Factors Controlling Gas Retention in Nonheated Doughs[1]

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ABSTRACT

Cereal Chem. 69(1):1–6

When fully fermented and molded doughs made from six flours of differing baking quality were allowed to proof for an extended time, each dough expanded to its maximum. The maximum dough proof height was highly correlated ($r = 0.990$) to loaf volume of bread produced by the same flours. Rheological study showed that the poor-quality flour dough was stiffer and less deformable under a constant stress than the good-quality flour dough. The gluten from poor-quality flour appeared to be easier to hydrate, more viscous, and less elastic than the good-quality gluten. However, doughs from the poor-quality flour were stiffer with less flow than doughs from the good-quality flour. Conclusions drawn from observations of the microscopic structure of optimally mixed dough indicated that the poor-quality gluten interacted strongly with starch granules. That interaction may decrease the flow properties of dough. Observations of the gas cells in fermenting dough from good-quality flour dough showed that they grew uniformly with time. However, in poor-quality flour dough, only a small number of cells enlarged, and most of the small cells expanded only slightly. The smaller flow properties of the poor-quality dough apparently did not allow the gas cells to expand at a rate fast enough to equalize the pressure. Thus, as the pressure in the cells increased, less CO_2 diffused into the cells and more gas diffused to the atmosphere, which resulted in a smaller loaf.

In bread dough, the insoluble but highly hydrated gluten protein system is the continuous phase, whereas starch and air cells are discontinuous within the gluten system. Yeast ferments sugar to produce CO_2 in the aqueous phase. Once CO_2 saturates the aqueous phase, newly produced CO_2 vaporizes to the atmosphere and/or to the preexisting air cells that are formed in dough during mixing. The rate of CO_2 diffusion in the dough is slow; thus, most of the CO_2 vaporizes to the nearby cells (Hoseney 1984). Because dough has viscous flow properties that allow the gas cells to expand, there is little increase in pressure. The pressure in gas cells has been reported to be slightly greater than atmospheric pressure, about 1.01 atm (Bailey 1955, Bloksma 1981). Bloksma and Bushuk (1988) attributed that small increase in pressure (0.01 atm) to be the result of surface tension at the gas-dough interface and the viscous resistance of dough to expansion.

Dough expansibility is mainly determined by its viscoelasticity. The viscous component allows gas cells to expand to equalize the pressure, whereas the elastic component provides the strength to prevent the dough from overexpansion and eventual collapse. Therefore, proper viscoelasticity is essential for dough to retain gas. The dough's viscoelasticity is generally determined by its continuous protein phase (MacRitchie 1980). The properties of the continuous phase can be modified by interactions among the proteins or between the proteins and the nonprotein constituents (Bushuk and MacRitchie 1988).

It is generally accepted that a weak flour hydrates faster than a strong flour during mixing. Smith and Mullen (1965) reported that short-mixing flour contained more water-soluble protein initially and produced more during mixing than did long-mixing flour.

Dynamic rheological studies (He and Hoseney 1991b) showed that when doughs made from gluten-water, the poor-quality dough had a lower storage modulus (G') and higher tangent value than the good-quality dough. However, when doughs were made from flour and the other bread dough ingredients (except yeast), the poor-quality dough had higher G' than the good-quality dough. Lower G' values indicate less effective cross-links in the dough. Therefore, they suggested that significant interactions probably exist between proteins and other components in poor-quality flour dough.

He and Hoseney (1991b) measured dough density after mixing and found that poor-quality flour incorporated more air during mixing than good-quality flour. However, quantification of CO_2 released during fermentation and in the early stages of baking showed that the poor-quality dough released much more CO_2 than did the good-quality dough. Those differences were not related to changes in starch or gluten proteins during heating but appeared to be mainly controlled by an inherent difference in the gluten proteins, that is, how the gluten proteins interact within themselves and with other components. Therefore, it is logical and reasonable to study the differences between quality flours prior to baking. The objectives of this work were to study at room temperature the differences in rheology, expansion, and microscopic structure of mixed and fermented doughs made from poor- and good-quality flours and attempt to relate these differences to their baking qualities.

