Effect of Surfactants on Air Incorporation in Dough and the Crumb Grain of Bread[1]

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ABSTRACT

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The origin of the fine grain imparted to yeast-leavened doughs by certain surfactants was studied by measuring the density of dough mixed to optimum. Surfactants that improve grain did not significantly alter dough densities. However, scanning electron microscopy of cryofractured dough showed that those surfactants that improve grain allowed more and smaller cells to form during the mixing stage than did nonimproving surfactants.

The use of surfactants in bread baking is so well established that nearly all bread produced in the United States contains one or more surfactants. Certain surfactants improve the grain of bread by creating many small cells that give the bread a fine grain.

Baker and Mize (1937, 1941) proposed that the grain of bread is controlled by the number of gas bubbles in dough. They showed that: 1) yeast cannot originate gas cells in the dough, 2) gases entrained in the endosperm, occluded in the flour or beaten in during an early stage of mixing have little or no consequence as a source of gas cells, 3) the last portion of the mixing period can emulsify all the gas required, and 4) punching and molding 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 the greatest resistance to mixing, and then declines after the normal mixing requirement has been exceeded.

We reasoned that the fine grain originated either from more air being incorporated into the dough or from air being subdivided

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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. Effects of surfactants 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 (SEM). Using those two methods, we investigated the mechanism by which certain surfactants improve the crumb grain of bread.

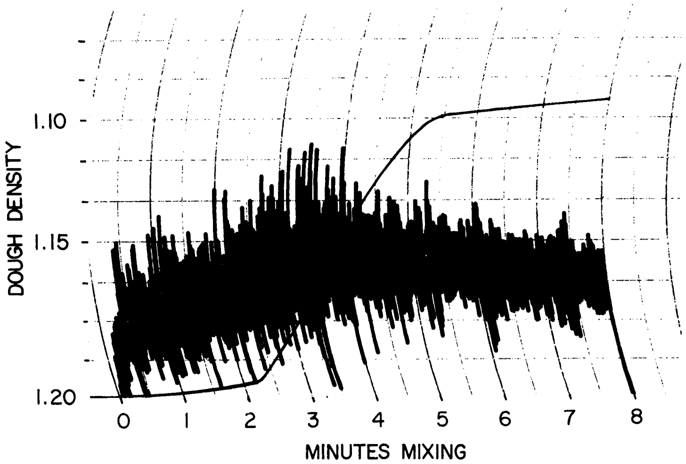

Fig. 1. Mixogram of a flour-water mixture, with a curve showing change in dough density (g/cc) during mixing.

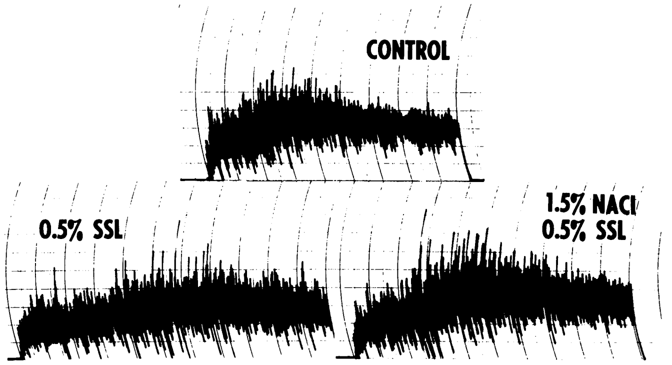

Fig. 2. Mixograms of flour-water control dough and doughs containing sodium stearoyl lactylate (SSL) and SSL plus NaCl.

