

Influence of Shortening and Surfactants on Retention of Carbon Dioxide in Bread Dough¹

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ABSTRACT

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During heating of bread dough containing shortening or surfactants in a resistance oven, carbon dioxide was lost at a slow rate for the first 9 min. During that same period the dough increased in height in a linear fashion. After 9 min of heating, carbon dioxide was lost at a greater rate, and the rate of dough expansion slowed. With no shortening or surfactant in the formula, the rate of carbon dioxide loss increased after only 2 min of heating. This also corresponded with a slower rate of dough expansion.

Artificially restricting dough expansion increased the rate of carbon dioxide loss. Measurement of dough rheology showed that dough without shortening undergoes a change at about 55°C, but dough with shortening does not. Thus, the increased loss of carbon dioxide at higher temperatures was found to be the result of a rheological change in the dough that restricted expansion rather than increased permeability of the dough to carbon dioxide.

A major effect of adding shortening to bread doughs is an increase in the volume of the bread. Doughs made with and without shortening typically proof to the same height but differ greatly in final loaf volume (Baker and Mize 1942, Elton and Fisher 1966). Doughs made with shortening have been shown to continue to expand for a longer time (to a higher temperature), thus attaining a larger volume than doughs made without shortening (Elton and Fisher 1966, Junge and Hosenev 1981).

Several mechanisms have been proposed to explain the effects of shortening on loaf volume. Baker and Mize (1942) demonstrated that increased loaf volume was not a result of the lubrication properties of the fat. They found that loaves containing hard fats and waxes attained volumes similar to those when commercial shortening was used. Elton and Fisher (1966) suggested three possible mechanisms for the shortening effect on increased time of loaf expansion and resultant increased volume. First, addition of shortening may alter dough permeability to water vapor and/or carbon dioxide. Second, shortening may delay the increase in apparent viscosity of the dough during starch gelatinization. Third, shortening may delay an irreversible change such as protein denaturation.

Moore and Hosenev (1986) found that doughs made with and without shortening expanded at the same rate during heating until the internal temperature reached 55°C. Doughs made with shortening continued to expand at the same rate, whereas doughs made without shortening expanded at a much reduced rate. The objective of this study was to determine the influence of shortening or surfactants on retention of carbon dioxide in bread doughs.

MATERIALS AND METHODS

Preparation and resistance heating (baking) of doughs was accomplished using the procedure described by Moore and Hosenev (1986). Presented data are averaged from at least three runs. The standard deviation of dough height was 0.3 cm. A commercial partially hydrogenated soybean oil (Crisco) was obtained from Procter and Gamble, Cincinnati, Ohio. Sodium stearyl-2-lactylate and distilled monoglycerides were obtained from Grindsted Products, Industrial Airport, Kansas. Commercial bread flour was obtained from Ross Mills, Wichita, Kansas. It contained 12.4% protein ($N \times 5.7$), 0.44% ash, and 0.8% free lipids on a 14% moisture basis. All other chemicals used were reagent grade. Protein and moisture were determined by AACC methods

46-10 and 44-15A, respectively (AACC 1983). Flour was defatted as described in Moore and Hosenev (1986).

Dough Relaxation

Rheological properties of doughs were evaluated by determining the residual force of the dough at a specified time interval after compression. The procedure was similar to one described by Frazier et al (1977). Doughs were heated in the resistance oven to the desired temperature and then allowed to cool at ambient conditions until the temperature had fallen to 45°C. An Instron universal testing machine, model 1132, was used to measure the residual force during stress relaxation of the heated doughs. While still in the resistance oven, doughs were pressed using a hemispherical probe (radius = 1.86 cm), which was lowered (5 cm/min) to contact and penetrate the dough until a force of 150 g was reached. Once that force was attained, the probe was held stationary and residual forces recorded for 5 min (chart speed 5 cm/min). Residual force at 2 min holding time was selected for comparison of treatments.

Dough Restriction

A Plexiglas restriction plate was constructed to fit within 1 mm of the electrodes and ends of the electrical resistance oven. Eighteen holes (1.0-cm diameter) were drilled through the restrictor, which then was covered with coarse bolting cloth. Doughs were placed in the bottom of the resistance oven, and the restrictor was positioned above the dough such that at the end of proof the top of the dough would be within 0.2 cm of the restrictor. Expansion of the dough during heating filled the volume defined by the resistance oven, electrodes, and restriction plate.