MATERIALS AND METHODS

Flour

Six hard red winter wheats grown in 1979—CI 12995, Shawnee (CI 14157), KS 644, KS 501097, KS 501099, and KS 619042—and two wheats grown in 1975—CI 12995 and KS 501097—were obtained from the Grain Marketing Research Laboratory, U.S. Department of Agriculture (Manhattan, KS). The wheats were stored at 4°C and were milled to straight grade flours. Their properties were described previously (He and Hoseney 1991b) and are summarized in Table I. CI 12995 and Shawnee were reported to be of good baking quality; KS 644 to be of intermediate baking quality; and KS 501097, KS 501999, and KS 619042 to be of poor baking quality. The flours were baked by AACC

TABLE I
Properties of Different Hard Red Winter Wheat Flours

Variety	Protein (%)[a]	Ash[a] (%)	Water Absorption (%)	Mixing Time (min)	Loaf Volume[b] (cm^3)
1979 Crop					
CI 12995	12.74	0.48	65	3.7	795
CI 14157	11.73	0.48	64	3.2	790
KS 644	10.93	0.47	63	2.0	610
KS 501097	13.95	0.48	65	1.2	480
KS 501099	13.85	0.48	65	1.2	445
KS 619042	12.39	0.47	58	1.1	455
1975 Crop					
CI 12995	12.90	0.53	61	6.0	943
KS 501097	13.70	0.49	62	1.4	650

[a] 14% moisture basis.

[b] Flours from the 1979 crop were baked with no nonfat dried milk (NFDM) and no oxidant. The flours from the 1975 crop were baked with NFDM and optimum level of $KBrO_3$.

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Method 10-10B (AACC 1983). The standard deviation was less than 20 cm^3 with three replicates.

Mixograph

The mixing properties were determined with a 10-g mixograph (TMCO-National Mfg. Lincoln, NE) using the AACC method (AACC 1983).

Compression and Relaxation Test

Doughs were prepared and fermented by AACC Method 10-10B (1983). Preparation of the test specimen was as given by Cullen-Refai et al (1988). After the third punch, three pieces were cut from each dough with a cookie cutter (diameter, 29 mm) and immediately immersed in mineral oil. Prior to testing, dough heights were measured.

Uniaxial compression tests were performed with an Instron Universal Testing Machine (Model 1130-C4) equipped with a 2,000-g load cell. The chart speed was 50 mm/min, and the cross-head speed was 25 mm/min. Deformation curves were obtained with a 60% deformation of the sample. After deformation, the head was stopped, keeping a constant stress of the sample. The sample underwent a relaxation period to generate the stress relaxation curve.

Gluten Washing

Flour and water (1:3) were shaken to form a slurry and then centrifuged (500 × *g*) to form a dough. The gluten was then hand washed using an additional part of water. Details of the procedure were given previously (He and Hoseney 1991a).

Vacuum Test

Dough was prepared by the 10-g flour baking procedure (Shogren and Finney 1984). After molding, the dough was placed in a 100-ml beaker with a ruler on the side and proofed for 55 min at 28°C, 85% rh. At the end of proofing, the beaker was placed in a transparent plastic container. After reading the dough height, 25 cm Hg vacuum was applied. Height of replicate doughs were read at 5, 10, 20, 30, 45, and 60 sec. The average increase in dough height after applying the vacuum was plotted against time.

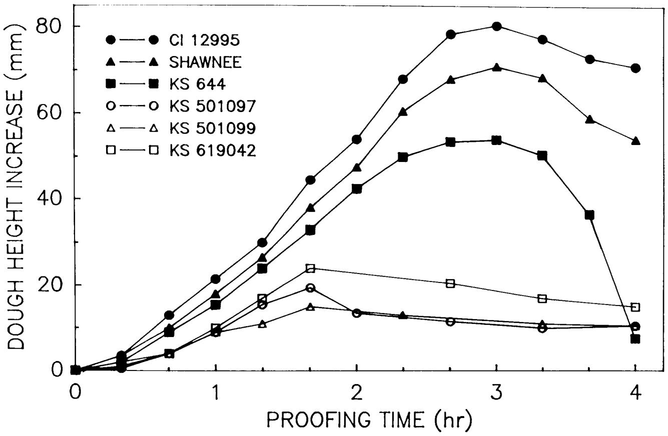


Fig. 1. Height increase of six doughs during proofing.

