Differences in Gas Retention, Protein Solubility, and Rheological Properties Between Flours of Different Baking Quality[1]

H. HE[2,3] and R. C. HOSENEY[2]

ABSTRACT

From six hard red winter wheat flours of various baking qualities, CI 12995 and KS 501097 were selected to represent flours of good and poor quality. During breadmaking, the volume of CI 12995 dough was larger than the KS 501097 dough. The biggest difference between the two occurred during oven spring. During baking, the KS 501097 dough started to lose large quantities of CO_2 at 33°C, whereas CO_2 loss was minimal in the CI 12995 dough until 72°C. The protein solubility of heated gluten, which was higher for KS 501097 than for CI 12995, did not change over the temperature range 25–60°C. Dynamic rheological tests of gluten-water dough and bread dough showed no change in rheological properties over that temperature range for either flour. However, the KS 501097 gluten-water dough had a lower G', and the KS 501097 flour-water dough had a higher G' than did the corresponding samples from CI 12995. This showed that KS 501097 had a more extensible gluten but a less extensible dough and suggested that more rheologically effective cross-links or interactions existed within the KS 501097 flour-water dough.

Cereal Chem. 68(5):526–530

Since Finney and Barmore (1948) established that wheat gluten proteins are primarily responsible for the differences in baking quality between wheat flours, several ideas have been advanced to explain the differences in protein quality. The earliest involved the glutenin-gliadin ratio, but no confirmation has resulted from experimental data (MacRitchie 1980). Another hypothesis was that baking performance was related to thiol and disulfide contents of flour protein. Again, no correlation has been established from analytical studies (Bloksma 1975, Graveland et al 1978). Studies on amino acid composition have also been disappointing because no obvious correlation with baking quality has emerged (McDonald and Gilles 1967). In addition, few firm or consistent conclusions have resulted from attempts to relate loaf volume potential to specific protein fractions.

However, a difference in hydrophobic interactions in proteins between flours of good and poor quality has been observed. Chung and Pomeranz (1979) showed that the glutenin from a poor-quality flour is less hydrophobic than that from a good-quality flour, whereas the gliadin from the former is more hydrophobic than that from the latter. Vakar and Kolpakova (1976) reported that the contributions of hydrogen bonds, ionic bonds, and hydrophobic interactions to the aggregation of both soluble and insoluble glutenin proteins were 56.3, 17.3, and 26.4%, respectively, for a variety with good-quality gluten and 80.1, 12.8, and 7.1%, respectively, for a variety with poor-quality gluten. Butaki and Dronzek (1979) found that stronger wheat flour had more acid-insoluble (0.05*N* acetic) gluten than weak flour. The extracted soluble proteins constituted about 90% of total protein from weak gluten and about 70% from strong gluten. Kobrehel (1984) also suggested that the hydrophobic interactions in proteins of good-quality flours are stronger (or greater in number) than in proteins of poor-quality flours, based on the fact that the good-quality proteins required a higher concentration of ionic detergent for equivalent dissolution.

Because gluten proteins have high molecular weight, limited solubility, undergo disulfide interchange during mixing, and interact with other components during dough mixing, fermentation, and baking, what controls gluten quality has been a challenging problem for cereal chemists. The purpose of this study was to investigate some of the differences between wheat flours of poor and good quality in terms of dough expansion, gas retention, protein solubility, and dough rheology.

MATERIALS AND METHODS

Flour

Six hard red winter wheat flours, CI 12995, Shawnee (CI 14157), KS 644, KS 501097, KS 501099, and KS 619042, were obtained from the USDA Grain Marketing Research Laboratory (Chung et al 1982). Their protein and ash contents are given in Table I. Their mixograms, determined with a 10-g mixograph (TMCO-National Mfg., Lincoln, NE), are shown in Figure 1.

Dough Density

Dough density was determined by the procedure of Baker and Mize (1946). A series of $CaCl_2$ solutions was made, with a range of densities from 1.00 to 1.30 g/ml, with 0.02 g/ml difference between each solution in the series. After dough was optimally mixed, small pieces (about 0.5 g) of dough were cut with scissors and immediately placed in the different $CaCl_2$ solutions. The density of that solution in which the dough remained suspended was taken as the dough density.

