A Mechanism by Which Shortening and Certain Surfactants Improve Loaf Volume in Bread[1]

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ABSTRACT

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Addition of shortening to the bread-making formula, among other things, increases loaf volume and delays the loss of carbon dioxide from short-time doughs during baking. With a conventionally fermented dough, however, carbon dioxide was released at the same rate from doughs with and without shortening. When a modified baking system with electric resistance heating was used to study the effects of shortening, doughs did not become permeable to carbon dioxide during baking. The dough with shortening and surfactants that replace shortening remained expandable longer and therefore produced a higher volume than dough with no shortening. The long-held belief that shortening somehow improves the gas-retaining properties of dough appears to be erroneous.

Shortening is used in bread production for several reasons including that of increasing loaf volume. The mechanism by which shortening improves loaf volume has been explained as delayed release of carbon dioxide during baking. Daniels and Fisher (1976) reported that, with the short-time Chorleywood Bread Process (CBP), doughs containing shortening retained carbon dioxide longer during the early stages of baking than did dough without shortening. Graphs of cumulative carbon dioxide released related to time in the oven were sigmoid shaped and showed an induction period averaging 4½ min for mechanically developed (ie, CBP) doughs mixed with fat and 2½ min for those without fat. The induction period is the time before carbon dioxide is released.

Baker (1939) developed a method to bake dough by heating it internally so that the temperature of the entire mass rose uniformly. The electric resistance oven did not produce a crust. In commercial baking, the temperature rise in bread dough is progressive from the outside to the inside. However, each portion of the dough must go through a heating cycle (or temperature regime) similar to that of dough in an electric resistance oven. Thus, reactions observed in dough 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 simultaneously rather than over the course of the baking as found in a hot air oven.

Elton and Fisher (1966) investigated the course of dough expansion in the oven by time-lapse cinematography and found that doughs containing fat started to rise more rapidly after entering the oven and continued to rise longer than did doughs containing no added fat. The goal of our study was to determine whether shortening delayed CO_2 loss with our formulation and bread-baking procedure and whether surfactants that replace shortening also delay the setting of dough in the oven.

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 otherwise mentioned. It contained 12.2% protein (N × 5.7) and 0.45% ash.

Surfactants and Oil

Sodium stearoyl lactylate and ethoxylated monoglycerides were obtained from C. J. Patterson Co., Kansas City, MO; diacetyl tartaric acid esters of monoglycerides (V 35.851) from Chemische Fabrik Grunau GMBH, Jllertissen, West Germany; pluronic polyol from BASF Wyandotte Corp., Wyandotte, MI; distilled monoglycerides (Myverol 18-04) from Eastman Chemical Products, Inc., Kingsport, TN; polyoxyethylene sorbitan monostearate from ICI America, Wilmington, DE; and corn oil (Mazola) from CPC International, Argo, IL.

Straight-Dough Formula and Procedure

The same formula was used for all experiments in bread baking. Ingredients, based on flour weight, were: flour, 100%; sugar, 6%; salt, 1.5%; nonfat dry milk, 4%; shortening (Crisco), 3%; yeast, 20%; and malt (60°L), potassium bromate, and water, optimum.

The doughs were mixed with a 100-g National pin mixer (National Mfg. Co., Lincoln, NE), and handled as described by Finney and Barmore (1943). In this procedure, doughs were punched after 105 and 155 min, panned after 180 min, and proofed for 55 min. The short-time baking process was as described by Daniels and Fisher (1976).

Carbon Dioxide Collection

Bread was baked in the container shown in Fig. 1. It is made of steel tubing 5/16 in. thick with a diameter of 5¼ in. A permanent seal (silicone rubber ring gasket) is mounted on the lip to ensure an airtight environment.

The lid of the container is made from 1-in. 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," which serves as an

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insulator, withstands the high temperature. Vacuum-tight feedthroughs are used to 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-covered wire is used to bring current to the baking container.

A schematic diagram of the apparatus used for collecting carbon dioxide during baking is shown in Fig. 2. Arrows indicate the flow of nitrogen gas (85 ml/min), which passes through the baking container and carries carbon dioxide through a double-surfaced condensor to gas dispersion tubes immersed in 2*N* NaOH in collecting tubes.