Proofing Test

Dough was prepared by AACC Method 10-10B (AACC 1983). After molding, dough was placed in the transparent plastic container with a cross-section area of 110 cm^2 (12.5 × 8.8 cm). The increase in dough height was read every 20 min for 4 hr, and the average height of doughs (at least two replicates) were plotted against time.

Scanning Electron Microscopy of Dough

The microscopic study of mixed and fermented dough and baked bread followed the procedure of He and Hoseney (1991a).

RESULTS AND DISCUSSION

Dough Expansion During Extended Proofing

When the fully fermented and molded doughs made from CI 12995, Shawnee, KS 644, KS 501097, KS 501099, and KS 619042 flours from the 1979 crop year were allowed to proof for an extended time, each dough expanded to its maximum (Fig. 1). The better quality flours had a faster rate of dough expansion and greater total expansion. It took about 3 hr for the good- and intermediate-quality flour doughs to reach maximum expansion, whereas it took only about 1.67 hr for the poor-quality flour doughs. When the expansion of the good- and intermediate-quality flour dough was near maximum, large bubbles appeared at the surface of the dough; these bubbles grew and finally ruptured. This emergence, growth, and rupture of bubbles was repeated several times before the dough collapsed. However, no noticeable bubbles were observed at the surface of the poor-quality flour doughs. The gassing power of all doughs was essentially the same (data not shown).

The maximum dough proof height was highly correlated ($r = 0.990$) to loaf volume (Fig. 2). Therefore, it appears that the expansion limit of dough without baking could estimate the loaf volume. Of course, this process would be relatively impractical since it takes nearly as long as the baking process.

Vacuum Test

Two flours milled from the 1979 crop year—CI 12995 (good quality) and KS 501097 (poor quality)—were selected for further study. When 25 cm Hg vacuum was applied to the fermented and proofed doughs, the CI 12995 dough initially expanded at a faster rate and continued to expand for 30 sec (Fig. 3). After

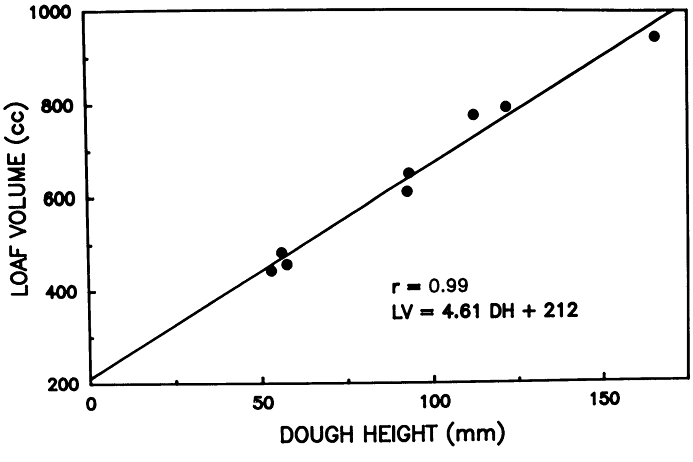


Fig. 2. Relationship between dough proof height and loaf volume.

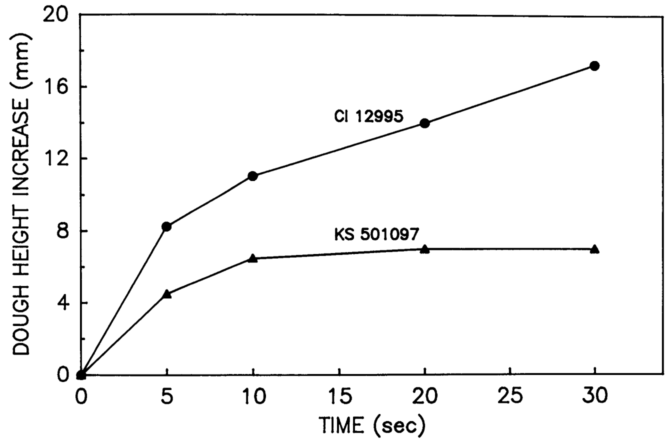


Fig. 3. Dough height of two doughs under 25 cm Hg vacuum.