Carbon Dioxide Quantification

Carbon dioxide was measured using a Beckman model 865 infrared analyzer. A flow diagram is presented in Figure 1. A baseline was established with nitrogen as the carrier gas, and upscale calibration was made with a gaseous mixture of known CO₂ concentration. Data presented are averaged from at least three determinations. Standard deviation for the determination of CO₂ was 4.1×10^{-6} moles/min.

RESULTS AND DISCUSSION

Carbon Dioxide Loss from Doughs Made With and Without Shortening

Data describing carbon dioxide evolved from doughs made with and without shortening are plotted in Figure 2. Doughs with and without shortening exhibited a low rate of CO₂ loss (1.95×10^{-5} moles CO₂/min) during the first 1-2 min of baking, a rate equivalent to the diffusion rate of an unheated, fully fermented dough. Doughs that contained shortening maintained essentially that low level of CO₂ loss throughout the first 8 min of baking.

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Continued baking caused an increase in the rate of CO₂ loss, which stabilized at a higher level after 14 min of baking. Following the initial delay of 2 min, loss of the CO₂ from doughs made with no shortening increased rapidly and stabilized at a higher level (10.4 × 10⁻⁵ moles CO₂/min) after about 11 min of baking.

For the first 9 min of baking dough containing 3% shortening, the rates of dough expansion and CO₂ loss are both approximately constant (Fig. 3). Comparison of the time at which measured CO₂ loss increased and the time at which the rate of loaf expansion decreased revealed that these two events occurred at approximately the same time. These results suggest an interdependence between loaf expansion rate and loss of carbon dioxide.

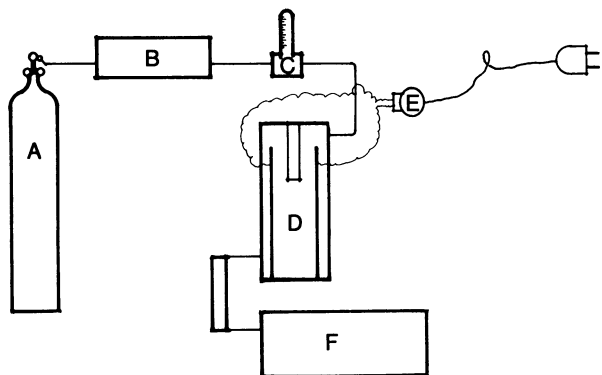


Fig. 1. Schematic drawing of the system used to quantify carbon dioxide evolved during baking: A, nitrogen gas source; B, soda lime CO₂ trap; C, gas flow meter; D, electrical resistance oven; E, variable transformer; F, Beckman infrared CO₂ detector.

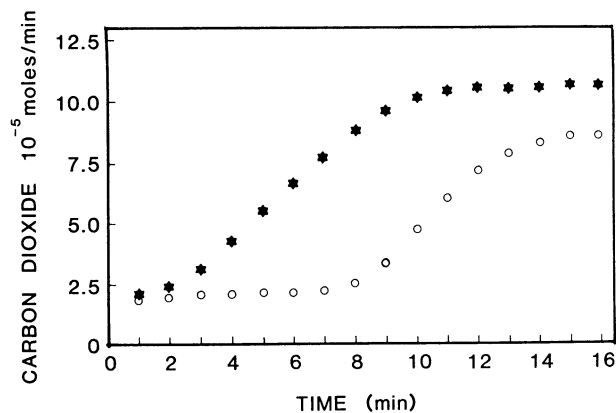


Fig. 2. Carbon dioxide ($\times 10^{-5}$ moles/min) evolved, as a function of time, from bread doughs baked in the electrical resistance oven: (O) 3% shortening, (*) no shortening.

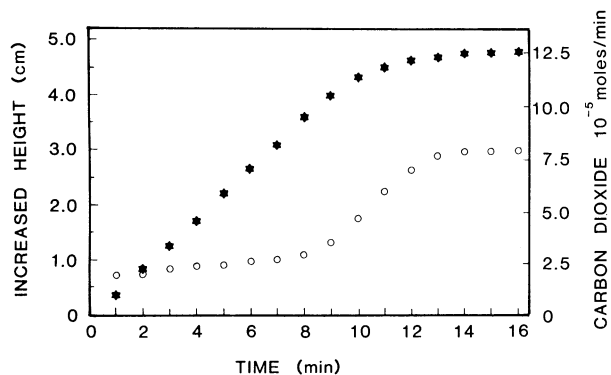


Fig. 3. Height increase (cm) and carbon dioxide ($\times 10^{-5}$ moles/min) evolved from bread doughs made with 3% shortening, as a function of time, baked in the electrical resistance oven: (*) height increase, (O) carbon dioxide evolved.

