# Using the Wheat Research Institute Chomper to Assess Crumb Flexibility of Staling Bread

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## ABSTRACT

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Experiments were performed to assess the performance of the Wheat Research Institute Chomper in evaluating bread staling. The Chomper produces a dynamic stress-strain curve, the chompergram. The peak height of the chompergram appears to indicate the strength of the gluten matrix of crumb. The initial slope of the chompergram provides a measure of crumb flexibility. These two parameters were found to be useful in assessing the staling of bread with respect to storage time, position of the sample in the loaf, and type of dough conditioner used. Chompergram slope increased with storage time, whereas peak height decreased with storage time. A unique finding that peak heights generally mirror chompergram slopes may support theories of water migration between gluten and starch fractions. The mechanical model proposed for the action of the chompergram was supported by the results of this study, in particular by the results obtained for Poisson's ratio.

This paper discusses experiments carried out to assess the performance of the Wheat Research Institute Chomper (Baruch and Atkins 1989) in evaluating the staling of bread. Two sets of trials provided information for two primary objectives.

The first was to examine the effect of staling of unsliced, unwrapped loaves on peak height and chompergram slope. Staling may be very complicated chemically, but its dependence on time is clear, and its effect on bread crumb is qualitatively definite.

The second objective was to obtain an indication of the correctness of the mechanical model proposed by Baruch and Atkins (1989) by evaluating Poisson's ratio.

Work to achieve these two goals was carried out in 1979. In addition, preliminary work including use of different dough conditioners in the formulation indicated that further work in this area might yield quantitative results of interest. Hence more experiments were carried out in 1986 to look at the decrease of peak height with advanced staling and staling differences due to dough conditioner type.

## MATERIALS AND METHODS

### 1979 Experiments

*Firmness and failure.* The factor chosen to establish suitable firmness and failure scales for bread crumb was the staling of unsliced, unwrapped loaves.

Loaves weighing 0.8 kg were prepared according to the 1979 formula in Table I. The loaves were stored at room temperature. Three slices were taken from the center of the loaves at 4.5, 23.5, 29.5, 34.5, and 40 hr after removal from the oven. Three holes were punched by the Chomper in each slice of bread at speeds proportional to 50, 25, and 10 Hz mains power supply. The high-speed punch was used first on one slice from each sample, then second, and finally third on succeeding samples. Flexibility and peak height (Baruch and Atkins 1989) were measured from the resulting graph for each slice.

*Mechanical model of instrument action and Poisson's ratio.* Poisson's ratio was determined in order to obtain an indication of the correctness of the mechanical model proposed for the action of the Chomper (Baruch and Atkins 1989).

Trials were carried out in quadruplicate for each of six different indentations of the plunger into the slice. The samples were from the center of one two-day-old loaf. An ANOVA indicated that the results of the four samples were from the same population. Thus Poisson's ratio for the four average values at the six positions could be calculated. This quantitative information was compared with visual qualitative observations to confirm the general nature of crumb reaction.

### 1986 Experiments

To confirm previous results, particularly those that indicated decreased peak heights at advanced staling and staling differences due to different dough conditioners, additional experiments were undertaken in 1986. All 1986 chompergrams were produced with a platform speed of 1.1 mm/sec, using a 50-Hz power supply.

*Slope and peak height.* Chompergram slope and peak height values of consecutive slices from loaves zero, one, and three days old provided data for this analysis. The loaves were aged at a temperature of 4° C to achieve faster staling (Stellar and Bailey 1938, Cornford et al 1964). A constant humidity above 95% maintained the loaves at a specific loaf volume of $4.40 \pm 0.06$ cm$^3$/g while aging.