30 sec, a large bubble became visible at the surface of the dough, became larger with time, and finally ruptured. The KS 501097 dough initially expanded at a slower rate, and the expansion rate decreased with time. After 10 sec of vacuum, the dough essentially stopped expanding. No bubbles were observed. The results of both the proof and the vacuum tests agree well with flour baking quality. This suggests that the differences between flours of different qualities can be distinguished at room temperature.

Rheological Properties of Dough and Gluten

When mixed into dough with or without bread-dough ingredients, the KS 501097 flour gave a dough that was less elastic but stiffer than that from the CI 12995 flour. Therefore, compression and relaxation tests were used to examine further the difference in rheology between the poor-quality KS 501097 and the good-quality CI 12995 flours. When the two fermented bread doughs were sheeted through rolls with the same gap setting, the CI 12995 dough was thicker than the KS 501097 dough. This indicates that the CI 12995 dough was more elastic. When the doughs were compressed to 60% of their original thickness, it took more time and force (to reach the peak) to compress the CI 12995 dough than to compress the KS 501097 dough (Fig. 4). However, if compression of the same absolute thickness of dough was compared (equal time in Fig. 4, i.e., 0.2 min), much more force was required to compress the KS 501097 dough than to compress the CI 12995 dough. This shows that the KS 501097 dough was more resistant to deformation than the CI 12995 dough. The relaxation curves (Fig. 4) also showed that the KS 501097 dough was less elastic than the CI 12995 dough.

When gluten was washed from both flours, the KS 501097 gluten retained much more water and had larger volume than the CI 12995 gluten (Table II). It was also more difficult to wash (nonprotein components) from KS 501097 gluten (Table II). These observations indicated that the poor-quality gluten had larger hydration capacity and a greater tendency to interact with nonprotein components (mainly starch granules) than did the good-quality gluten. This supports the dynamic rheological findings (He and Hoseney 1991b).

Microscopic Structures of Mixed Doughs

To better understand the differences in the structure of doughs made from poor- and good-quality flours, the optimally mixed doughs from CI 12995 and KS 501097 flours with the full bread formula were cryofractured, freeze-dried, and viewed by scanning electron microscopy (Fig. 5). There were few, if any, broken starch granules in the CI 12995 dough, whereas in the KS 501097 dough, many of the starch granules (both large and small) at the surface of the fractured cross-section were broken. The breaking of the starch granules indicates that the bonding or interaction between starch granules and gluten in KS 501097 dough was strong. The starch granules broke instead of separating at the starch-gluten interface. In contrast, in the CI 12995 dough the separation mainly took place at the starch-gluten interface. Similar differences are found between hard and soft wheat kernels (Hoseney and Seib 1973). The strong bonding of the protein to the starch granules in the KS 501097 dough shows that the starch granules serve not only as inert fillers but also interact with gluten (presumably hydrogen bonds) to effectively form cross-links. Those interactions apparently decrease the flow properties of the KS 501097 dough. Because earlier studies have shown no difference in the baking properties of various wheat starches (Hoseney et al 1971), the difference between the two flours is presumed to be due to differences in their proteins.

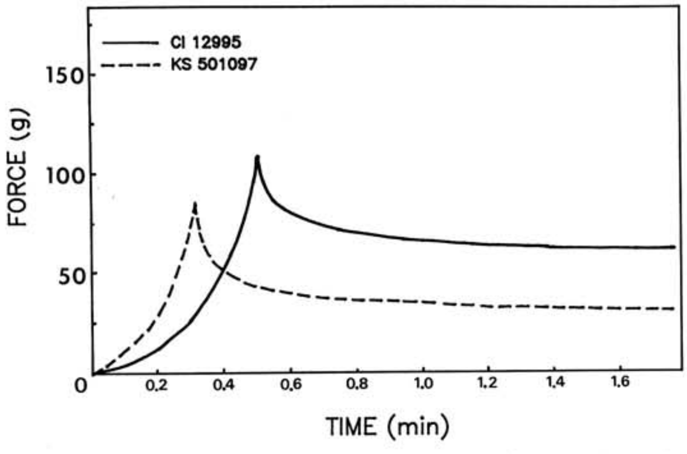


Fig. 4. Compression and relaxation curves of two flour doughs made with the full bread formula.