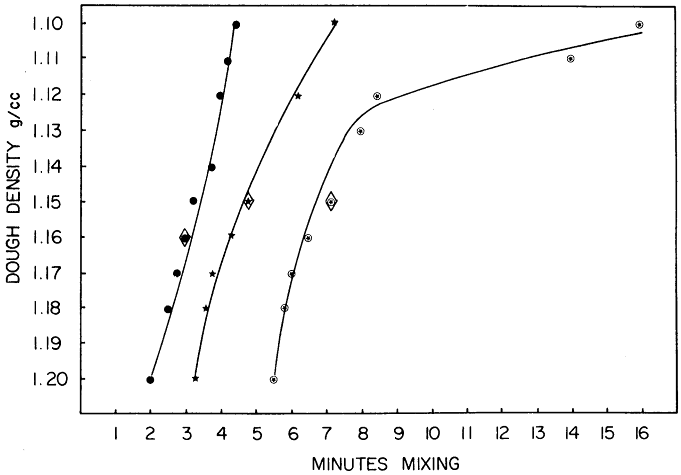

Fig. 3. Changes in dough density during mixing for flour-water dough: • = Control, ⊛ = 0.5% sodium stearoyl lactylate (SSL), ★ = 0.5% SSL and 1.5% NaCl, ◊ = optimum mixing.

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 × 5.7) and 0.45% ash.

Surfactants

Sodium stearoyl lactylate (SSL) and ethoxylated monoglycerides (EMG) were obtained from C. J. Patterson Co., Kansas City, MO; diacetyltartaric acid esters of monoglycerides (DATEM, 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; propylene glycol monoesters (PGME) of palmitic and stearic acid (Promodan

TABLE I
Baking Data for Certain Surfactants

Dough Treatment	Proof Height (cm)	Loaf Volume (cc)	Crumb Grain
Control	7.6	950	Medium
No shortening	7.5	855	Open
With addition[a] of			
SSL	7.8	955	Fine
EMG	7.7	970	Open
Poly 60	7.7	960	Medium
PGME[b]	7.6	790	Very fine
F108	7.9	990	Open
DATEM	7.8	945	Slightly open
Mono	7.5	860	Open
PGME + EMG[c]	7.6	925	Fine
Corn oil[d]	7.6	920	Open

[a] Additions of 0.5% unless otherwise specified: SSL = sodium stearoyl lactylate, EMG = ethoxylated monoglycerides, poly 60 = polyoxyethylene sorbitan monostearate, PGME = propylene glycol monoesters, F108 = pluronic polyol, DATEM = diacetyltartaric acid esters of monogycerides, Mono = distilled monoglycerides.

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

[c] A portion (0.25%) of both PGME and EMG was ground for 60 sec in a Stein mill with the flour.

[d] Addition of 3%.

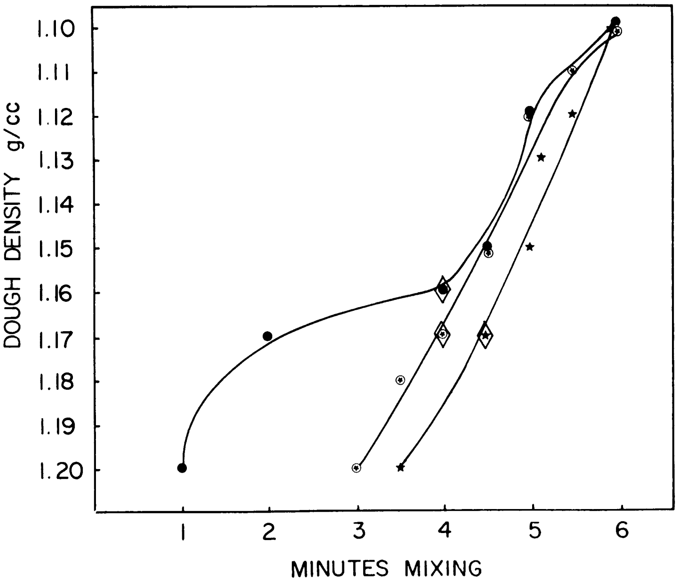

Fig. 4. Changes in dough density during mixing for full-formulation doughs. ⊛ = Control, ★ = 0.5% sodium stearoyl lactylate without shortening, • = 0.25% ethoxylated monoglycerides and 0.25% propylene glycol monoesters without shortening, ◊ = optimum mixing.

SP) from Grindsted Products, Overland Park, KS; and polyoxyethylene sorbitan monostearate (poly 60) from ICI America, Wilmington, DE.

