NOTE

Elastic Properties of Bread Crumb[1]

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The use of methods to characterize bread texture has been reported by many investigators (Hibberd and Parker 1985, Dahle and Sambucci 1987, Kamel 1987, Walker et al 1987, Joensson and Toernaes 1987, Baker and Ponte 1987, Baker et al 1988). A wide range of instruments have been used to measure the applied force and the deformation of bread crumb samples. The Baker compressimeter, for instance, measures either the deformation corresponding to an applied force or the force required to compress a bread sample to a given deformation (Platt and Powers 1940, Crossland and Favor 1950).

Much information can be found on bread firmness testing. However, there is still a need for quantitative evaluation of other mechanical properties of bread. Bread crumb is a chewy, aerated material that is viscoelastic, i.e., it generally does not behave as an ideally elastic material. In fact, bread is elastic only over a low, narrow, poorly defined range of stresses (Lasztity 1980).

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Many manufacturers often claim that various additives are capable of improving bread softness. Unfortunately, little is known about ingredients that can improve bread elastic properties that can be measured quantitatively. Therefore, the establishment of a simple test that can provide useful information on the elastic properties of bread crumb is needed. One simple technique that yields much information about the structure of food is the recoverability of a compressed specimen to its original state (Lee et al 1983). This study investigated the loss in percent recoverable work of bread crumb as a measure to determine its elasticity at various storage periods.

MATERIALS AND METHODS

Bread Preparation

A short-time bread-making procedure was used in this study. The dough consisted of 100 g of flour, 60 g of water, 2 g of active dry yeast, 1.5 g of salt, 4.7 g of sugar, 2 g of nonfat dry milk, 3 g of shortening (Crisco), 0.25 g of calcium propionate, and 0.15 g of potassium sorbate. Wheat flour (King Arthur Flour, Andover, MA) contained 12.2% protein (wet basis, wb), 0.49% ash (wb), and 13.3% moisture (wb). This information was provided by the manufacturer. Basic bread ingredients were obtained from a local supermarket. No oxidizing agent was added to the dough, and we made the assumption that commercial bread texture quality follows the same trend of change in elastic property after compression and during storage.

The bread dough was mixed and kneaded in a Hobart mixer (model M-300, Troy, OH) at approximately 100 rpm in a mix bowl (42.8 cm diameter, 31.0 cm high). The mix time was 10 min, the dough temperature was 32°C, the floor time was 15 min, and the intermediate proof time was 10 min. A 500-g portion of dough was molded manually, proofed for 55 min, and then baked for 20 min at 193°C (Garland electric oven, model 680-z, Garland Commercial Industries, Inc. Freeland, PA). This temperature was lower than that used commercially for bread baking to avoid the extensive drying and browning of the crust found in the preliminary test using a higher temperature. In addition, convection in this oven might have removed some surface moisture from the bread, reducing the bread temperature. Evidently, the moisture in the crumb remained relatively high (42%) after baking, possibly a result of the relatively low baking temperature. The legal moisture limit for commercial bread after baking is 38%. After baking, the loaves were cooled for 1 hr and weighed, and the volumes were measured by the rapeseed displacement method. The bread specific volume was 5.42 ± 0.025 cm^3/g. Each loaf was double wrapped in polyethylene bags and stored under ambient conditions until tested for recoverability.

Moisture Determination

Moisture loss was determined in duplicate by drying bread specimens in a vacuum oven at 60°C and pressure of 30 mmHg for 24 hr. This method was compared to the AACC procedure (AACC 1983) and was found to give moisture content values only 0.2% different. The experimental error for moisture determination was within 5%.

Mechanical Testing

Flat, cylindrical specimens were cut out from the center of a bread slice with a sharp, cylindrical cork borer, avoiding the crust. The bread was sliced with an electric slicer (Hobart) using a guide to keep the sides perpendicular and the thickness constant. There were 20–25 loaves per batch. Because moisture is not uniformly distributed in a loaf of bread, half of each loaf was used for moisture determination, and the other half was used for mechanical testing. The half used for mechanical testing (20–25 halves total per batch) was sliced into three 25-mm-thick slices (60–75 slices per batch). Each slice was cored at the center to obtain a cylindrical specimen 25 mm in diameter and 25 mm high (60–75 specimens per batch). The specimens were measured with a caliper to obtain the exact dimensions; the variation in both height and diameter among the samples was within 2–3%. The specimens were randomly selected in three replicates and then tested for mechanical properties. Extra care was taken to prevent moisture loss when the samples were cut and transferred.

