeast-leavened dough is to impart a fine grain to bread crumb. The origin of the fine grain was studied by measuring the density of dough mixed to optimum and containing surfactants. Scanning electron microscopy of cyrofractured dough was used to study the distribution and relative size of air cells in those doughs. Surfactants that improve grain did not significantly alter dough densities. However, SEM photomicrographs showed those surfactants allowed more and smaller cells to form during the mixing stage.

The addition of shortening to the breadmaking formula, among other things, increases the loaf volume. This has been explained as a delay in the release of carbon dioxide from the dough during baking. We were able to confirm that shortening delays the loss of carbon dioxide, if a short time system was used. However, with a conventionally fermented dough carbon dioxide was released at the same rate from shortening and no-shortening doughs.

A modified baking system whereby the dough is baked by electric resistance heating, was used to study the effects of shortening. That system of baking results in all portions of the dough having the same temperature. Surprisingly it was found that the dough does not become permeable to carbon dioxide during baking. The presence of shortening and those surfactant that replace shortening delays the gelatinization

of starch in the dough. Thus, the dough with shortening remains expandable longer and therefore has a higher volume than does dough containing no shortening. The long-held belief that shortening somehow improves the gas-retaining properties of dough appears erroneous.