Straight Dough Formula and Procedure

The formula for fully formulated doughs, used for dough density measurements, scanning electron micrographs, or bread baking, was (percent flour weight): flour, 100; sugar, 6.0; salt, 1.5; nonfat dry milk, 4.0; shortening (Crisco), 3.0; and malt (60° L), potassium bromate, and water, optimum. The doughs were mixed in a 100-g National pin mixer (National Mfg. Co., Lincoln, NE) 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 of fermentation.

Dough Density Procedure

Density of the doughs were determined immediately after mixing as described by Baker and Mize (1946).

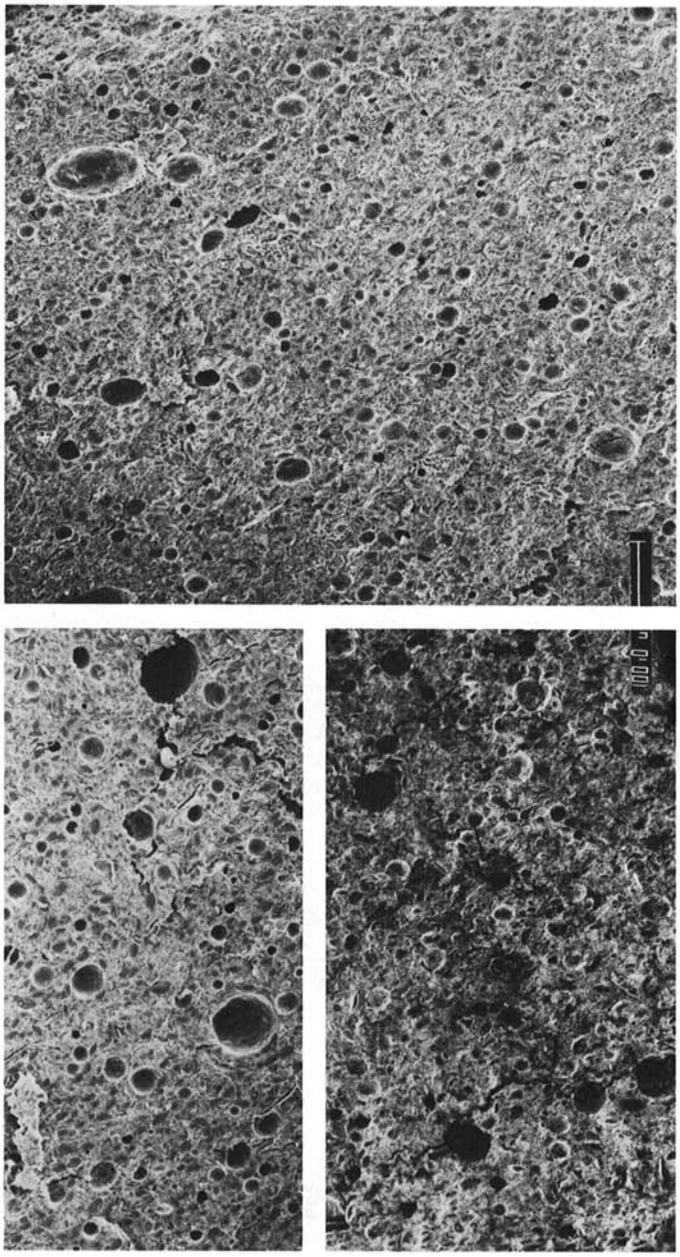

Fig. 5. Scanning electron micrographs of cryofractured freeze-dried, flour-water doughs. **Top,** dough containing 0.5% sodium stearoyl lactylate; **lower left,** flour-water control dough; **lower right,** dough containing 3% shortening.

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 with an Edwards tissue freeze-dryer (Varriano-Marston 1977). Samples were freeze-dried at −80° C for 48 hr. The dry dough samples were mounted on specimen stubs with silver paste and 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 SEM operating at an accelerating voltage of 5 KV. Images were photographed on Polaroid film, type 55.