The formulation for the four loaves in this experiment is given in the 1986 formula in Table I. The dough received 6 Whr/kg (work input of mixing) from a Tweedy MDD (mechanical dough development) mixer. The dough was then molded on a Mono universal molder and placed longitudinally in open pans of 21 × 12 cm top, 19 × 10 cm base, 11 cm depth. Proof time was 50 min at 40° C and 100% humidity. Baking time was 25 min at 230° C in a Baker Perkins Slimline Rotel oven. The loaves cooled for 2 hr in a walk-in refrigerated space maintained at 95% humidity at 4° C. Three unwrapped loaves were then sealed in a constant humidity chamber maintained at 95% humidity by a saturated solution of zinc sulfate in equilibrium with the air in the chamber at 4° C. The fourth loaf was tested immediately. Subsequent loaves were taken from the chamber to be tested at 24, 50, and 71 hr out of the oven.

Each loaf was weighed when it emerged from the oven and again when it left the humidity chamber. Loaf volumes were determined by rapeseed displacement when the loaves were removed from the chamber. This procedure allowed assessment of specific loaf volume.

A Mono reciprocating slicer provided approximately 18 12.5-mm thick slices from each loaf. End slices were discarded.

*Dough conditioners and loaf shapes.* To test the effects of dough conditioners and loaf size, six loaves were baked from three

**TABLE I**
**Formulation for Breads Studied**

| Ingredient | 1979 | 1986 |
|---|---|---|
| Flour | 1,000 g | 1,000 g |
| Yeast | 30 g | 30 g |
| Sugar | 7.5 g | 7.5 g |
| Salt | 20 g | 20 g |
| Lard | 15 g | 15 g |
| Water | 550 ml | 580 ml |
| Ascorbic acid | 100 ppm | 100 ppm |
| Potassium bromate | 50 ppm | 50 ppm |

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doughs. The doughs were prepared identically, except dough conditioner L was added to the first, dough conditioner E to the second, and no conditioner or fat to the third.

Another factor examined was the shape of the pan. Each dough was divided and molded. One part was placed longitudinally in a "stubby" pan of bottom dimension 19× 10 cm, top dimension 21× 12 cm, and depth 12 cm; the second division was placed in a "long" pan of bottom dimension 25× 9 cm, top dimension 26× 11 cm, and depth 9 cm. The loaves were baked in a Baker Perkins Slimline Rotel oven, cooled for 2 hr, sealed in plastic bags by wire twists, and then stored at room temperature. Chompergrams were made from 12.5-mm slices cut on the Mono slicer at 24, 70, and 95 hr out of the oven.

## RESULTS

All data were tested for normality and homoscedasticity where appropriate to fulfill the assumptions required for statistical analysis. Grubb's test (Grubbs and Beck 1972) was used to detect outliers. Because time is a fixed quantity in their experiments, data are suitable for model I regression and analysis of covariance (ANCOVA) according to Berkson's (1950) criteria.

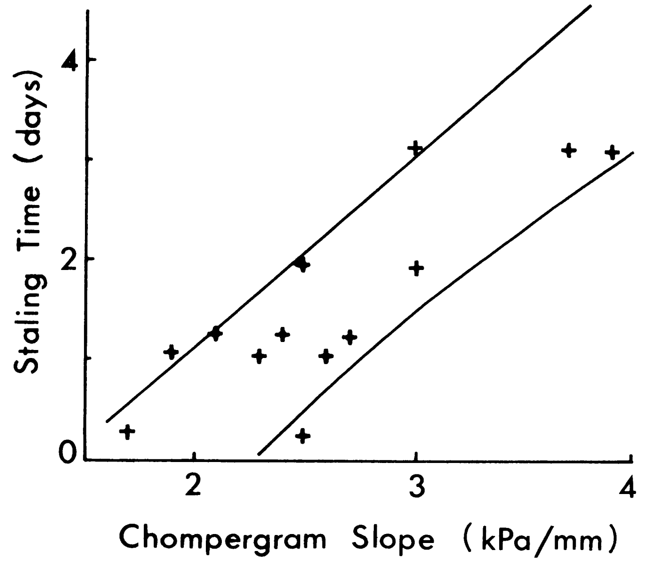

**Fig. 1.** Inverse of the regression of chompergram slope on staling time for 1979 data. The two lines are the upper and lower boundaries of the 95% confidence interval.