The baking container containing the proofed dough was placed in an oven set at 450° F and the container connected to the carbon dioxide collecting system. The internal heater mounted in the lid of the baking chamber was adjusted with a variable transformer to give optimum baking.

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 were found in the overflow tubes. After each minute, the gas stream was redirected to the second set of collection tubes, and the first tube was 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 because it can be used to titrate NaOH in the presence of Na_2CO_3.

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. When the mixture was put in the baking chamber and heated, recovery of CO_2 was 96 ± 2% of that predicted.

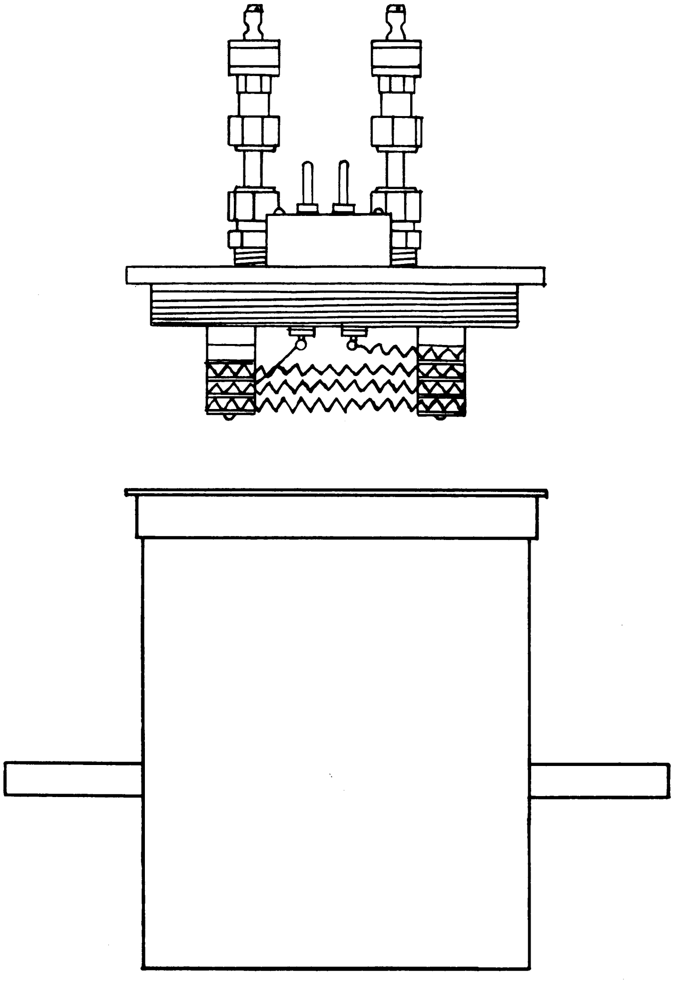

Fig. 1. The baking container.

Resistance Baking Oven

The baking chamber was constructed from ¼-in. plexiglas (Fig. 3). Its outside dimensions are 5½ × 4⅛ in. × 10½ in. in height. The distance between the plates is 2½ in. The bottom is thus the same size as the bottom of our pup loaf baking pans. The electrical connections bring current to the stainless steel electrode plates; the carrier gas (nitrogen) flows into the upper inlets, passes over the dough, and goes out through the lower outlet.

The voltage was adjusted by a variable transformer to the desired rate of heating. An alcoholic solution of quinhydrone (Vogel 1978) was used to coat the electrode surfaces. The quinhydrone decreases surface effects between the dough and the electrode (Baker and Mize 1939a). Carbon dioxide was collected and quantified by the method described earlier.

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 of 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 on Kodak high contrast copy film 5069.

Pressure Measurement

Pressure was determined with an S-shaped capillary tube (2.5 mm i.d.) filled with methanol and carefully immersed in the dough just before baking. The dough seals well to the tube.