Gas Cells in Fermenting Dough and in Bread

To understand how the interaction between gluten and starch granules affects dough expansion, bread doughs were made from CI 12995 and KS 501097 flours and not fermented; fermented for 30, 60, 90, or 105 min; or fully baked. The samples then were cryofractured, freeze-dried, and viewed by scanning electron microscopy (Figs. 6 and 7). No significant differences in the number or size of gas cells between the CI 12995 and KS 501097 doughs were found after mixing (with zero fermentation).

However, after 30 min of fermentation, the gas cells in the CI 12995 dough appeared to be larger than those in KS 501097 dough. After 60 min of fermentation, the difference between the two doughs became more obvious. The gas cells in the CI 12995 dough were enlarged and more uniform in size. The KS 501097 dough had a few very large and many very small gas cells. With additional fermentation, the gas cells in the CI 12995 dough continued to grow and remained uniform in size. In the KS 501097 dough, the large gas cells became larger, whereas most of the small bubbles enlarged only slightly.

In baked bread, the gas cells in the CI 12995 loaf were small and uniform with thin cell walls, whereas in the KS 501097 loaf, the gas cells were large, the total number of cells was much smaller,

TABLE II
Comparison of Gluten-Washing Properties

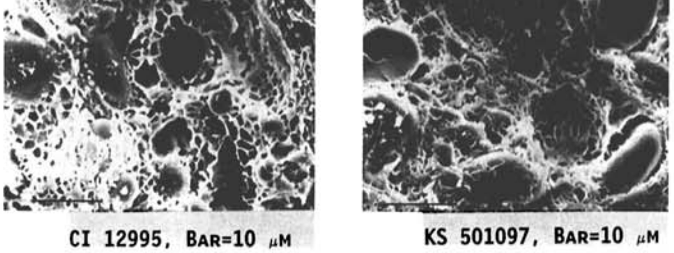
Properties	KS 501097	CI 12995
Flour weight,[a] g	500	500
Wet gluten,[b] g	280 ± 0	182 ± 1
Lyophilized gluten,[c] g	79 ± 5	62 ± 1
Volume of lyophilized gluten, cm^3	202 ± 4	142 ± 4
Protein content,[a] %	77 ± 0	83 ± 0
Nonprotein components,[d] %	23	17

[a] 14% moisture basis.

[b] The weight was taken immediately after gluten was washed.

[c] 3% moisture basis.

[d] Nonprotein components were estimated by 100% − percent protein content.