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: 1) more air being occluded during mixing of

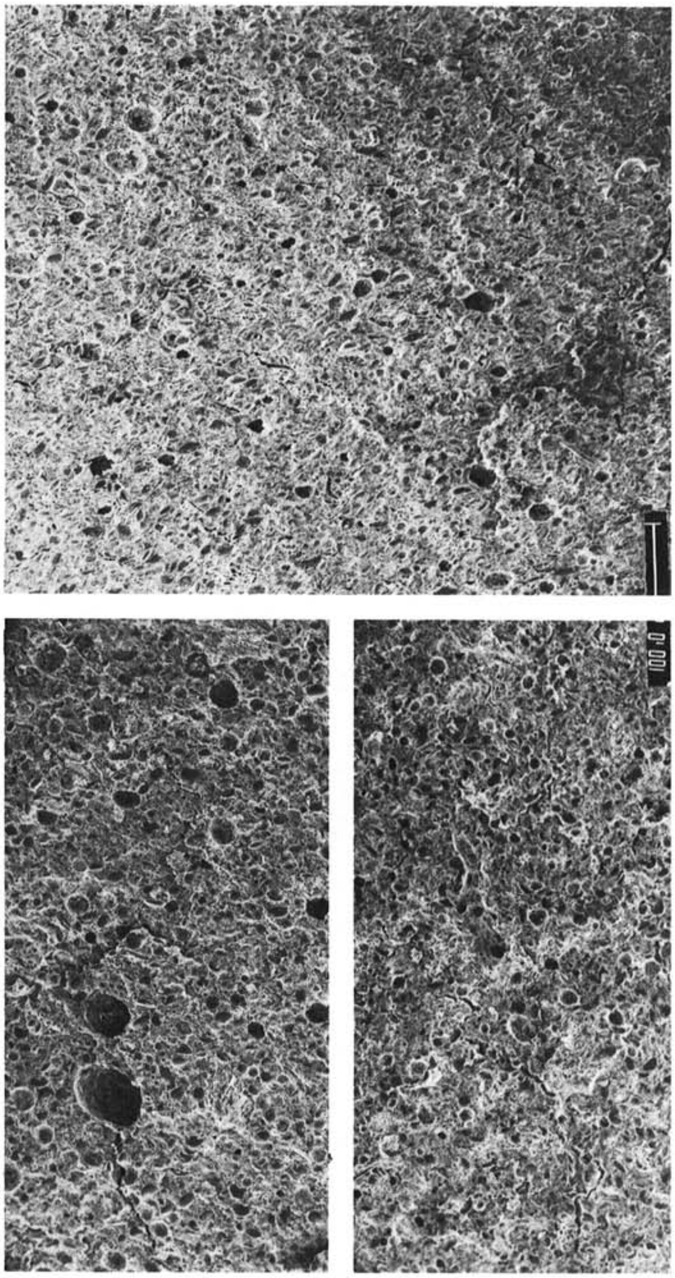

Fig. 6. Scanning electron micrographs of full-formulation doughs containing no shortening that were cryofractured and freeze-dried. **Top,** dough containing 0.25% ethoxylated monoglycerides (EMG) and 0.25% propylene glycol monoesters (PGME); **lower left,** dough containing 0.25% EMG; **lower right,** dough containing 0.25% PGME.

doughs containing the surfactants, 2) the surfactants causing smaller cells to form during mixing, or 3) both an increased occlusion of air and the formation of smaller cells.

Baker and Mize (1946), who followed the occlusion of air in dough throughout dough mixing, showed that air occlusion occurs slowly as the flour-water dough hydrates and then proceeds rapidly as the protein matrix is developed. We confirmed those results (Fig. 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 3½ min, at which the dough density is 1.16. Thus, air is still occluded rapidly during the first phase of overmixing.

Rheological properties of dough can change when certain surfactants are added. The addition of 0.5% SSL in a flour-water dough mixed in a mixograph (Fig. 2) delayed optimum development from 3¾ min (control) to 7 min. In addition, the mixing stability or mixing tolerance also was increased. Interestingly, part of SSLs effect on rheological properties is reversed when NaCl is added to the dough. Adding 1.5% NaCl with the 0.5% SSL shortened the mixing time back to 4¾ min.

The time when dough starts to occlude air changes when the rheological properties of the dough are changed (Fig. 3). When 0.5% SSL is added to a flour-water dough, 5½ min of mixing elapses before the dough starts to occlude air. The occlusion rate is the same as that of the control, so the protein matrix that incorporates air forms more slowly in the presence of SSL.