Flour Defatting

Free lipids were extracted from flour (400 g) with petroleum ether in a Soxhlet apparatus for 24 hr. Heating was adjusted to

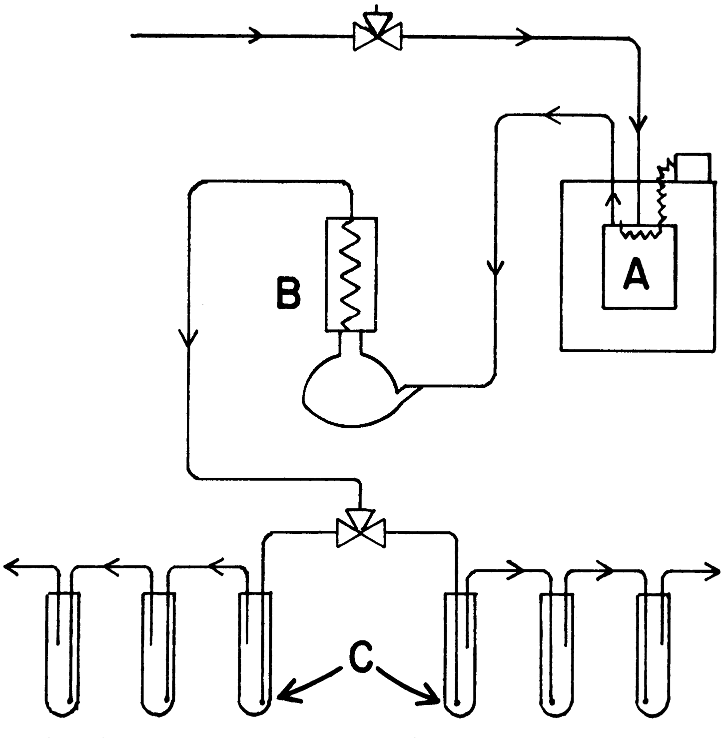

Fig. 2. Apparatus used to collect carbon dioxide: **A,** baking container in a conventional oven; **B,** condenser; **C,** collection tubes. Arrows indicate flow of nitrogen carrier gas.

ensure a complete change of solvent in 25–30 min. The defatted flour was dried at room temperature until no trace of solvent odor remained.

RESULTS AND DISCUSSION

None of the numerous hypotheses discussed in the literature provides a clear explanation for the mechanism by which fat improves loaf volume. Daniels and Fisher (1976) have shown that release of carbon dioxide is delayed by adding shortening to the formula in the short-time CBP. We found their data interesting and undertook to confirm it by our baking procedure.

