Effect of the Quantity of Wheat Flour Protein on Bread Loaf Volume[1]

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

ABSTRACT

Cereal Chem. 69(1):17-19

The effect of flour protein content on dough expansion and rate of CO_2 loss from doughs during baking and extended proofing were studied. When baked in a conventional oven, the doughs containing more protein expanded at a faster rate than those containing less protein. Profiles of CO_2 loss from doughs during baking were not significantly affected by flour protein contents above 8.5%. When proofed for an extended period, the doughs containing more protein expanded at a faster rate and, more importantly, continued to expand longer than the doughs containing less protein. The difference in dough expansion rate might be attributed to the effect of flour protein on dough extensibility. Calculation of the difference in thickness of gas cell walls between doughs containing 8.5 and 11.5% protein suggests that the extent of dough expansion is mainly determined by how thin the gas cell walls can be stretched before reaching their expansion limit.

Finney (1943) and Finney and Barmore (1948) found that when an optimized baking formula was used, the relationship between protein content and loaf volume was linear for a given wheat cultivar over the protein range examined (8–18%). They also reported that the slope of protein content vs. loaf volume regression line varied from one cultivar to another, and the slope of the regression line is a measure of the cultivar's baking quality. Since their work, factors that control the difference in baking quality between wheat varieties have received extensive study.

The linear relationship between loaf volume and protein content has been accepted, with essentially no studies reported on the mechanism of protein content effects on loaf volume. Limited studies have reported on the effect of protein content on dough rheology. Aitken and Geddes (1939) and Markley et al (1939) found that farinograph dough development time and water absorption increased in protein content. Aitken et al (1944) studied a series of wheats that varied widely in both protein content and dough strength. They found that protein content of flour was positively correlated with farinograph mixing time, farinograph mixing tolerance, and extensigraph dough extensibility but negatively correlated with alveograph height. In contrast, Finney and Shogren (1972) showed that mixing time of flours decreased as a function of protein content up to about 12% and remained constant above 12%; they used a higher speed mixer (mixograph), which may explain the different results.

Hibberd (1970) studied the rheological behavior of "synthetic" doughs composed of mixtures of gluten and starch in different proportions. He found a decreasing dynamic storage modulus (G′, the elastic modulus) in gluten-starch doughs with increases in protein content. Dreese et al (1988b) reported similar results.

The objectives of this study were to 1) document the effect of protein content on dough expansion and gas retention during the breadmaking process and 2) develop an understanding of how flour protein content manifests its effect on the loaf volume of the bread.

MATERIALS AND METHODS

Flour

Flours with the same protein quality but different protein contents were established by the addition of starch isolated from the base flour back to that flour. The base flour was a commercial bread flour (Cargill, Wichita, KS) containing 11.5% protein and 0.48% ash. The starch isolation from the flour was described by He and Hoseney (1991a). Flour and water (1:3) were shaken in a closed container to form a slurry. The slurry was centrifuged for 20 min at about 500 *g*. The gluten was washed from the flour using one additional part of water to rinse the gluten. The combined water fractions were centrifuged (at 1,000 *g*) to recover the starch fraction. The starch, gluten, and water-soluble fractions were lyophilized. Four flours containing 7.0, 8.5, 10.0, and 11.5% protein resulted.

Baking

AACC Method 10-09 was used to prepare dough and bake bread (AACC 1983). Optimal water, 10 ppm of $KBrO_3$, and 4.0 g of nonfat dry milk (based on the weight of flour) were added to the formula. Fermentation time was 180 min.

Oven Spring Determined by Time-Lapse Photography

The oven spring of dough during baking was determined from time-lapse photographs, as described by He and Hoseney (1991b). Time-lapse photographs were taken during baking bread at the following baking times: 0.0, 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, and 24.0 min. The distance between

[1]Contribution No. 91-322-J from the Kansas Agricultural Experiment Station, Manhattan, KS 66506. Address correspondence to R. C. Hoseney.
[2]Graduate research assistant and professor, respectively, Department of Grain Science and Industry, Kansas State University, Manhattan.
[3]Present address: Anheuser-Busch Companies, Inc., St. Louis, MO 63118-1852.

the top of the dough or bread and the top edge of pan was measured as an indication of oven spring of dough. The standard deviation was less than 2 mm.

Baking in the Electric Resistance Oven and Measurement of CO_2 Loss

When dough was baked in an electric resistance oven, the methods of preparing dough, baking, and measuring CO_2 loss during baking were those described by He and Hoseney (1991c).