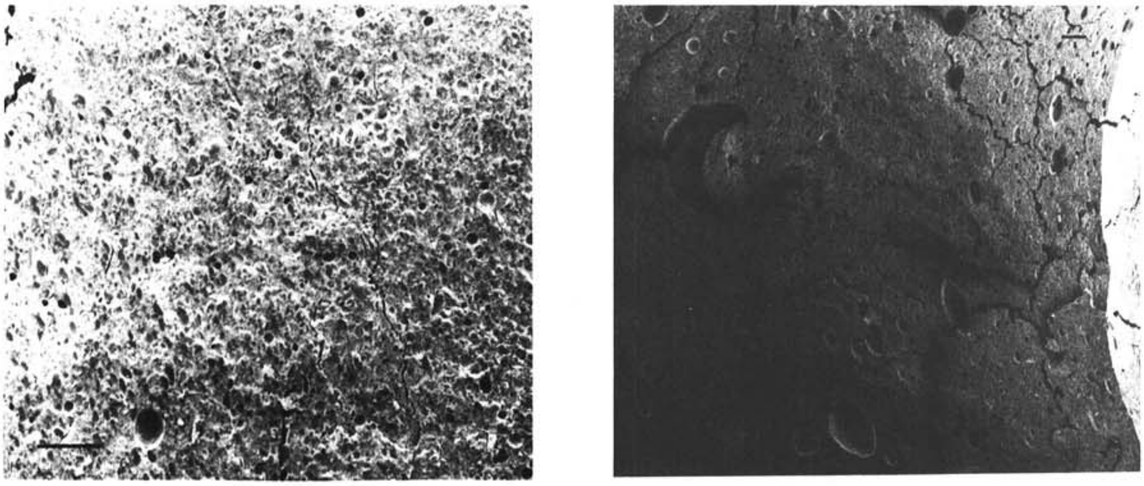

CI 12995, BAR=10 μM

KS 501097, BAR=10 μM

Fig. 5. Scanning electron micrograms of cryofractured, freeze-dried mixed doughs made from two flours with the full bread formula.

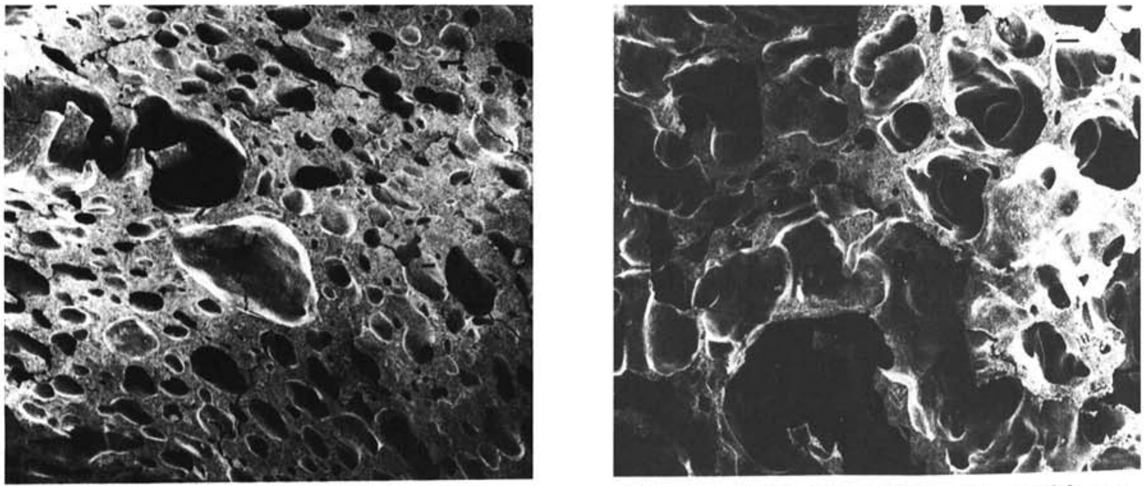
and the cell walls were thick. In other words, the CI 12995 flour produced a loaf with fine crumb grain, whereas the KS 501097 flour gave a very coarse crumb grain.

From this study, the mechanism for the poor gas retention ability of poor-quality flour dough could be visualized as follows. Because the gluten in the poor-quality flour readily interacts with starch granules, the resultant dough has poor viscous flow properties. When gas diffuses to the preformed air cells, the gas cells cannot expand fast enough to equalize the pressure. As the pressure in the gas cells increases, less CO_2 diffuses into them, and