### Peak Height and Slope Measurements Related to Staling

Preliminary ANOVAs indicated that neither order of punching nor slice number contributed significantly to variations in peak height or chompergram slope when the results were confined to the center of the loaf.

### 1979 Chompergram Slope Versus Time

Staling time is plotted against chompergram slope in Figure 1. Comparison of the correlation ratio to the coefficient of determination (Weatherburn 1968) indicated that the plot was not significantly nonlinear. ANCOVA between slope and time groups of different platform speeds indicated that different platform speeds produced no significant difference between the corrected means of the chompergram slopes and that the time gradient of the chompergram slopes was not significantly different for the three speeds. However, the standard error of estimate of the chompergram slopes made at 50 Hz and the concomitant improvement in the coefficient of determination indicated that more consistent results were obtained at this frequency. The regression equation of chompergram slope on days for a platform speed of 1.1 mm/sec, where $y$ is the chompergram slope in kPa/mm and $x$ is in days, is

$$y = 0.54x + 1.8,\ Syx = 0.18,\ r^2 = 0.90$$

The inverse (Sokal and Rohlf 1981) of this equation has the 95% confidence interval shown in Figure 1.

### 1986 Chompergram Slope Versus Time

Nineteen slices from the centers of the four loaves examined on four consecutive days provided the data for Figure 2. The regression equation of $y$ on $x$, where $y$ is the chompergram slope in kPa/mm and $x$ is time in days, is

$$y = 1.5x + 0.86,\ Syx = 0.71,\ r^2 = 0.86$$

Figure 2 shows the 95% confidence interval for the inverse of this equation.

### 1979 Peak Heights Versus Time

Figure 3 illustrates the peak height results for 1979 obtained at a platform speed of 1.1 mm/sec. The plot shows the 95% confidence interval around the inverse of the equation obtained from regression of peak height in kPa on time in days. The equation is

$$y = -7.8x + 44,\ Syx = 2.7,\ r^2 = 0.93$$

where $y$ is in kPa and $x$ in days.

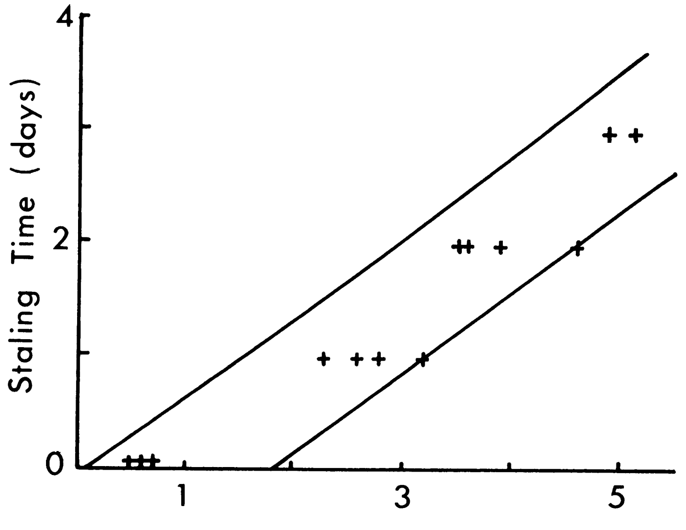

**Fig. 2.** Inverse of the regression of chompergram slope on staling time for the 1986 data. The lines enclose the 95% confidence interval.

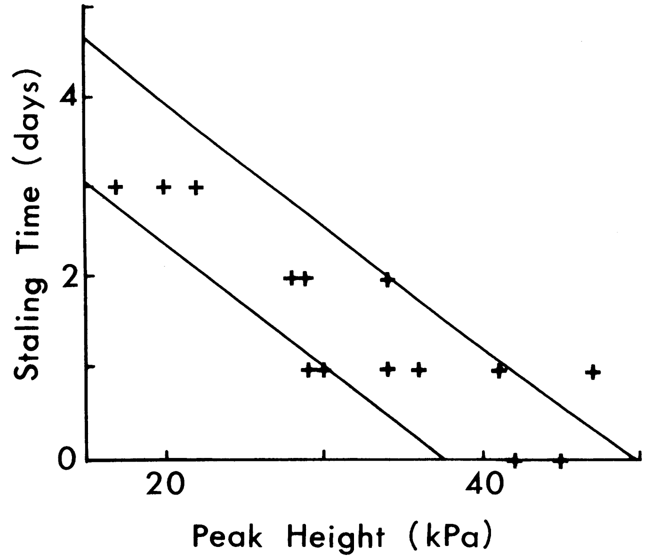

**Fig. 3.** Inverse of the regression of peak height on staling time for the 1979 data. The lines enclose the 95% confidence interval.