Measurements of Dough Volume

Doughs were freeze-dried at various stages of the 10-g baking procedure (Finney and Shogren 1984): immediately after mixing, at 105 min fermentation (before first punch), at 155 min (before second punch), at 180 min (before panning), and after 55 min of proofing. The volumes of dried doughs were measured by the rapeseed displacement. A slight shrinkage was observed during freezing; therefore, the measured dough volumes were smaller than those before freezing, but still relative.

Oven Spring Determined by Time-Lapse Photography

Time-lapse photographs were taken before baking and at various times during baking: 0.0 (unbaked control), 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0, 6.0, 7.0, 8.0, 10.0, 14.0, or 24.0 min. The distance between the top of dough or bread and the top edge of the pan was measured as an indication of oven spring.

Measurement of CO_2 Release During Baking

CO_2 released from dough during baking was determined after

TABLE I
Properties of the Different Flours[a]

Wheat Variety	Protein (%)	Ash (%)
CI 12995	12.74	0.48
Shawnee	11.73	0.48
KS 644	10.93	0.47
KS 501097	13.95	0.48
KS 501099	13.85	0.48
KS 619042	12.39	0.47

[a] Results are based on 14% moisture, average of duplicate determinations.

[1]Contribution 90-594-J, Kansas Agricultural Experiment Station, Manhattan.
[2]Graduate research assistant and professor, Department of Grain Science and Industry, Kansas State University, Manhattan 66506-2201.
[3]Present address: Anheuser-Busch Companies, Inc., St. Louis, MO 63118-1852.

baking the dough in an electrical resistance oven and measuring the CO_2 released with a Beckman model 865 infrared analyzer. The procedure was described in detail previously (He and Hoseney 1991a).

Protein Extraction

About 0.12 g of gluten (14% moisture) was vigorously stirred with a magnetic bar in 5 ml of 1% sodium dodecyl sulfate (SDS) solution (pH 7.0, adjusted with 0.1*N* HCl) until it was uniformly dispersed, about 15 sec. Thereafter, an additional 20 ml of 1% SDS was added, and the dispersion was stirred at room temperature at about 60 rpm for 3 hr and then centrifuged at 10,000 $\times$ *g* for 15 min. The protein content of the supernatant was determined by AACC method 46-10 (1983). Each sample was made in duplicate.

Dynamic Rheological Test

Gluten and dough preparation. The gluten doughs were prepared with 8 g of gluten flour (14% mb), using 110% water absorption (based on gluten weight) for KS 501097 gluten and 120% water absorption for CI 12995 gluten. The optimum level of water was determined by running a series and subjectively determining optimum absorption. Gluten doughs were mixed in a 10-g mixograph (TMCO-National Mfg. Lincoln, NE) to optimum, 8.0 min for CI 12995 gluten and 2.0 min for KS 501097 gluten. The preparation of gluten-water dough for dynamic rheological testing is given by Dreese et al (1988). Bread dough was optimally mixed with the full bread formula, except for yeast (method 10-10B, AACC 1983), and then placed between the two heating plates of the rheometer. The edges were trimmed and greased to prevent moisture loss.

Dynamic Rheological Testing

A homemade dynamic rheometer (Dreese 1987) was used. Dough (about 10-mm thick) was tested at 5 Hz and heated with an alternating current. The heating rate was about 3°C/min. The readings of force transducer wave peak height, linear variable differential transformer wave peak height, and phase lag angle from the oscilloscope display were taken at every 5°C rise in temperature. The rheological parameters (G', elastic modulus; G'', loss modulus; and tangent G''/G') were calculated according to Faubion et al (1985) and plotted. The complex viscosity (G^*) was defined as $G' + iG''$.