Effects of Two Surfactants on Loaf Volume and Carbon Dioxide Loss

Two surfactants were evaluated as replacements for shortening: distilled monoglycerides (DMG), normally used as a softening or antistaling agent, and sodium stearyl lactylate (SSL), a volume improver, were each used at the 0.5% level.

During the first 8 min of baking, doughs containing DMG increased in volume rapidly (Fig. 4). During the next 5 min, the volume expansion rate decreased to a point where volume remained constant. Doughs prepared with 0.5% DMG attained volumes equal to doughs containing 3% shortening. Gas retention by doughs containing DMG but no shortening was similar to that of doughs containing shortening. The amount of CO₂ evolved from the doughs increased as the dough expansion rate started to decrease at about 10 min baking.

Expansion rate of doughs containing SSL was equivalent to that of dough made with shortening (about 0.46 cm³/min) during the first 9 min. During the next 5 min, the expansion rate decreased to zero at 5.0 cm, about 0.3 cm greater than the mean height of doughs made with shortening. Concurrent with the decreased expansion rate was an increase in the CO₂ evolved from the dough (Fig. 5). SSL used at 0.5% flour weight was an effective replacement for 3% shortening in the improvement of height and CO₂ retention properties.

Effects of Defatted Flours on Height and Retention of CO₂

Baked doughs prepared from defatted flour attained greater heights than nondefatted flour doughs when shortening was deleted from the formula (Moore and Hosney, in press). The retention of carbon dioxide by bread doughs made with defatted

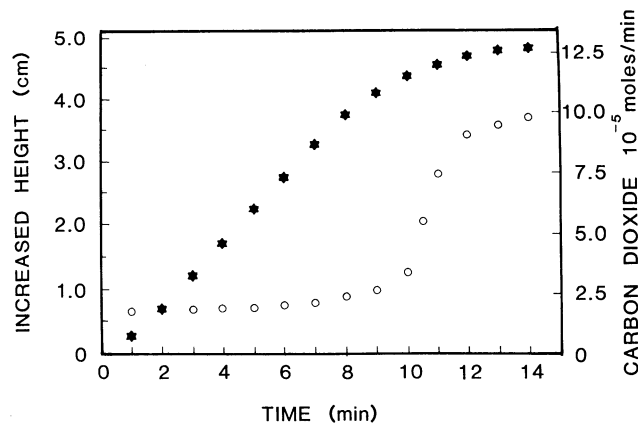


Fig. 4. Height increase (cm) and carbon dioxide ($\times 10^{-5}$ moles/min) evolved from bread doughs made with 0.5% finely divided distilled monoglycerides as a function of time baked in the electrical resistance oven: (*) height increase, (O) carbon dioxide evolved.

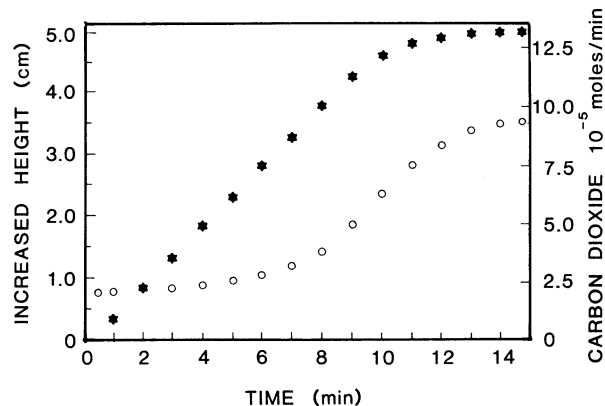


Fig. 5. Height increase (cm) and carbon dioxide ($\times 10^{-5}$ moles/min) evolved from bread doughs made with 0.5% sodium stearyl-2-lactylate, as a function of time, baked in the electrical resistance oven: (*) height increase, (O) carbon dioxide evolved.

flour (no shortening) was equivalent to CO₂ retention by doughs made with untreated flour that contained 3% shortening. Release of carbon dioxide occurred after about 9 min baking for both treatments (Fig. 6).