### 1986 Peak Height Versus Time

The correlation ratio (Weatherburn 1968) between the 19 peak height points in Figure 4 and the time out of oven to obtain them indicated that the 1986 relationship was significantly different from linear. However the function

$$f(x) = -3.5x^2 + 5.8x + 44$$

where $x$ is measured in days, provides a linear base for the peak height data. Regression of the peak height data onto this base, inversion of the regression, and retransformation of the time axis back to a scale based on days provided the data for Figure 4. It should be noted that the function is not single valued.

### Chompergraph Slope and Peak Height Versus Position in Loaf

When the chompergram slope data in the 1986 experiments were plotted against slice number for each of the four loaves, the graphs qualitatively indicated that central slices were firmer than outer slices. In general, there was an increase in chompergram slope, particularly at the center of the loaf, as the time out of oven increased.

The graphs of peak height against slice approximately mirror the situation of chompergram slope against slice. The lower peak heights are at the centers of the loaves. Figures 5 and 6 are plots at three days for chompergram slope versus slice and peak height versus slice, respectively.

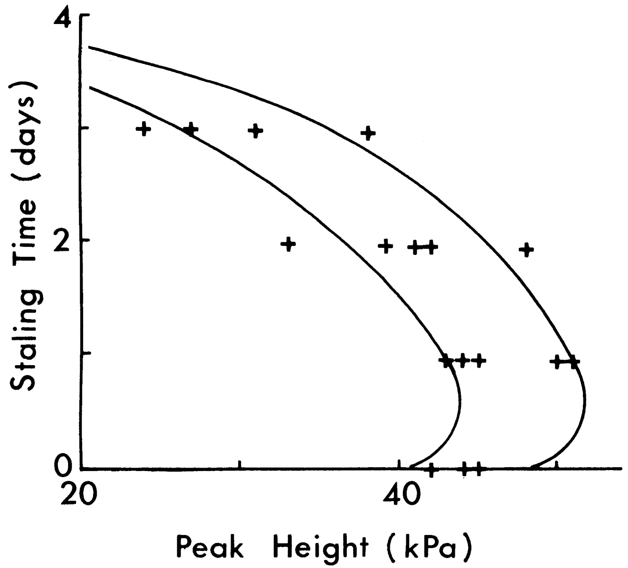

**Fig. 4.** Inverse of the regression of peak height on staling time for the 1986 data. The lines are the upper and lower boundaries of the 95% confidence interval.

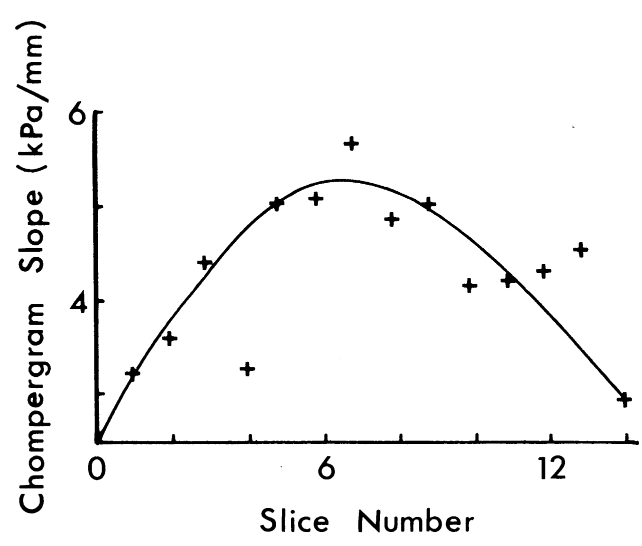

**Fig. 5.** Chompergram slope as a function of slice number at 71 hr out of the oven.

### The Effect of Dough Conditioners

A single criterion ANCOVA for each dough conditioner type showed that there was no significant difference between long and short loaves for time response of chompergram slope or means of chompergram slope corrected for time. Hence values of the long and short loaves were pooled within each conditioner type for analysis.