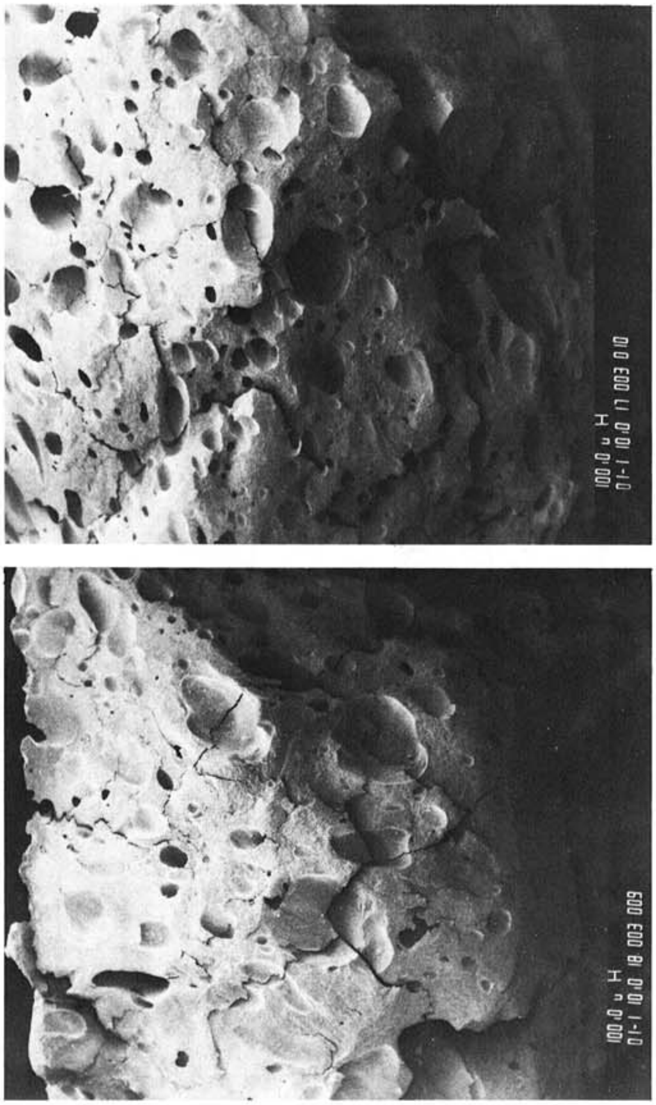

Fig. 7. Scanning electron micrographs of fully formulated doughs that were cryofractured and freeze-dried. Doughs were punched for the second time after 155 min of fermentation. **Top,** dough containing 0.5% sodium stearoyl lactylate but no shortening; **bottom,** dough containing 3% shortening.

Adding NaCl and SSL again changes the time when dough starts to occlude air. The dough density curves (Fig. 3) and the mixograms (Fig. 2) suggest that air occlusion depends on the dough's rheological properties. When SSL was added to dough, the amount of air occluded at optimum development did not differ significantly (1.15 vs 1.16 g/cc) from the flour-water control.

We next studied the rate of air occlusion in fully formulated doughs. Density curves are shown in Fig. 4 for the control dough, the control plus 0.25% EMG and 0.25% PGME, and the control with 0.5% SSL. The dough densities at optimum development were 1.17, 1.16, 1.17, respectively. Again those surfactants did not affect the amount of air occluded at optimum mixing.