Proofing Test

The molded dough was placed in a transparent container (Plexiglass) with a cross-section area of 110 cm^2 (125 × 88 mm) and proofed for 12 hr at 28°C and 85% rh. The height of the top of the dough was read every 15 min, and the increase in dough height was plotted against time. The standard deviation was 10 mm with 2 replications.

Calculation of Total Surface Area of Starch Granules

If total starch weight of dough is assigned as W, the density of starch granule (1.55 g/cm^3) as d, the average diameter of starch granule as D, the volume of single starch granule as V_0, the total volume as V, the total number of starch granules as N, the surface area of single starch granule as S_0, and the total surface area of starch granules as S, then

$$V = W/d,$$
$$N = V/V_0 = 6W/3.14dD^3, \text{ and}$$
$$S = NS_0 = (6W/3.14dD^3)(3.14D^2) = 6W/dD.$$
$$S_{8.5} = 6\ W_{8.5}/dD = 6 \times 73/1.55 \times 9.5 = 29.75 \text{ m}^2$$
$$S_{11.5} = 6\ W_{11.5}/dD = 6 \times 70/1.55 \times 9.5 = 28.52 \text{ m}^2$$

RESULTS AND DISCUSSION

Loaf Volume and Oven Spring

The loaf volume of bread increased as a function of increasing protein content from 7.0 to 11.5% (Table I). This is essentially consistent with the results of Finney and Barmore (1948). The results of time-lapse photography during baking of doughs containing 8.5 and 11.5% protein are shown in Fig. 1. Although data are not shown, the other flours gave similar results.

TABLE I
Effect of Flour Protein on Loaf Volume

Flour Protein (%)	Loaf Volume[a] (cm^3)
7.0	707 ± 12.6
8.5	818 ± 10.4
10.0	903 ± 5.8
11.5	932 ± 11.5

[a] ± Standard deviation.

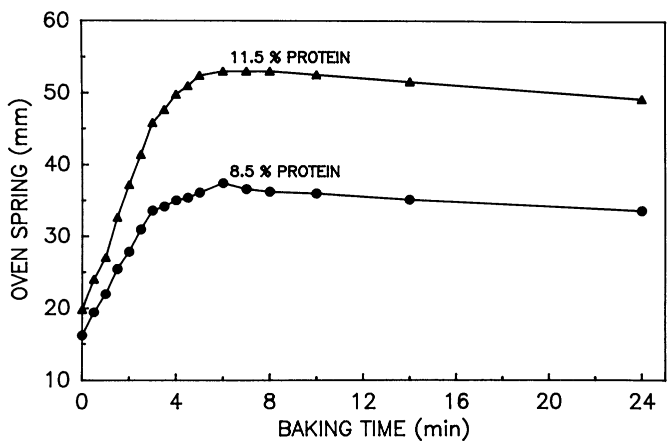

Fig. 1. Oven spring of doughs made from flours with different protein contents.

Prior to baking, the proof height of the dough made from 11.5% protein flour was slightly greater than that of the dough made from 8.5% protein flour (Fig. 1). The difference in the heights of the two doughs became much greater during baking. During the first 3 min of baking, the dough containing more protein expanded at a faster rate than the dough containing less protein (8.6 and 5.3 mm/min, respectively). After 3 min of baking, the expansion rate for both doughs decreased; however, the dough containing more protein still expanded at a faster rate (3.5 vs. 2.5 mm/min). Both doughs stopped expanding after 6 min of baking. With additional baking, the loaves became slightly smaller, presumably because of drying and shrinking. Clearly, the difference in loaf volume between the two breads was due to the small difference in proof height and the rate of expansion during the first 6 min of baking.

Loss of CO_2 During Baking

The rates of CO_2 loss during baking from doughs made from flours with the four protein levels are shown in Fig. 2. During the early stages of baking, the rate of gas loss from each of the doughs was small and essentially constant. This implies that all the doughs retained gas. Doughs made from flours containing more than 8.5% protein started to lose much more CO_2 at essentially the same temperature, 72°C. The dough made from 7.0% protein flour started to lose gas at a lower temperature. A standard flour, with 4% of its dry weight substituted for with gluten, gave results similar to the 8.5% protein and greater flours (data not shown).