The mean chompergraph slope-time graphs of the six points for each dough conditioner were considered. At the no-conditioner level, a plateau appeared at 69 hr. The two 95-hr points were excluded from the data at this level so that the initial linear time response could be compared to the other two levels (Fig. 7). A single criterion ANCOVA performed on the remaining four mean chompergraph slope-time pairs at the no-conditioner level and the six pairs for each of the conditioners E and L demonstrated that

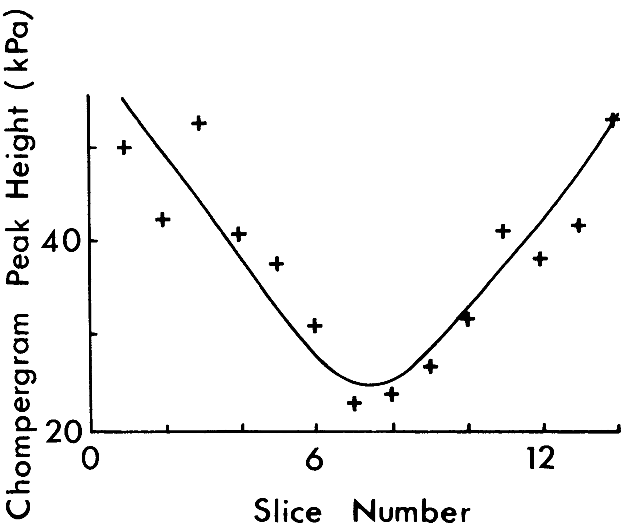

**Fig. 6.** Chompergram peak heights as a function of slice number at 71 hr out of the oven. Note how the pattern mirrors Fig. 5.

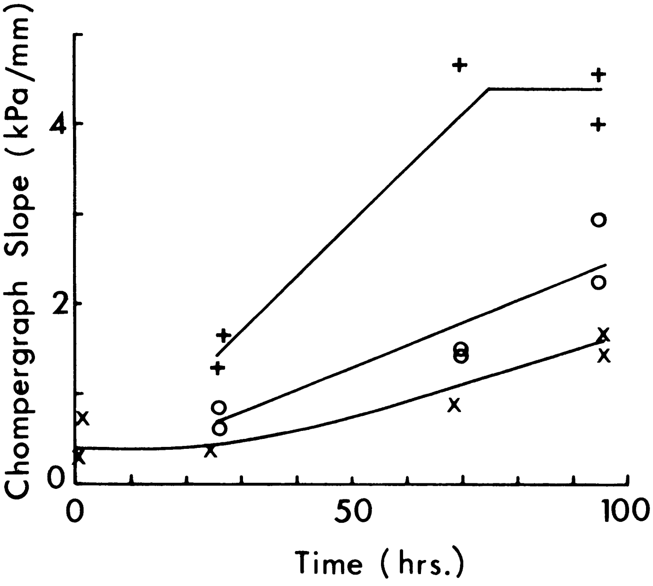

**Fig. 7.** Chompergram slope as a function of time for no conditioner and the two dough conditioners E and L. Without the conditioner, the staling rate is noticeably greater. For the two conditioners, the rate is not significantly different, but the loaf containing L is softer at all times than the loaf containing E. No conditioner = +, E = o, and L = x.

one of the time response line gradients was significantly different ($P < 0.05$).

No significant difference was found to exist between the time response gradients due to conditioners E and L. However when time was taken into account, a significant difference ($P < 0.05$) still remained between the mean chompergram slope values of L and E. Conditioner L had the lower values.