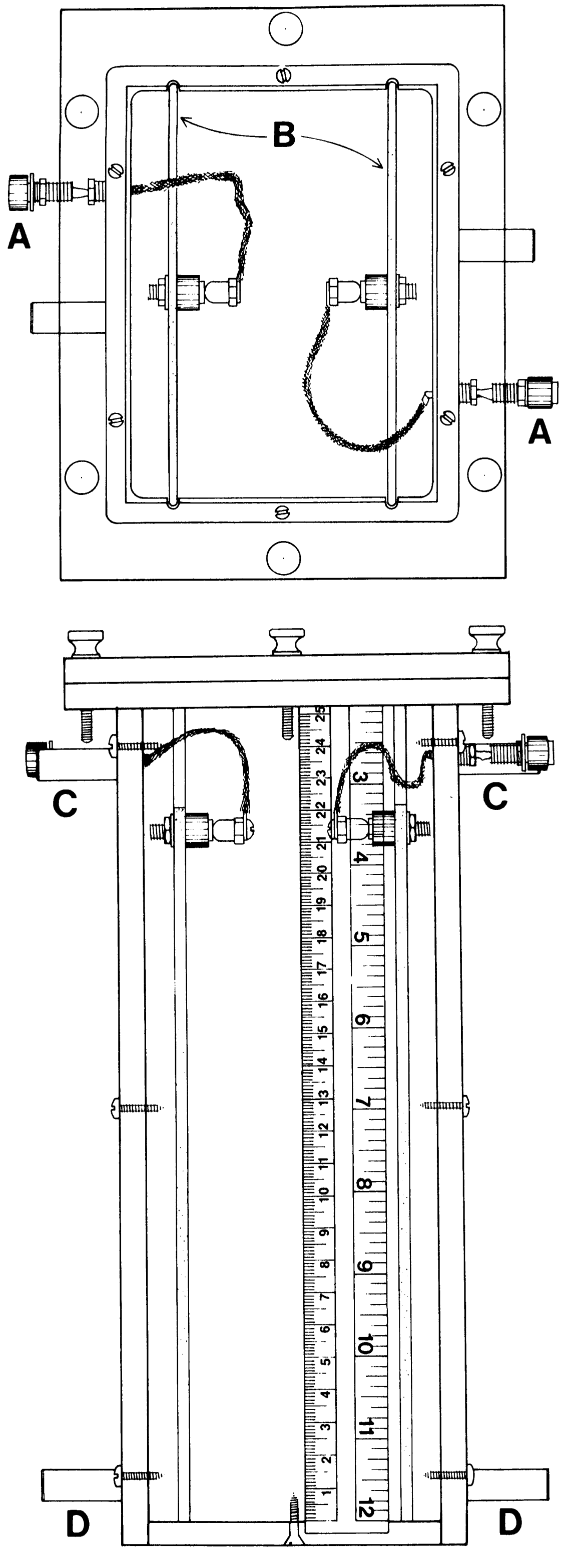

Fig. 3. Resistance baking oven: **A,** electrical connection; **B,** stainless steel plates; **C,** carrier gas intake; **D,** carrier gas outflow.

Oven Baking

With our straight-dough procedure and 3-hr fermentation, we found no apparent difference in the time or amount of carbon dioxide lost from dough formulated with or without shortening (Fig. 4), which appeared to contradict Daniels and Fisher's (1976) results. However, with their formulation and procedure we obtained results similar to those they reported. Doughs containing shortening gave slightly delayed evolution of carbon dioxide.

Effects of Shortening

We used the resistance oven, as described by Baker (1939), to study the release of carbon dioxide during baking because this oven heats the dough 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. 5 and 6) showed that the doughs containing shortening expanded longer and to a greater height than did doughs with no shortening. The presence or absence of shortening did not affect the rate of temperature rise in the dough. These results confirmed the data reported by Baker and Mize (1939a, 1939b) and Elton and Fisher (1966). They all explained height differences between loaves containing shortening and no shortening by assuming that the

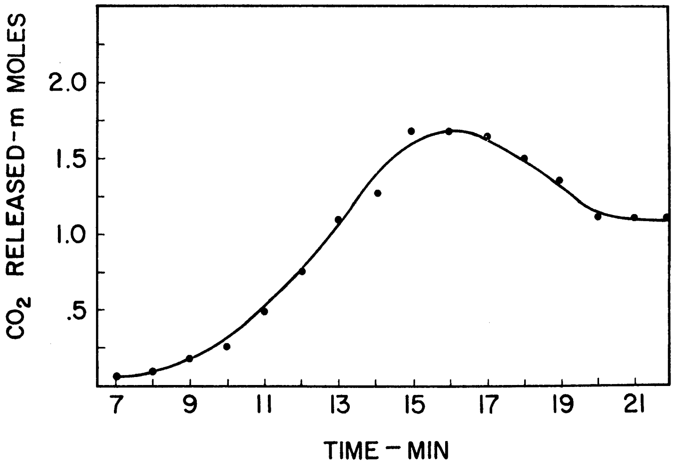

Fig. 4. Release of CO_2 as a function of time in the conventional oven baking procedure. The curve was the same for doughs with or without shortening.

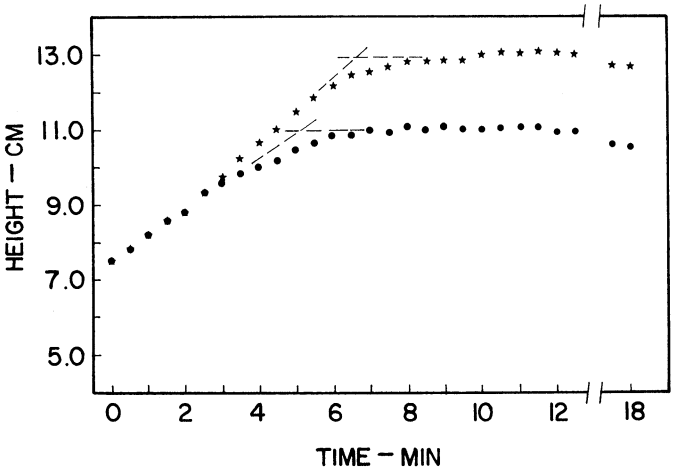

Fig. 5. Dough height as a function of baking time in the electric resistance oven. ★ = with 3% shortening, ● = without shortening.

shortening prolonged retention of carbon dioxide.