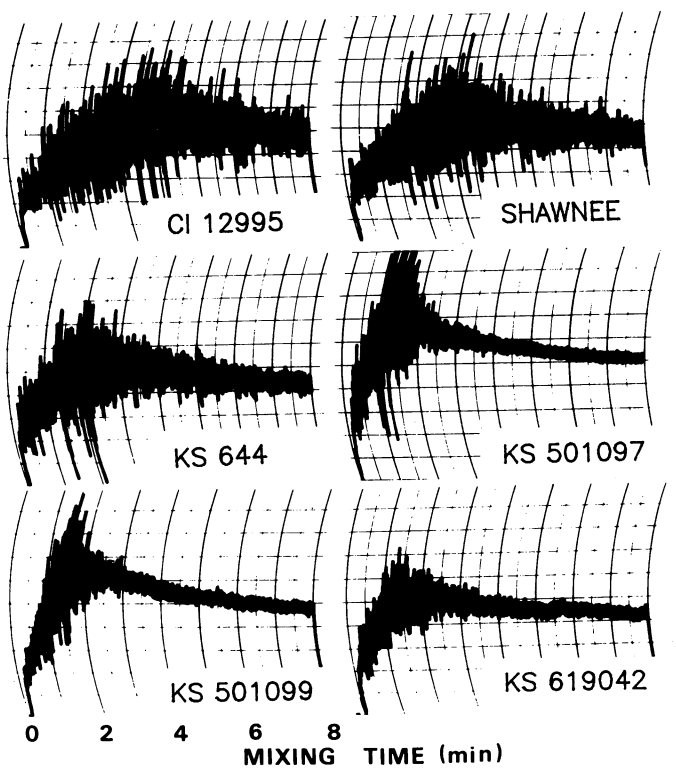

Fig. 1. Mixograms of CI 12995, Shawnee, KS 644, KS 501097, KS 501099, and KS 619042 flours.

RESULTS AND DISCUSSION

Loaf Volume

The loaf volumes of breads from six hard red winter wheat flours varied widely (Fig. 2). CI 12995 and Shawnee were bread flours of good quality; KS 644 was of intermediate quality; and KS 501097, KS 501099, and KS 619042 were of poor quality. To simplify this study, CI 12995 and KS 501097 flours were used as representative samples of good- and poor-quality flours.

Dough Expansion During Breadmaking

The differences in volume between CI 12995 and KS 501097 flour doughs at different breadmaking stages were examined (Fig. 3). After mixing, KS 501097 dough had a slightly larger volume than CI 12995 dough, because more air was incorporated during mixing. The density of KS 501097 dough was about 1.08 and that of CI 12995 was about 1.17. Doughs made from poor-quality flour incorporated more gas, which is consistent with the report of Baker and Mize (1946).

After 1 hr 45 min of fermentation (first punch), CI 12995 dough had a much larger volume than KS 501097 dough. As the number of punching steps increased and the fermentation time between punches decreased, the volumes of both doughs and the differences between them decreased. After molding and proofing, the difference between the two doughs again became obvious. However, by far the largest difference in volume occurred after baking.

To further investigate the difference in dough expansion rate and setting time during baking, time-lapse photography was used. The oven spring of CI 12995 and KS 501097 flour doughs is

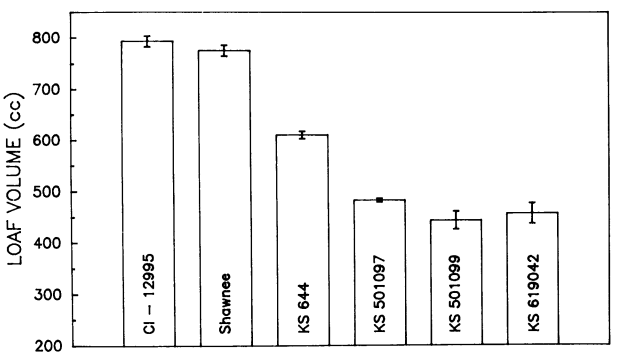

Fig. 2. Loaf volumes of CI 12995, Shawnee, KS 644, KS 501097, KS 501099, and KS 619042 flour doughs.

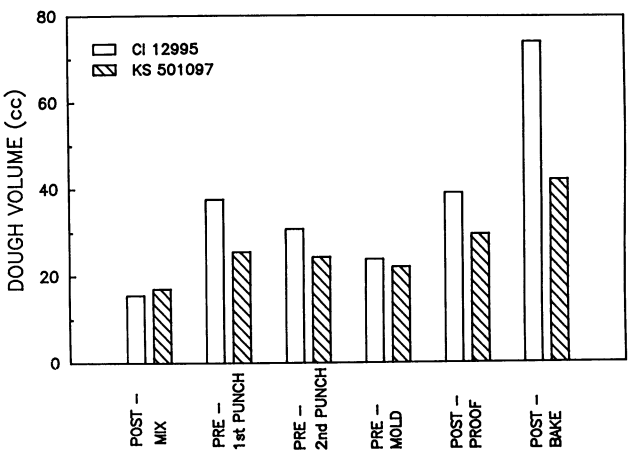

Fig. 3. Comparison of dough and loaf volumes (10 g of flour) of CI 12995 and KS 501097 flours.