There was no significant difference for any conditioner level ($P < 0.05$) between loaf type (long or short) for peak height. Within the time range of the experiment, there was no significant time response of the mean peak heights regardless of factors. A one-way ANOVA between conditioners indicated that at least one mean peak height was significantly different ($P < 0.05$).

A second ANOVA indicated that there was no significant difference between the mean peak height of conditioners E and L ($P < 0.05$) when the no-conditioner level was excluded. The mean peak height of the no-conditioner treatment was therefore significantly higher than the mean peak height of treatments containing conditioners.

### Poisson's Ratio

The two curves in Figure 8 show values of Poisson's ratio at different platform motion distances for $k = 0.62$ and $k = 0.54$, where $k$ = proportionality constant relating plunger indentation to extension of crumb cone beyond the slot face (Baruch and Atkins 1989). The range $k = 0.54$ to $k = 0.62$ includes much of the white bread crumb that has been examined to date.

For $k = 0.62$, Poisson's ratio was initially in the range of 0.38. The value decreased to 0.29 as the platform moved past the slice width distance. For $k = 0.52$, the values initiated at 0.32 and finished at 0.05.

## DISCUSSION

An outstanding feature of these experiments was the linearity of the chompergram slope with time out of oven. Hartree's (1958) geometric method enables similar slope measurements from Figure 10 in Bice and Geddes (1949) and from Figure 2 in Crossland and Favor (1950). An equal degree of linearity was evident when the values of their initial slopes were plotted against time out of oven. Slope values reported by Bice and Geddes range from 0.31 kPa/mm at 19 hr to 1.99 kPa/mm at 67 hr, and those of Crossland and Favor range from 0.37 kPa/mm at 4 hr to 2.47 kPa/mm at 90 hr. These values and the values obtained by the Chomper have comparable magnitudes despite the differences in experimental techniques. A similar calculation from Figure 2 in Hibberd and Parker (1985) provides a value of 0.26 kPa/mm at the center of the loaf for fresh crumb measured by an Instron universal testing machine (UTM).

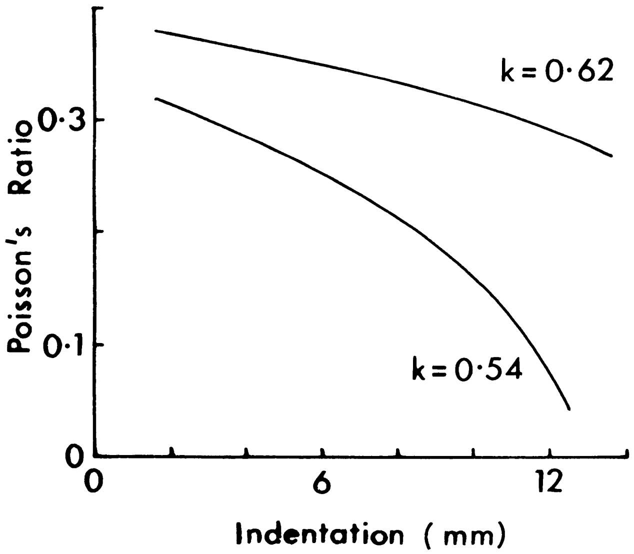

**Fig. 8.** Poisson's ratio as a function of indentation for $k = 0.62$ and $k = 0.54$.

The time gradient of the 1986 chompergram slope data was nearly three times that of the 1979 data. This discrepancy was probably due to the difference in storage temperature (room temperature in 1979, 4°C in 1986). Boussingault (1852) first noticed an increased staling-time gradient in bread stored at lower temperatures (down to 4°C). The phenomenon is the keystone of Katz's (1928) argument that starch crystal formation is partially responsible for staling. Stellar and Bailey (1938) and Cornford et al (1964) provided supporting quantitative data. Both authors used static methods to measure crumb response.