However, when we measured the carbon dioxide evolved during baking with the resistance oven, we found only small amounts. In addition, no difference was found between doughs made with or without shortening. The total CO_2 lost was very small (2 mmol) compared with that lost from bread baked in the conventional oven (20 mmol).

Carbon dioxide loss in the electrically heated dough, measured at 1-min intervals during baking, was erratic. Most of the CO_2 was released after 7 min of baking, which is after the loaf had set. Typical data were 0.51 mmol during the first 7 min of baking (oven spring) and 1.83 mmol during the last 11 min of baking. This suggested that retention of CO_2 has little to do with shortening's loaf-improving effect. We explain the large amount of CO_2 evolved when bread is baked in a conventional oven as the result of the heat at the surface of the loaf vaporizing water and the CO_2 dissolved in the water. A moisture gradient then develops, and more water with its 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. With the resistance oven, much less water is lost during baking than with the conventional oven.

The height profile (Fig. 5) of the shortening and no-shortening doughs baked by resistance heating clearly showed that the time at which dough containing shortening stopped expanding was longer than the time at which dough with no shortening stopped expanding. The time-temperature relationship was the same for dough with or without shortening (Fig. 6). Therefore, the dough containing shortening expands to a higher temperature than does the no-shortening dough. If one assumes that dough sets because starch gelatinizes, those data indicate that the gelatinization temperature of starch was delayed in the dough containing shortening, a possibility suggested, but not tested, by Elton and Fisher (1966).

TABLE I
Baking Data for Certain Surfactants

Treatment[a]	Loaf Volume (cc)
Control	950
No shortening	855
No shortening plus	
SSL (0.5%)	955
EMG (0.5%)	970
Poly 60 (0.5%)	960
F108 (0.5%)	990
DATEM (0.5%)	945
monoglycerides (0.5%)	860
corn oil (3.0%)	920

[a] SSL = sodium stearate lactylate, EMG = ethoxylated monolgycerides, poly 60 = polyoxyethylene sorbitan monostearate, F108 = pluronic polyol, DATEM = diacetyl tartaric acid esters of monoglycerides.

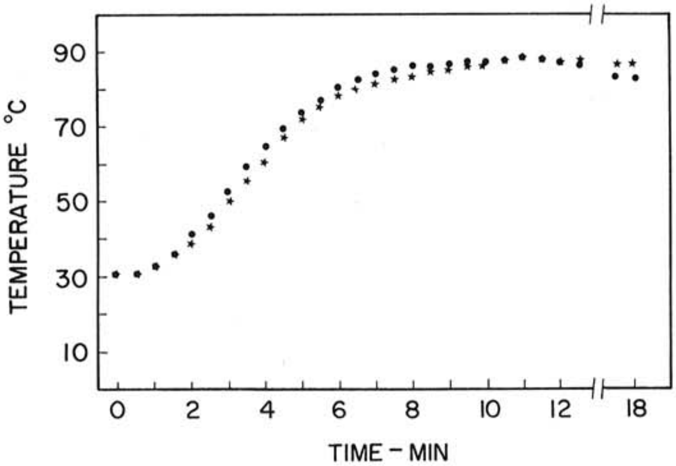

Fig. 6. Dough temperature as a function of baking time in the electric resistance oven. ★ = with 3% shortening, ● = without shortening.

The resistance oven gave two advantages in studying starch gelatinization in bread dough: 1) the dough could be raised to essentially any desired temperature up to 100°C, and 2) once that temperature was obtained, the power could be turned off and the temperature would immediately stop rising. Hoseney et al (1971) have shown that starch gelatinization is delayed in a full-formula bread dough. The problems encountered and methods used to study starch gelatinization in baked foods have been discussed by Varriano-Marston et al (1980).