Restricted Dough Expansion

The data presented indicate that loss of carbon dioxide is related to decreased expansion rate of bread doughs (Figs. 3–5). The correlation of CO₂ loss and decreased expansion rate has two possible sources: a) the dough might become more permeable to CO₂, or b) the dough might become more resistant to expansion, increasing the intracellular gas pressure responsible for the increased rate of gas diffusion. Because of the widely differing temperatures (no shortening, 55°C; 3% shortening, 75°C) at which the increase in CO₂ evolution was found, we thought it unlikely that dough permeability was responsible for the decreased expansion rate.

Doughs made with and without shortening produce the same amount of CO₂ during fermentation. Because doughs of various treatments proof to the same height, the gas within each dough would be essentially the same. Therefore, doughs with and without shortening have the same potential for expansion. Measurements of CO₂ loss during baking from dough made with and without shortening show a difference of only 3.1×10^{-4} moles (9 cm³ at 80°C). The volume of CO₂ lost is inadequate to account for the difference of approximately 140 cm³ between the volume of bread made with and without shortening. Thus, a mechanism other than

the retention of CO₂ must be responsible for the differences in doughs with and without shortening.

If dough rheology were an important factor in gas retention, containing the dough to a volume less than that of a fully baked loaf should result in gas loss sooner than that observed for the fully expanded loaf. However, if changes in dough permeability caused gas loss, then restricting the dough volume should have no effect. Restriction of the dough volume resulted in earlier loss of carbon dioxide (4 min) compared to the unrestricted dough (9 min) (Fig. 7). If dough permeability was responsible for CO₂ loss, then the dough with 3% shortening should have retained the major portion of CO₂ until a higher temperature was reached. However, gas was evolved soon after the voids in the resistance oven were filled, which indicates that the inability of the dough to expand influenced the loss of CO₂. Those results suggest that the ability of the dough to expand has an important effect on gas retention.

Dough Relaxation

Dough relaxation was measured to determine the elastic properties of doughs. Doughs heated to low temperatures (30–45°C) were found to retain a higher residual force than doughs heated to higher temperatures (80°C; Fig. 8). Doughs containing shortening and heated to 45°C were found to maintain a relatively high residual force. Doughs heated to 55°C retained about 85% of the residual force of doughs heated to 45°C. Those heated to 80°C retained only about 50% of the residual force (Fig. 8).

Relaxation measurements of doughs made without shortening were substantially different than those for doughs made with shortening. Nonshortening doughs heated to 55°C retained only about 65% of the residual force found for doughs heated to 45°C. Doughs made without shortening and heated to 80°C showed an additional decrease of residual force (Fig. 9). These results are consistent with the findings of Bloksma and Nieman (1975), who

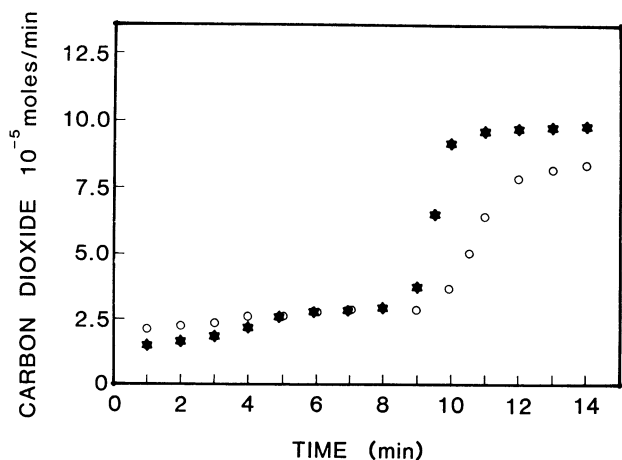


Fig. 6. Carbon dioxide ($\times 10^{-5}$ moles/min) evolved from doughs made using (*) defatted flour (no shortening) and (O) native flour (3% shortening) during baking in the electrical resistance oven.