During baking, dough expansion is fast, and at higher temperatures, about 65°C (He and Hoseney 1991a), the starch gelatinizes. Gelatinized starch reacts much better than ungelatinized starch with gluten and greatly increases the G′ of the system (Dreese et al 1988a). Because of the larger G′, that interaction greatly decreases the dough's expansion rate.

Because of the increase in G′, dough can no longer expand under gas pressure, and, as a result, the cell wall ruptures and CO_2 is lost to the atmosphere. With white pan bread of our formulation, this occurs at about 72°C (He and Hoseney 1991a). As shown in Fig. 2, with doughs made from flour containing 8.5% or more protein, the rapid loss of CO_2 occurred at the same temperature. For the 7% protein sample, it appears that the cell walls reached their expansion limit before starch gelatinized. In this case, not only does the dough stop expanding, but gas is lost as the cell walls fail. An example of this is seen in Fig. 2 with the dough made from 7% protein flour. It should be noted that the time in the electric resistance oven (Fig. 2) cannot be related to the time in Fig. 1 because a different baking system was used.

Dough Expansion During Extended Proofing

Extended proofing at room temperature (23°C) eliminated the heating factor affecting dough expansion during baking and allowed further analysis of the effect of flour protein. The increase in dough height was recorded as a function of time, and only

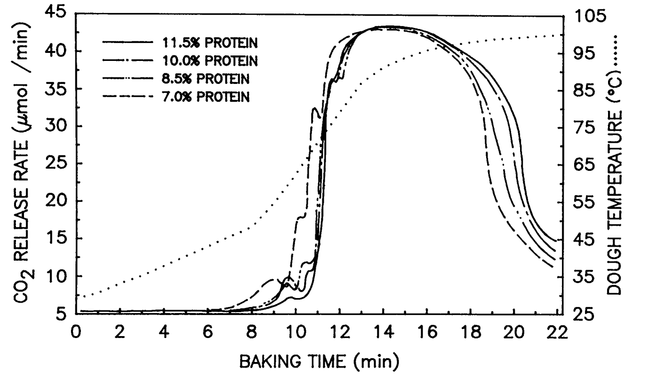

Fig. 2. Effect of protein content on CO_2 release during baking.

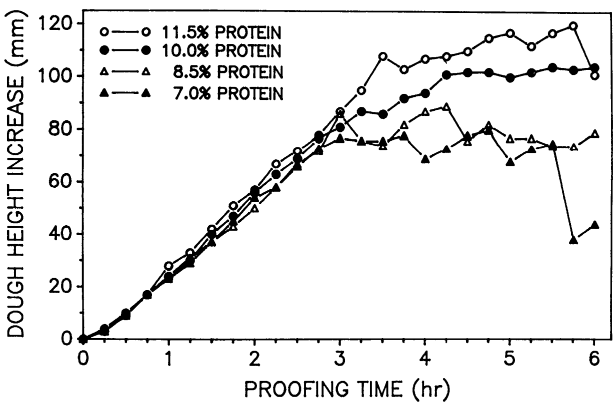

Fig. 3. Effect of protein content on increase in dough height during extended proofing.

the first 6 hr of proofing is plotted in Fig. 3. In general, during the first 3 hr of proofing, the doughs containing more protein expanded slightly faster than the doughs containing less protein. After 3 hr, the lower protein doughs stopped expanding, whereas the higher protein doughs continued to expand. When the maximum height was reached for each dough, large bubbles appeared at the top of the dough, grew, and finally ruptured. The emergence, growth, and rupture of bubbles was repeated several times before the dough finally collapsed. The doughs made from higher protein flour took a much longer time to reach their maximum expansion and to collapse (about 10 hr for the 11.5% protein dough) than the doughs made from lower protein flours.

The studies of Aitken et al (1944) and Hibberd (1970) imply that the more gluten a dough contains, the more extensible it is. This was confirmed by Dreese et al (1988b), who showed that G′ decreased as the gluten content of a starch-gluten dough increased. Therefore, the increase in extensibility of doughs as a result of more flour protein may explain why higher protein dough expanded at a faster rate during fermentation and baking (Figs. 1 and 3).

The next question was, What determines the maximum expansion of dough? In a bread dough system, the gluten matrix is the continuous phase, and the starch is discontinuous. Decreasing flour protein content significantly increases G′ (Dreese et al 1988b) and at the same time decreases the thickness of the gluten matrix. The change is derived mainly from the decrease in gluten and only to a small extent from the increase in the total surface area of starch granules. This can be shown by calculating the decrease in gluten and the increase in the total surface area of starch granules when protein content of flour decreases from 11.5 to 8.5%.