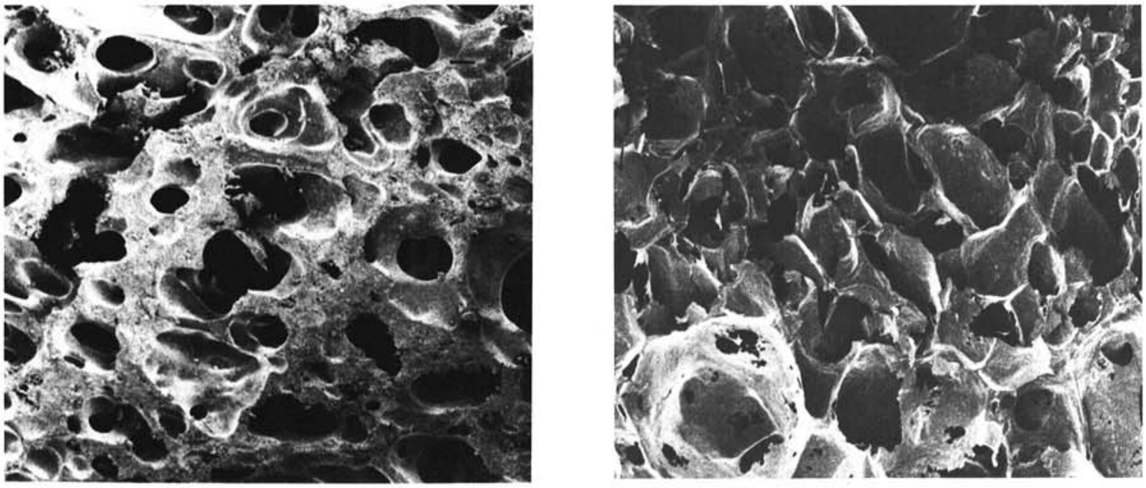
POST - MIX, BAR=100 μM

30 MIN FERMENTATION, BAR=100 μM



60 MIN FERMENTATION, BAR=100 μM

90 MIN FERMENTATION, BAR=100 μM

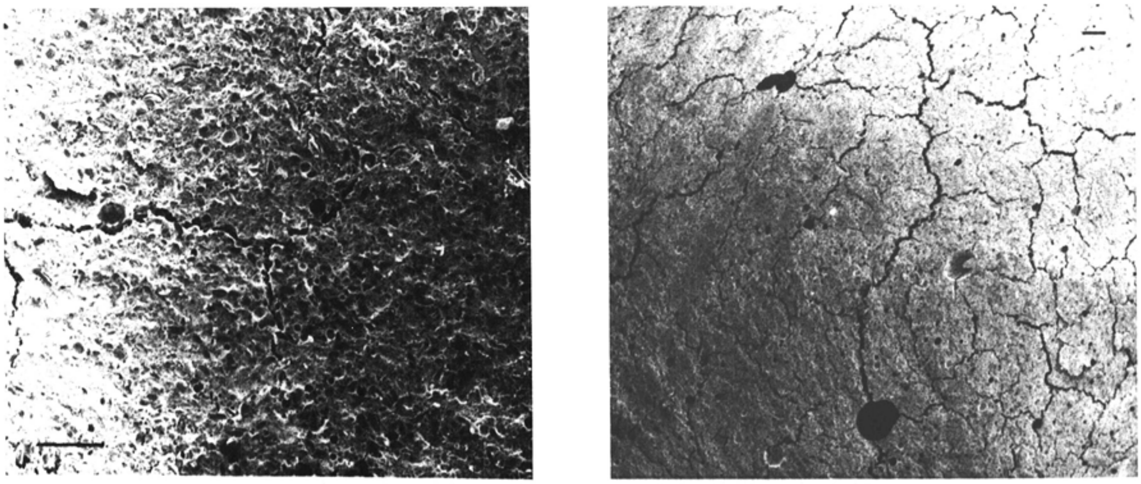


PRE - 1ST PUNCH, BAR=100 μM

POST - BAKE, BAR=100 μM

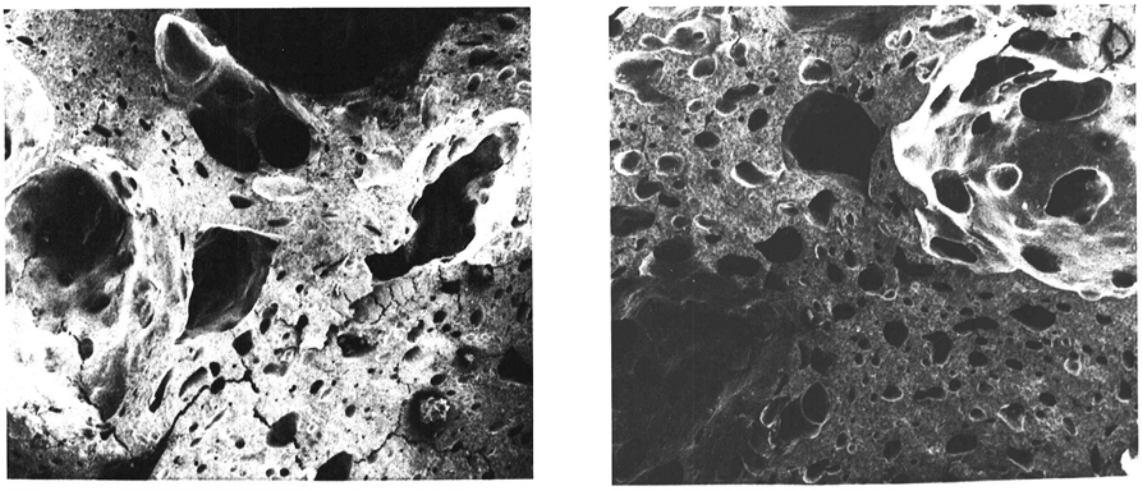
Fig. 6. Scanning electron micrograms of cryofractured, freeze-dried CI 12995 doughs after mixing and after 30, 60, 90, and 105 min of fermentation and of CI 12995 bread.

more gas diffuses to the atmosphere. As a result, the dough does not expand as much as a good-quality dough with proper viscous flow properties. On the other hand, because the bubble size distribution in the poor-quality dough is not uniform, and the pressure is in inverse proportion to the bubble size (Hoseney 1984), some of the CO_2 diffuses into a small number of large bubbles. Therefore, the