Each bread specimen was compressed between parallel plates (15 cm diameter) coated with Teflon. This was done at a speed of 10 mm/min using an Instron universal testing machine (UTM, model 1000, Instron Corporation, Canton, MA). The Instron was interfaced with a MacIntosh II computer (2-MB RAM and 40-MB disk) by an analog-to-digital conversion interface (model ACM2-12-8A, Strawberry Tree Computers, Sunnyvale, CA). A specially developed program (written in Microsoft QuickBASIC by M. D. Normand, University of Massachusetts) was used to acquire the voltage data from the Instron at two samples per second and then convert the voltage data to stress and strain values. A compression-decompression cycle was applied to a given sample by applying a force to compress the sample to a predetermined strain or deformation (manual stop) and then retrieving the plunger or decompressing the sample to the original plunger position.

Because the sample height and deformation rate were known, a stopwatch was used to determine when to switch the Instron from a downward to an upward direction. Both compression and decompression were done at the same rate (10 mm/min). This slow rate was chosen to minimize the experimental error caused by manual switching. Deformation up to 75% was used. Three replicate bread crumb specimens were used for each deformation level and storage time. Thus, each data point represents a mean of three bread crumb specimens selected at random from 60–75 specimens per batch. For each storage time (e.g., each column in Table I), three specimens were randomly selected from the pool of all specimens in each batch and thus did not come from a single loaf. These three specimens were used for mechanical testing at a given deformation, and seven deformation levels were used. Thus, 21 of the 60–75 total specimens were selected for mechanical testing. The results of the compression-decompression tests are expressed as percent recoverable work, i.e., the work recovered from the total work applied at a given deformation. A schematic view of the stress-strain relationship in a single compression-decompression cycle is presented in Figure 1. Percent

TABLE I
Percent Reoverable Work[a] of Bread Crumb Under Various Degrees of Deformation at 6 and 24 hr After Baking

Percent of Deformation	6 hr	CV (%)	24 hr	CV (%)
10	69.8 ± 0.7	1.0	62.1 ± 4.8	7.7
20	50.3 ± 4.9	9.7	42.7 ± 3.0	7.0
30	39.2 ± 4.1	10.4	31.7 ± 4.2	13.2
40	31.2 ± 1.3	4.2	24.2 ± 2.7	11.1
50	23.3 ± 0.8	3.4	19.0 ± 2.3	12.1
60	21.6 ± 0.5	2.3	15.0 ± 2.3	15.3
75	16.5 ± .03	1.8	13.8 ± 0.2	1.4

[a] Results are mean of three determinations on separate specimens ± SD.

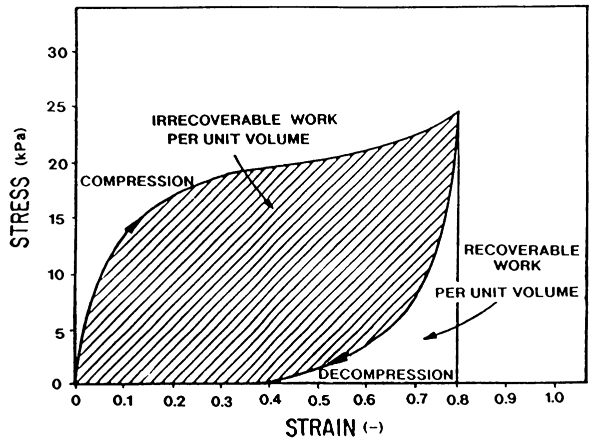

Fig. 1. Schematic view of the stress-strain relationship of bread crumb specimen in a single compression/decompression cycle.

recoverable work was calculated according to Lee et al (1983) as follows:

$$\% \text{ recoverable work} = \frac{\text{area under the decompression curve}}{\text{area under the compression curve}} \times 100.$$

The measurement was also done to compare the storage time up to 240 hr. The experimental error for percent recoverable work was mostly within 15% but in a few cases went as high as 20–25%. Significant difference was tested using the *F* test at $P < 0.05$ (Steel and Torrie 1980).

RESULTS AND DISCUSSION

Table I demonstrates the effect of various degrees of deformation on the recoverable work of bread at 6 and 24 hr after baking. The percent recoverable work decreased with the level of deformation. At 10% deformation, the recoverable work was about 60–70% and decreased to about 13–16% as the degree of deformation increased to 75%. The loss in recoverable work after compression can be explained as a result of increased damage to the cellular structure of bread due to a considerable rupture, breakage, or collapse of the cell wall (Peleg et al 1989). Thus, the more the bread is deformed, the greater is the unrecoverable damage to its structure, resulting in a decrease in the percent recoverable work (Kou and Chinachoti 1991).