shown in Figure 4. The difference in proof height between the two doughs was about 18 mm. As baking proceeded, CI 12995 dough had a much larger oven spring and continued to expand for 6 min, whereas KS 501097 dough had a smaller oven spring and stopped expanding after 2 min. The difference in final loaf height was 43 mm.

Gas Retention

The results in Figure 4 show that differences in performance became obvious during the first few minutes of baking, although undoubtedly the pattern for those differences had been set well beforehand. However, it was unclear whether the smaller oven spring was the result of more CO_2 loss or higher gas pressure within the dough. To elucidate this, CI 12995, KS 644, and KS 501097 doughs were baked in an electrical resistance oven system, and the rates of CO_2 release from the doughs during baking were measured.

CI 12995 dough essentially retained gas until the temperature reached about 72°C (Fig. 5). KS 644 dough started to lose large amounts of gas at a lower temperature (about 42°C), whereas KS 501097 dough lost gas at about 33°C. The gas loss at 72°C is assumed to be the result of the increased interaction between gelatinized starch and gluten (He and Hoseney 1991b). However, the gas release from the poor-quality flour dough that occurred at much lower temperature cannot be explained by the effect of starch gelatinization. Starch is not gelatinized at those temperatures. A possible explanation might be the changes occurring in gluten during baking. Therefore, the change in protein solubility of heated gluten was examined.

Effect of Heat on Protein Solubility

The amount of protein soluble in 1% SDS (pH 7.0) solution from unheated and heated glutens washed from CI 12995 and KS 501097 flours was determined (Fig. 6). The protein extracted from unheated KS 501097 gluten was about 86%, much higher than that extracted from CI 12995 gluten (about 78%). These results are in good agreement with those of Butaki and Dronzek (1979). When gluten was heated, a decrease in protein solubility occurred at 60°C for KS 501097 gluten but not until 70°C for CI 12995 gluten. At 65°C, the protein solubility of KS 501097 gluten decreased to 78%. There was a marked decrease in solubility between 75 and 85°C for both glutens. With further heating of gluten, the solubility continued to decrease. Therefore, the results showed that the protein solubility of glutens from both flours did not change below 60°C. Therefore, protein solubility and the changes in protein that it implies cannot explain the changes in gas retention of KS 501097 dough at 33°C.

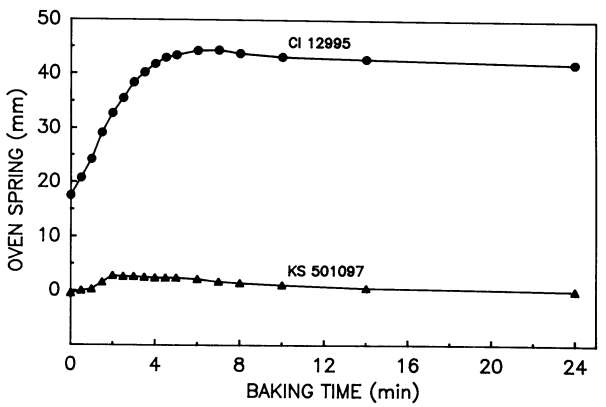

Fig. 4. Comparison of oven spring of CI 12995 and KS 501097 flour doughs.

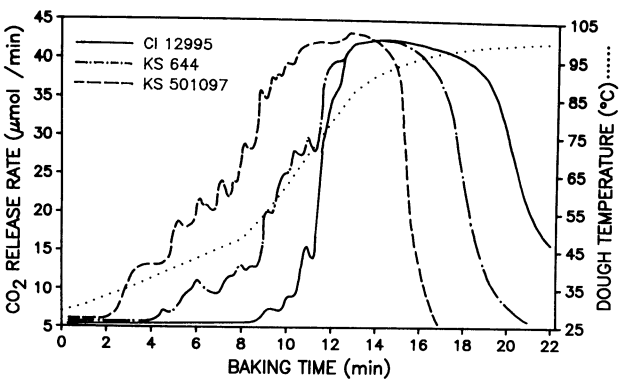

Fig. 5. Comparison of CO_2 release from CI 12995, KS 644, and KS 501097 flour doughs.