Stellar and Bailey measured the crumb softness and Cornford et al measured the firmness. According to Bice and Geddes (1949), softness measures the deformation achieved by a fixed load, whereas firmness measures the load necessary to achieve a fixed deformation. Although the two measurements differ (Bice and Geddes 1949), there is a high correlation (Kamel and Rasper 1986) between the precision penetrometer and the Baker compressimeter, two devices that employ the two different measurement modes. Hibberd and Parker (1985) demonstrated a high correlation between firmness and initial UTM firmness-deformation slopes similar to the chompergram slope. Therefore an increased chompergram time gradient was expected at lower storage temperatures. The smaller width of the 95% confidence interval surrounding the 1986 chompergram slope measurements corresponds to better experimental control of both temperature and humidity. The 1986 humidity of 95% maintained constant specific loaf volume throughout the experiment. If chompergram slopes were used to determine the staleness of bread of unknown history, similar confidence intervals to those in Figure 1 would limit significance. However, any unknown pedigree measurements could be compared with central slices from bread of pedigree similar to Figure 2 and the result graded in terms of the known pedigree. Chompergraph measurements confirmed that such a step becomes even more imperative when dealing with cross pan molded loaves. Hibberd and Parker (1985) first observed such confounding.

Qualitatively the peak height measurements mirrored the chompergram slope measurements. The most striking example is shown by comparison of Figures 5 and 6. Dahle and Montgomery (1978) used a punch and dye technique similar in many respects to the Chomper to measure strength and extensibility. The greatest difference between the two instruments is the 8-mm gap around Dahle and Montgomery's punch that could allow the shear patterns to differ between samples. These authors claim that the structural collapse seen at peak resistance to deformation indicates rupture of the gluten matrix. Chompergrams (*unpublished data*) of special coeliac bread from which the gluten had been removed displayed an insignificant peak height. Chompergrams (*unpublished data*) of bread made from four flours reconstituted with different levels of gluten displayed peak heights that varied with their gluten contents. These results support Dahle and Montgomery's hypothesis.

The 1979 chompergram peak height-time out of oven gradient was constant and negative (Fig. 3). The 1986 data (Fig. 4), which benefitted from more rigorous control, revealed little difference between results during the first two days, but during the second two days, the peak height-time out of oven gradient was negative. These results agree with those of Dahle and Montgomery (1978), who found no significant difference between strengths during the first three days but then found an increasing strength-time gradient during the next two days.

Willhoft (1971) derived an overall firming equation that employs three terms. The first term describes the firming of the starch fraction due to crystallization; the second describes the softening of the starch fraction due to moisture redistribution from denatured gluten to the starch fraction. The third term describes the starch firming contribution by the gluten due to a transformation of gluten to structurally modified protein.

Chompergram slope and peak height data resemble these aspects qualitatively. It should be noted that failure in shear is equivalent to failure in tension at 45° to the shearing plane (Lindsay 1933). The chompergram peak heights during conditions of minimal moisture loss indicate a loss in strength of the gluten matrix due to the transformation of gluten to modified protein. Possibly Dahle and Montgomery's results were achieved without minimization of moisture loss. Further, more quantitative experiments, particularly with Willhoft's equation in mind, could lead to a resolution of this difficulty. Figures 5 and 6 compare the chompergram slopes and peak heights at various positions in a three-day-old loaf. The same pattern as in Figure 6 was observed with static firmness measurements by Platt and Powers (1940), Short and Roberts (1971), and Hibberd and Parker (1985).

Platform displacement can be measured from the horizontal axis of the chompergram (Baruch and Atkins 1989), so it was possible to examine the relationship between peak height and platform displacement at the point of peak height. No discernible pattern was found between peak height and platform displacement for either the 1979 or the 1986 experiments.

Reflection of the chompergram slope-slice number pattern by the peak height-slice number pattern similar to Figures 5 and 6 occurred at all the other day-out-of-oven levels in this experiment. Since the peak height is presumed to be an indication of the gluten matrix strength, these observations also indicated a weakening gluten matrix concurrent with a firming starch fraction.