The obvious conclusion from the density data is that surfactants do not change the amount of air occluded at optimum mixing. Data for surfactants in bread baked with no shortening are given in Table I. Certain surfactants did replace shortening (SSL, EMG, poly 60, pluronic polyol, and DATEM), whereas others did not (monoglycerides, PGME, and corn oil). The crumb grains

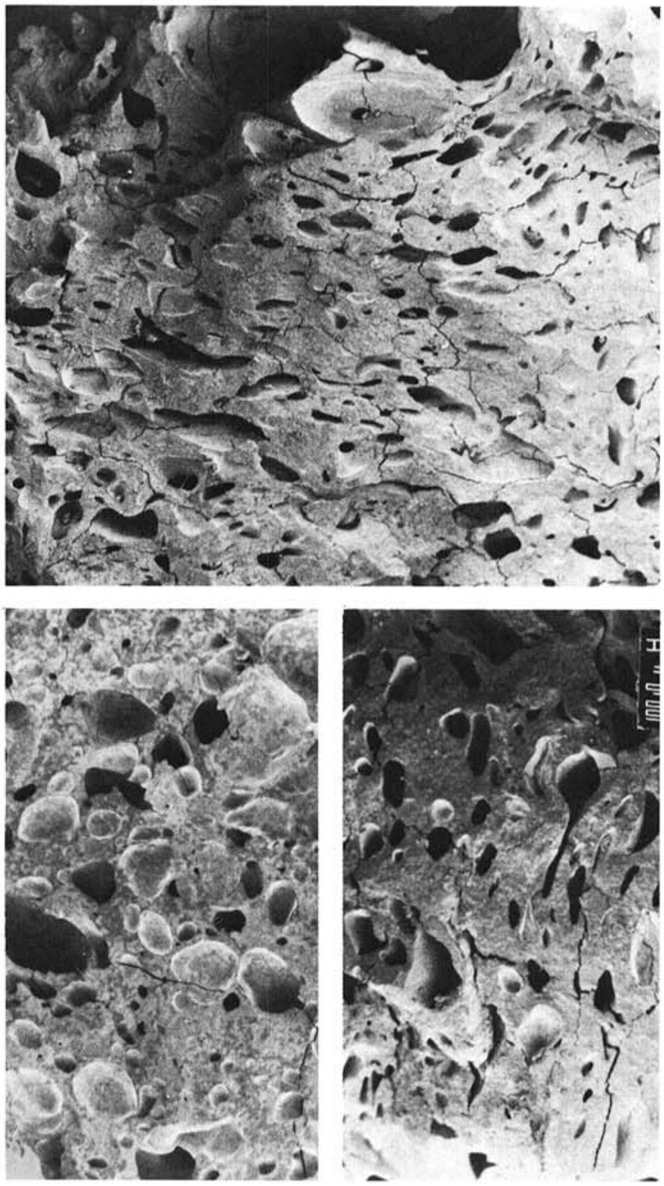

Fig. 8. Scanning electron micrographs of full-formula doughs that were cryofractured and freeze-dried after 180 min of fermentation and after the third punch. **Top,** dough containing 0.5% sodium stearoyl lactylate but no shortening; **lower left,** dough containing no shortening; **lower right,** dough containing 3% shortening.

produced with the various surfactants varied widely. Because the surfactants do change the grain of bread, we can assume that they form more but smaller air cells during mixing.

Baker and Mize (1946) found that the grain of bread originates from those operations that "work" the dough, namely mixing, punching, and molding. We used the SEM to study how the grain originates during mixing and how subsequent punching steps affect it. Doughs were studied with and without added surfactants.

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

Photomicrographs of three fully formulated doughs mixed to optimum are shown in Fig. 6. The dough containing EMG has large air cells, whereas the dough containing PGME and that containing a mixture of PGME and EMG have more and smaller air cells, which agrees with our findings for bread baked with these surfactants. The EMG improved loaf volume but gave an open, undesirable grain (Table I). PGME gave a fine grain but depressed loaf volume. Adding both EMG and PGME to the dough improved both bread volume and grain.

The effect of punching on crumb grain was studied by taking SEM photomicrographs of dough after the second (Fig. 7) and third punches and just before molding (Fig. 8). Effects of SSL on air incorporation are shown clearly in both figures. Formation of more air cells during mixing, followed by more subdivision of cells during punching, are all important in producing a fine grain in the finished product.

CONCLUSIONS

The densities of doughs mixed to optimum with and without added surfactants did not appear to differ significantly. So surfactants do not alter the amount of air occluded during mixing. Certain surfactants change dough rheology (and greatly extend 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. More and smaller cells, maintained throughout punching and thus present in the finished products, were responsible for the fine grain.

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