resultant dough has a very coarse structure. During the early stage of baking, temperature increases the pressure in gas cells. Because of the nature of the cross-linked poor-quality dough that resists rapid expansion, the rate of gas diffusion to the atmosphere is greatly accelerated (He and Hoseney 1991b), which results in a small loaf with essentially no oven spring.



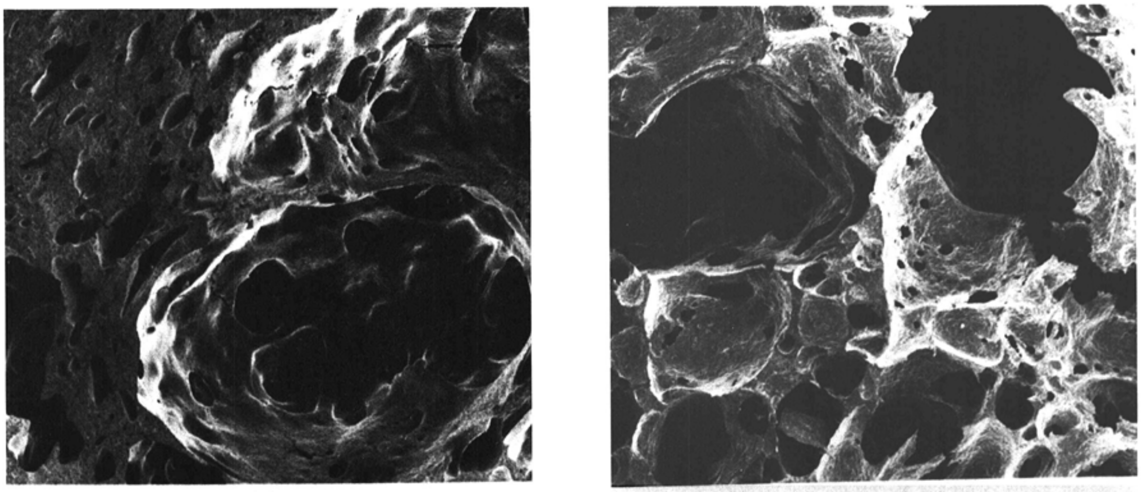
POST - MIX, BAR=100 μM

30 MIN FERMENTATION, BAR=100 μM



60 MIN FERMENTATION, BAR=100 μM

90 MIN FERMENTATION, BAR=100 μM



PRE - 1ST PUNCH, BAR=100 μM

POST - BAKE, BAR=100 μM

Fig. 7. Scanning electron micrograms of cryofractured, freeze-dried KS 501097 doughs after mixing and after 30, 60, 90, and 105 min of fermentation and of KS 501097 bread.

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[Received November 30, 1990. Accepted July 12, 1991.]