Table I indicates that the bread lost 10–25% of its elastic properties by 24 hr after baking. This is not surprising since there have been reports about other mechanical properties changing dramatically within the first 24 hr after baking. For example, Hibberd and Parker (1985) found that the mean value of the force measured at 10% deformation increased by a factor of 3.3 by 24 hr after baking. The relative error in percent recoverable work, as represented by the coefficient of variation (CV), varied from 1 to about 15% (Table I). This variation was probably a reflection of the nonuniformity in bread structure. It may also be due in part to imperfections in the procedure itself.

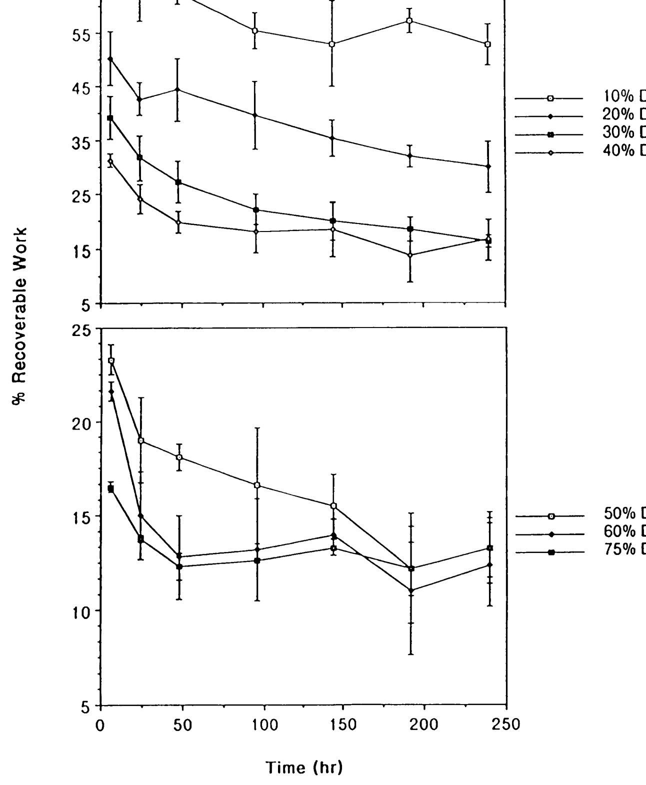

Fig. 2. Changes in percent recoverable work with time. Def. = deformation. Each data point represents a mean of three bread crumb specimens selected at random from 60–75 specimens per batch.

The loss in percent recoverable work over 240 hr after baking is shown in Figure 2. It is clear from this plot that the bread crumb lost its elastic property over time. The greatest loss occurred during the first 24 hr after baking; the loss was less drastic beyond this point. At a relatively low and moderate deformation (10–50%), the percent recoverable work decreased gradually with storage time, approaching different asymptotic levels. The loss in percent recoverable work at 60 and 75% deformation was insignificant beyond 24 hr after baking, whereas at lower deformation levels, some decrease in recoverable work was observed over the entire storage time studied. This result relates to the level of compression and its ability to destroy the bread structure. At a lower deformation, the damage was slight or moderate and, thus, some recoverable work was observed and its relative change during storage was evident. At 60 and 75% deformation, the percent recoverable work was the lowest (approximately 10–15%) among all deformations because of the collapse of the cell wall structure discussed earlier. Thus, when the compression damage to the bread structure was very high, the recoverable work was always low throughout most of the storage period.

CONCLUSIONS

Experiments were done to study the influence of storage time on the elastic properties of bread crumb. The bread crumb specimens were compressed to deformation levels of 10–75%. Percent recoverable work was found to decrease with deformation due to the increased structural damage to the bread structure. Percent recoverable work also decreased with storage time. Most of the changes occurred within the first 24 hr after baking, and subsequent changes were less evident, especially at 60–75% compression. Curves for 30–50% compression showed the most consistent changes over the entire storage period study, which perhaps suggests that this level of compression would be most useful to observe any loss in elastic properties during storage. It is evident that the bread lost its elastic property with time. This loss was probably an indication of textural change caused by staling and possibly some moisture loss. During the 240 hr of storage after baking, the bread lost about 5% of the moisture from the original value of 42% (total basis).

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