The reduction of protein was 26% [(11.5 − 8.5%)/11.5% × 100]. Assuming that doughs made from flours of the same quality but with different levels of protein incorporate the same amount of air, produce the same numbers of gas cells during mixing and punching, and have a constant surface area of starch granules, then the thickness of the gluten matrix will also decrease by 26%.

To estimate the surface area of starch granules, we assumed that they are spherical. With 30% large granules of 20-μm diameter and 70% small granules of 5-μm diameter (Lineback and Rasper 1988), the average diameter will be 9.5 μm [(30% × 20μm + 70% × 5μm)/100%]. If pup-loaf bread dough (100 g of flour) made with 11.5% protein flour contains 70 g of dry starch, and that made with 8.5% protein flour contains 73 g of dry starch, then the total surface areas of starch granules in both doughs and their difference can be calculated by using the equations shown in the materials and methods section. The calculation shows that the total surface area of starch granules in 8.5 and 11.5% flour protein dough is 29.75 and 28.52 m^2, respectively. Therefore, the total surface area of starch granules is increased by only 4.3% [(29.75 − 28.52)/28.52]. Thus, starch surface area does not appear to be an important factor affecting the thickness of the gluten matrix.

Bread dough is a viscoelastic material made up of gluten, an amorphous highly entangled, but essentially uncross-linked polymer, which is filled with starch. As with other polymers (Sperling 1986), the filler raises the G′ of the system by forming a variety of physical and chemical bonds with the polymer. Therefore, dough made from lower protein flour has a thinner polymer matrix (gluten) with a higher ratio of filler (starch). This results in a higher G′ and a dough that expands less and at a slower rate.

LITERATURE CITED

AITKEN, T. R., and GEDDES, W. F. 1939. The relation between protein content and strength of gluten-enriched flours. Cereal Chem. 16:223.

AITKEN, T. R., FISHER, M. H., and ANDERSON, J. A. 1944. Effect of protein content and grade on farinograms, extensigrams, and alveograms. Cereal Chem. 21:465.

AMERICAN ASSOCIATION OF CEREAL CHEMISTS. 1983. Approved Methods of the AACC. Method 10-09, approved September 1985. The Association: St. Paul, MN.

DREESE, P. C., FAUBION, J. M., and HOSENEY, R. C. 1988a. Dynamic rheological properties of flour, gluten, and gluten-starch doughs. I. Temperature-dependent changes during heating. Cereal Chem. 65:348.

DREESE, P. C., FAUBION, J. M., and HOSENEY, R. C. 1988b. Dynamic rheological properties of flour, gluten, and gluten-starch doughs. II. Effect of various processing and ingredient changes. Cereal Chem. 65:354.

FINNEY, K. F. 1943. Fractionating and reconstituting techniques as tools in wheat flour research. Cereal Chem. 20:381.

FINNEY, K. F., and BARMORE, M. D. 1948. Loaf volume and protein content of hard winter and spring wheats. Cereal Chem. 25:291.

FINNEY, K. F., and SHOGREN, M. D. 1972. A ten-gram mixograph for determining and predicting functional properties of wheat flour. Baker's Dig. 46(2):32.

HE, H., and HOSENEY, R. C. 1991a. Gas retention in bread dough during baking. Cereal Chem. 68:521.

HE, H., and HOSENEY, R. C. 1991b. Differences in gas retention, protein solubility, and rheological properties between flours of different baking quality. Cereal Chem. 68:526.

HE, H., and HOSENEY, R. C. 1991c. A critical look at the electric resistance oven. Cereal Chem. 68:151.

HIBBERD, G. H. 1970. Dynamic viscoelastic behavior of wheat flour doughs. III. The influence of the starch granules. Rheol. Acta 9:501.

LINEBACK, D. R., and RASPER, V. F. 1988. Wheat carbohydrates. Page 277 in: Wheat: Chemistry and Technology, Vol. I, 3rd ed. Y. Pomeranz, ed. Am. Assoc. Cereal Chem.: St. Paul, MN.

MARKLEY, M. C., BAILEY, C. H., and HARRINGTON, F. L. 1939. The colloidal behavior of flour doughs. VI. Dough formation from flours of diverse types. Cereal Chem. 16:271.

SPERLING, L. H. 1986. Page 350 in: Introduction to Physical Polymer Science. John Wiley and Sons: New York.

[Received February 25, 1991. Accepted July 31, 1991.]