Doughs prepared with and without shortening were heated to 60, 64, and 68°C. In each case, a sample of dough was removed from the resistance oven and dispersed in water. Photomicrographs (Fig. 7) appear to show that starch gelatinization (loss of birefringence) was delayed in doughs containing shortening. However, differential scanning calorimetry thermograms did not confirm a delay in starch gelatinization.[4] Thus, although dough containing shortening remains extensible longer, as shown in the height curve (Fig. 5), the reason is not clear.

Effect of Surfactants

Certain surfactants (monoglycerides) and corn oil do not give a shortening effect (Table I). Height in the resistance oven for dough containing monoglycerides or corn oil (Fig. 8) was only slightly higher than that obtained with no shortening in the formula. The time (temperature) that doughs containing monoglycerides or corn oil stopped expanding was similar to that of no-shortening doughs.

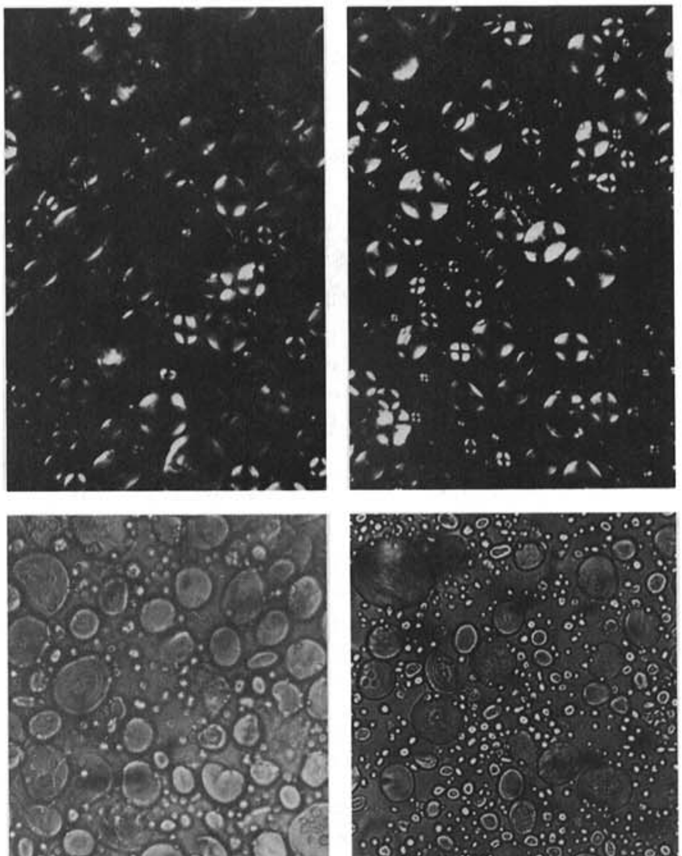

Fig. 7. Photomicrographs, brightfield (top) and polarized light (bottom), of the same field and with the same magnification, of doughs heated to 64°C in the electric resistance oven. Right, with 3% shortening; left, with no shortening.

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[4] K. Ghiasi, R. C. Hoseney, and E. Varriano-Marston. Unpublished data.

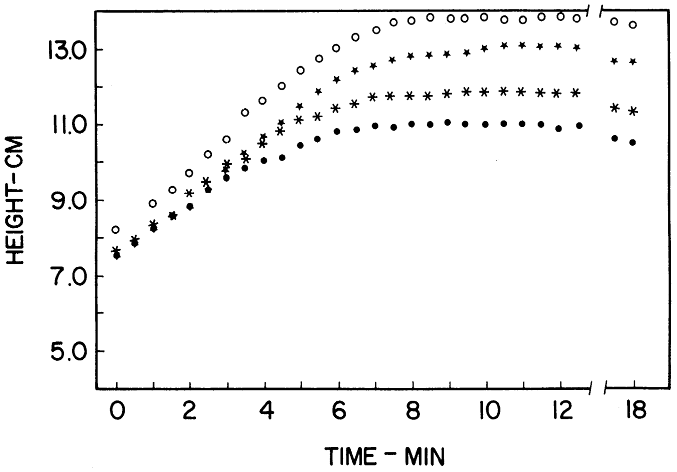

Fig. 8. Dough height as a function of baking time in the electric resistance oven. o = no shortening but 0.5% sodium stearoyl lactylate, diacetyl tartaric acid esters of monoglycerides, polyoxyethylene sorbitan monostearate, pluronic polyol, or ethoxylated monoglycerides; ★ = 3% shortening; * = no shortening but 0.5% monoglycerides or 3% corn oil; ● = no shortening.