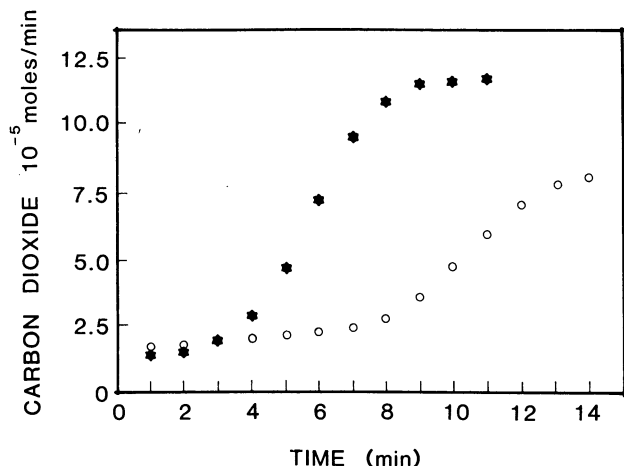


Fig. 7. Carbon dioxide ($\times 10^{-5}$ moles/min) evolved from bread doughs baked in the electrical resistance oven: (*) restricted dough volume, (O) unrestricted dough volume.

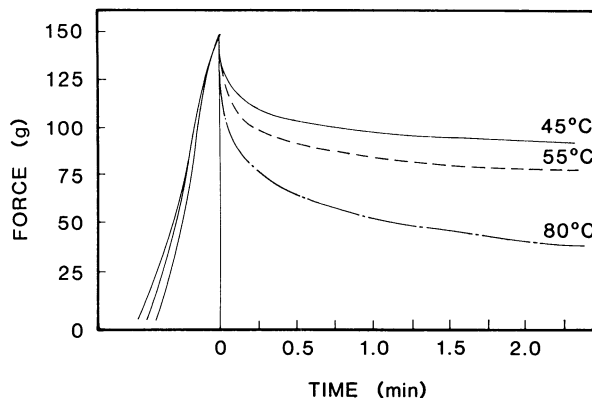


Fig. 8. Residual force of doughs made with 3% shortening heated to 45, 55, and 80°C, then cooled to 45°C for measurement.

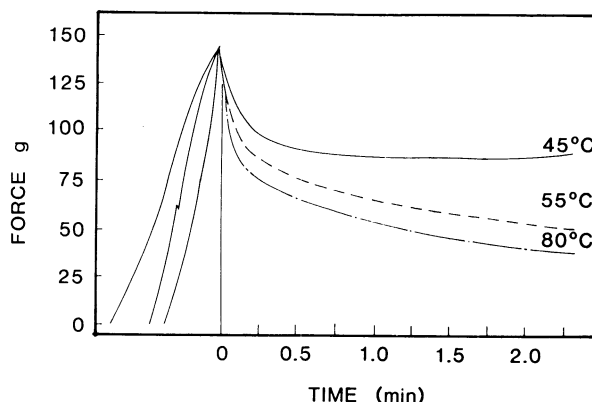


Fig. 9. Residual force of doughs made without shortening heated to 45, 55, and 80°C, then cooled to 45°C for measurement.

reported a rheological change at about 55°C in doughs made without shortening.

Gas Diffusion of Wheat Flour Doughs

The rate of gas diffusion through this aqueous phase of dough is an important factor in determining the final loaf volume (Hoseney 1984). Carbon dioxide produced by yeast first saturates the aqueous phase of the dough. Continued fermentation and production of CO₂ results in diffusion of gas across the water-air interface and into the atmosphere of air cells. Additional production of CO₂ causes additional gas to diffuse into the air cells and develop a slight pressure, maintained by the slow diffusion through the aqueous phase. The viscoelastic nature of wheat flour dough responds to the slight increase in pressure by expanding in volume. This process continues throughout fermentation, and results in a leavened dough. Carlson (1981) and Rajapaksa et al (1983) suggested that certain lipid phases have an important effect on the gas retention and subsequent loaf volume of wheat flour doughs. Although this is an attractive hypothesis, the data presented in this and a companion paper (Moore and Hoseney, in press) tend to minimize their importance. Doughs made with defatted flour and doughs made with unextracted flour containing 3% shortening were found to proof to the same height and increase in height at the same rate during heating. If the lipids in unextracted flour were changing gas retention, the rate of height increase should be different. The defatted flour gave a lower final height because the dough stopped expanding at a temperature lower than the dough from unextracted flour containing shortening (77°C vs. 80°C). Similarity of diffusion rates through doughs made using defatted flour and nondefatted flour with 3% shortening is shown by the diffusion rates of CO₂ from proofing doughs (1.63×10^{-5}

moles/min for doughs from defatted flour and 1.93×10^{-5} moles/min for nondefatted flour containing shortening).

ACKNOWLEDGMENT

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