Water migration from the interior of the loaf through the crumb to the crust suggested by Alsberg (1936) seems at first to explain the overall picture. Willhoft's (1971) theory suggests that water would initiate in the gluten fraction and then migrate to the starch fractions, which according to Alsberg include both crust and crumb separated by a high water concentration gradient. The process of diffusion of water from protein to starch is much slower than the protein denaturation itself. Therefore the diffusion step is rate-controlling, and is proportional to the concentration gradient of water between protein and starch. The ratio of crust to crumb at the ends is much greater than at the centers, hence the quantity of water available for starch crystallization as water crosses the crumb fraction into the crust would be greater in the center portions of the loaf. The lower gradient at the center of the loaf could also cause increased weakening of the gluten matrix due to softening caused by passive retention. Protein denaturation is a first-order process and thus will occur even in excess of water. Unfortunately, such an explanation does not account for the disappearance of the pattern when the loaf is cross molded (Hibberd and Parker 1985). Comparison of a decrusted loaf and a crusted loaf stored at high humidity was not undertaken in this work.

Figure 7 shows the effect of dough conditioners on firmness, and indicates the ability of these additives to control chompergram time gradient. The crumb containing no conditioner was easily separated from the other two crumbs, and the most effective conditioner could also be selected. Cornford et al (1964) obtained similar patterns using static firmness measurements.

The peak height data indicated that there was no response to time within the time limits of the experiment. This result appears to differ from the negative time gradient results in Figures 3 and 4, but the time and temperature storage conditions for this experiment would have placed it completely in the right-hand section of Figure 4 where there is little significant difference between peak heights. The data indicated that these dough conditioners not only diminished the firmness time gradient of the starch fraction but also decreased the tensile strength of the gluten matrix.

Figure 8 shows the values of Poisson's ratio as the plunger indentation increases. Poisson's ratio is calculated from the equality of the two stresses with the added constraint that there is a linear relation between $w$ (extension of crumb cone from the platform) and $x$ (indentation of plunger into crumb). The method of calculation is indirect, since Poisson's ratio is defined as the change in diameter per unit change of length. In the elastic region of the deformation, the ratio should remain reasonably constant. In the more plastic region, the ratio should fall toward zero. At rupture one expects severe elongation and hardly any diameter contraction. Figure 8 confirms this prediction. The present work does not include sufficient data to predict how this ratio behaves as a function of time out of oven.

The chompergram slope represents the rate of change of Young's modulus as a function of indentation at very small deformations. Ponte and Faubion (1985) point out that measurement of Young's modulus is not satisfactory because crumb does not generally behave as an ideally elastic material. If crumb were an ideally elastic material, one would expect Young's modulus to be constant. But neither Young's modulus nor Poisson's ratio remain constant. Possibly the change of Young's modulus with indentation rather than Young's modulus itself, accounts for the sensation when pressure is applied with fingers. Quantitative procedures could clarify this point.

Ponte and Faubion also raise the point that the crumb experiences not only compressive stresses but also flexural shear stresses when compressed with the Baker compressimeter, UTM, etc. Measurements by Platt and Powers (1940), Nikolayev (1941), Ponte et al (1962), Short and Roberts (1971), Dahle and Montgomery (1978), Kamel et al (1984), Kamel and Rasper (1986), and Baker et al (1986) all suffered this defect. On the other hand, Platt (1930), Stellar and Bailey (1938), Cathcart (1940), Cornford et al (1964), Laszitity (1980), and Hibberd and Parker (1985) all used prisms or cylinders cut so that the edge of the crumb did not extend beyond the periphery of the applied plunger mechanism. Platt and Powers (1940) discussed the advantages of the first condition. Crossland and Favor (1950) showed a clear difference between firmness measurements of the two shapes and pointed out that a sample is only in pure compression if its periphery is within the periphery of the compressing instrument. Additional comparisons by Walker et al (1987) showed similar results.

The chompergram slope measurement is dynamic and therefore more closely resembles a sensory finger pressure test. The data presented in this paper demonstrate responses very similar to those obtained with static techniques. Additional information concerning the gluten matrix becomes available from peak height measurements. In addition, the shapes of the chompergram patterns are qualitatively distinctive among different conditions and can provide visual information without any quantitative measurement.

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