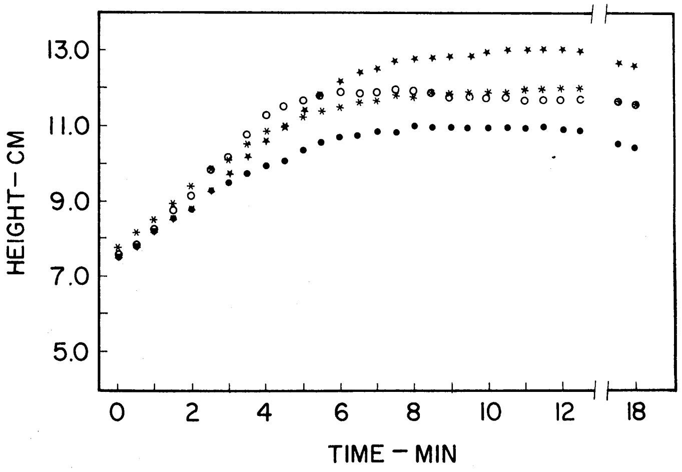

Fig. 9. Dough height as a function of baking time in the electric resistance oven. ★ = 3% shortening and regular flour, o = defatted flour without shortening, * = defatted flour with 3% shortening, ● = regular flour without shortening.

The other five surfactants, which are known to replace shortening, each gave curves similar—particularly in relation to the time (temperature) at which the dough no longer expands—to those of shortening doughs. Thus, of the surfactants tested, those that delayed setting in a dough system (with limited water) gave the shortening effect, whereas those surfactants and oils that did not delay setting also did not replace shortening.

Defatted Flours

Doughs prepared with and without shortening from flour extracted with petroleum ether were baked in the resistance oven (Fig. 9). The addition of 3% shortening to the defatted flour dough gave essentially a no-shortening response. With no shortening, doughs from defatted flour gave a greater height than did doughs from nondefatted flour. In general, these results agree with those reported by Pomeranz et al (1968) on the baking responses of defatted flours.

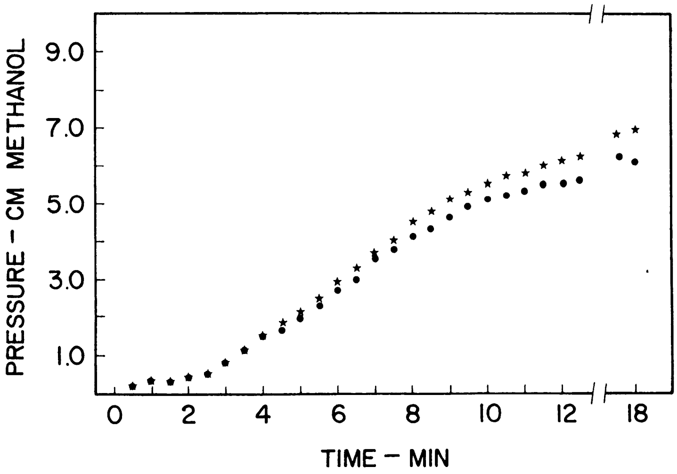

Fig. 10. Pressure within dough as a function of baking time in the electric resistance oven. ★ = dough containing 3% shortening, ● = dough without shortening.

Measurement of Pressure in Dough

The results of this study shows that 1) only small amounts of carbon dioxide were evolved when doughs were heated between electrodes, and 2) shortening produces higher volume in bread because setting of the dough 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, pressure within a dough should rise as dough temperature rises. If the dough becomes permeable, the pressure should fall at the same temperature that the dough become permeable.

A method to measure pressure within a dough was developed. Pressure measurements taken during baking in the resistance oven on doughs made with or without shortening (Fig. 10) showed no loss of pressure when the dough set (4¾ min for no-shortening dough and 6½ min for shortening dough). Thus, no significant amount of gas was lost from the system during baking. The preliminary data with pressure support our previous conclusions that dough does not become permeable to CO_2 during the early stages of baking.

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