Dynamic Rheology

Gluten. The changes in G' (shear storage modulus) and the tangents for KS 501097 and CI 12995 gluten-water doughs during heating are shown in Figure 7. The G' of both gluten-water doughs decreased from 25 to 55°C. This was a completely reversible effect: on cooling to 30°C the rheological properties returned to their original values (Dreese et al 1988, LeGrys et al 1981). The G' of both gluten doughs increased from 55 to 75°C. Dreese et al

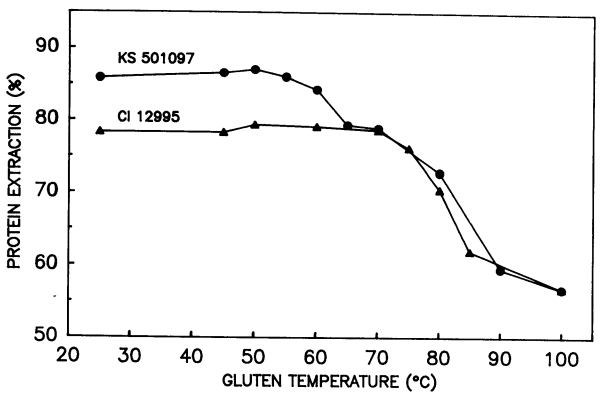

Fig. 6. Protein extraction from CI 12995 and KS 501097 glutens in a 1% sodium dodecyl sulfate, solution, pH 7.0.

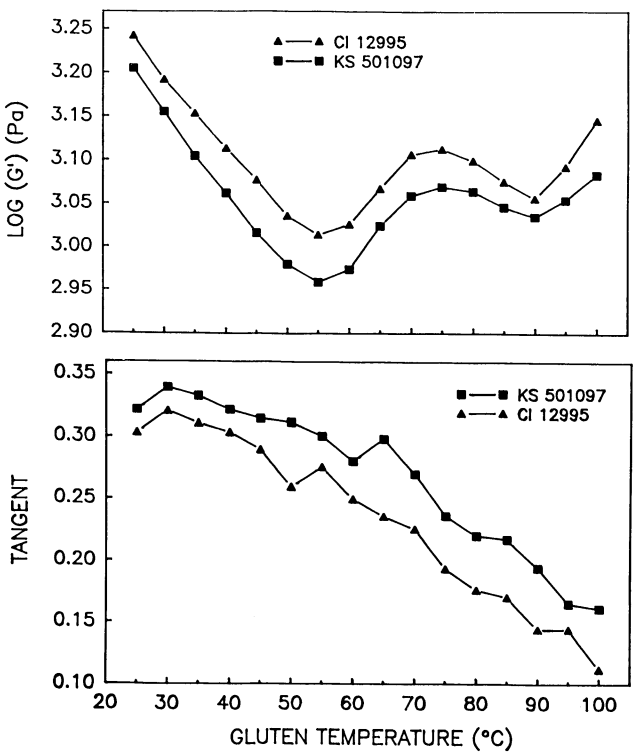

Fig. 7. Log G' and tangent vs. temperature for CI 12995 and KS 501097 gluten-water doughs.

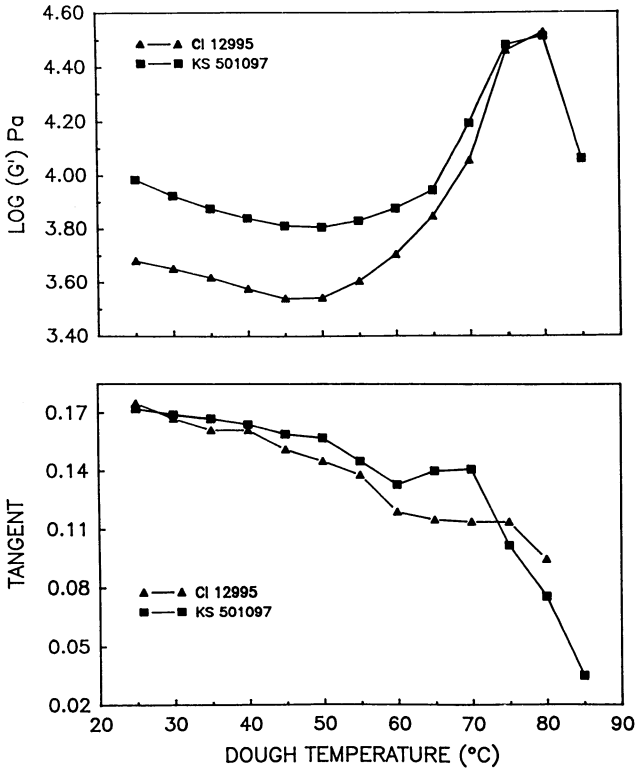

Fig. 8. Log G' and tangent vs. temperature for complete bread doughs, except yeast, made from CI 12995 and KS 501097 flours.

(1988) showed that this was caused by the gelatinization of the residual starch in the gluten. The G' decreased from 75 to 90°C, presumably because of the weakening of noncovalent bonds. G' increased again above 90°C, which may be attributed to the polymerization or cross-linking of the gluten proteins (Schofield et al 1983).

Over the temperature range of 25–100°C, KS 501097 gluten-water dough had a lower G' and a higher tangent than the CI 12995 gluten-water dough. The lower G' and higher tangent suggest that the cross-links in KS 501097 gluten-water dough were less effective than in the CI 12995 gluten-water dough. Presumably these are because of less hydrophobic interactions between the gluten proteins (Vakar and Kolpakova 1976, Chung and Pomeranz 1979, Kobrehel 1984).

Dough

The changes in G' and tangent of CI 12995 and KS 501097 nonyeasted bread doughs, were further examined. The G' of both doughs decreased when the temperature increased from 25 to 50°C and then started to increase (Fig. 8). At about 65°C, the G' increased rapidly. This can be attributed to the effect of gelatinized starch (Dreese et al 1988).

Figure 8 clearly shows that KS 501097 dough had a significantly higher G' than CI 12995 dough below 65°C. The higher G' suggests that KS 501097 dough had more effective cross-links than the CI 12995 dough.

The tangents of both doughs decreased with increasing temperature (Fig. 8) and were essentially equal below 70°C. Below 65°C, the larger G' for KS 501097 dough, together with essentially equal tangent values for the two doughs, shows that G'' for the KS 501097 dough is also larger. The combination of large G' and G'' gives a much larger complex viscosity (G^*) for the KS 501097 dough than for the CI 12995 dough. Thus, more gas pressure would be required to expand the KS 501097 dough.

Taken together, our data on changes in protein solubility or dynamic rheological properties of either the gluten-water or bread doughs cannot explain the increase in gas release rate from KS 501097 flour dough at temperatures as low as 33°C (Fig. 5). However, the higher solubility of KS 501097 gluten and the lower G' of KS 501097 gluten-water dough indicate that KS 501097 gluten proteins were easier to dissociate and had less rheologically effective cross-links than CI 12995 gluten proteins. The higher G' of the KS 501097 bread dough indicated that there were stronger or more rheologically effective cross-links when the dough was made with all the flour components.

CONCLUSIONS

Dough from poor-quality flour produced small loaf volumes. This was not because less air was incorporated during mixing, but because dough released more carbon dioxide during fermentation and the early stages of baking. The gas loss at the early stage of baking cannot be explained by starch gelatinization, changes in protein solubility, or dynamic rheological properties of either the gluten-water or bread doughs.

The differences in dough expansion, protein solubility, and rheological properties between bread flours of poor and good quality and between gluten-water and bread doughs made from those flours were clearly observed even without baking. The higher solubility of KS 501097 gluten and the lower G' of KS 501097 gluten-water dough indicated that KS 501097 gluten proteins were more easily dissociated and had less rheologically effective cross-links than CI 12995 gluten proteins. However, the higher G' of KS 501097 bread dough indicated that there were stronger or more rheologically effective cross-links when the dough was made from all the flour components.

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[Received September 10, 1990. Accepted March 29, 1991.]