Creep-Recovery of Bread and Correlation to Sensory Measurements of Textural Attributes[1]

Lin Carson[2] and Xiuzhi S. Sun[2,3]

ABSTRACT

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Bread crumb firmness has been studied extensively with many instruments. Other texture attributes like springiness, cohesiveness, and adhesiveness can be obtained through sensory analysis or by texture analysis using texture profile analysis. In this study, mechanical analysis (MA) was used to study the creep-recovery of several commercial breads. A descriptive panel was used to analyze these attributes and the results were correlated to MA measurements. With use of a small probe force in the linear viscoelastic portion (50 mN), bread sensory firmness was correlated quadratically to MA creep deformation ($r^2 = 0.77$) and sensory springiness was correlated quadratically to the combination of MA recovery percentage and its rate ($r^2 = 0.82$). With use of a large probe force in the nonlinear viscoelastic portion (600 mN), bread cohesiveness was correlated linearly to the MA recovery percentage ($r^2 = 0.98$). These results indicate that the creep-recovery test can be used to determine some texture attributes of bread crumb.

Texture significantly influences the consumer's perception of good quality bread. The most important texture attributes of bread includes firmness (hardness), springiness, cohesiveness, and adhesiveness. Firmness is defined as the amount of force required to bite through bread samples; springiness is the degree to which the sample returns to its original size after partial compression; cohesiveness is the degree to which the mass holds together during mastication; and adhesiveness is the degree to which the bread sample sticks to the palate (Setser 1993). Bread crumb firmness has been studied extensively using various instruments such as the texturometer, Instron tensile testing machine, Voland-Stevens texture analyzer, baker compressimeter, precision penetrometer, and other texture analyzers (Friedman et al 1963; Bashford and Hartung 1976; Baker et al 1987; Bourne 1993). Other texture attributes such as springiness, cohesiveness, and adhesiveness are more difficult to measure instrumentally, unless using sensory methods or more complex instruments.

Texture profile analysis was used to measure these texture attributes with either an Instron tensile testing machine or a TA.XT2 texture analyzer (Bourne 1978; Meullenet et al 1998; Szczesniak 1998). Of the attributes, hardness was the only one with high correlations between sensory and instrumental measurements; springiness and cohesiveness show relatively low degrees of correlation (Szczesniak 1998).

The objectives of this study were to measure the creep-recovery of bread crumb using MA and to determine the relationships between MA measurements and sensory texture attributes of firmness, springiness, cohesiveness, and adhesiveness.

MATERIALS AND METHODS

Bread Samples

Six commercial breads representing a range of textures were used. They were white (Wonder, Interstate Brands Corp., Kansas City, MO), whole wheat (Earthgrains 100% whole wheat, The Earthgrains Co., St. Louis, MO); rye seedless, and dark pumpernickel classic (Pepperidge Farm, Norwalk, CT); and honey cocktail whole grain and rye cocktail (Rubschlager Baking Corp., Chicago, IL).

Creep-Recovery Measurements

Dynamic mechanical analysis (DMA) has been used to determine rheological properties of viscoelastic materials such as food. In this study, DMA was used to determine the recovery without utilizing dynamic force, and thus DMA was referred to as the mechanical analysis (MA). MA was used to measure the creep-recovery of the bread samples (DMA 7e, Perkin-Elmer, Norwalk, CT). A 15-mm parallel-plate probe was used, and the test was performed in a controlled temperature environment (25°C). A sample with 1- × 1-cm surface area was cut from each slice of bread (the thickness of slice remained the same as purchased), covered with a plastic film wrap, and taped carefully to the edge of the plate. The plastic film prevented the bread sample from losing moisture during the test. Preliminary compressive tests were performed to determine the force required for both linear and nonlinear viscoelastic portions for all the breads: 50 mN was within the linear viscoelastic portion, and 600 mN was in the nonlinear viscoelastic portion. For firmness and springiness, a 50-mN static force was applied to compress the bread, and then the bread was allowed to creep for 1 min. The static force then was decreased to 5 mN, and the bread was allowed to recover for 1 min. For cohesiveness, a 600-mN static force was applied to compress the bread, and then the same procedure for firmness and springiness was followed. Three samples (from three different slices) of each bread were tested as replicates.

Sensory Analysis on Bread Texture

A descriptive sensory panel consisted of eight panelists (one male and seven female, ages 28–68) who were randomly chosen. They were specially trained for 8 hr on the texture properties of bread. During training, the attributes as defined by Setser (1993) were discussed with bread references set in front of the panelists seated at a round table with normal lighting. The definition ballot is shown in Fig. 1.

For testing, the crumb of each bread sample was cut carefully into a 1-in. square and sealed in a 1-pint plastic bag (Ziploc, Racine, WI). A three-digit random number was assigned to each bread sample, and samples were served in a random order to the panelists. The panelists tested the firmness, springiness, adhesiveness, and cohesiveness of the bread samples in comparison to the references and marked their answers on a 1–15 cm structured line-scale ballot. Rinsing of the mouth and palate was done with deionized water between each sample. Three replicates were made for sensory analysis. Means and standard deviations for sensory analysis and MA results were calculated and used for regression analysis (Sigma Plot 4.0, SPSS Inc., Chicago, IL).

RESULTS AND DISCUSSION

Texture Definition from Creep-Recovery Test

Mechanical analogs composed of springs and dashpots can be useful in conceptualizing the viscoelastic behavior of bread crumb. The spring is considered an ideal solid element obeying Hooke's

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[1] Contribution 00-305-J from the Kansas Agricultural Experiment Station, Manhattan, KS 66506

[2] Dept. Grain Science and Industry, Kansas State University, Manhattan, KS 66506.

[3] Corresponding author. Phone:785-532-4077. Fax: 785-532-7010. E-mail: xss@wheat.ksu.edu

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Texture Attribute	Definition	References and Scores
Firmness	Analysis at first bite: degree of force required by the molars to penetrate sample.	WW = 2 and HBR = 8
Springiness	Analysis between thumb and forefinger: recovery speed and% of recovery as sample returns to original size and shape after partial compression between fingers. Degree of force used was less than that required to compress the bread beyond linear viscoelastic portion.	BSR = 12
Cohesiveness	Masticatory analysis: degree to which mass holds together at the most extreme point during the mastication process.	FB = 10
Adhesiveness	Analysis after compression between the tongue and palate: degree to which the product adheres to the palate.	HBR = 2 and WW = 14

Fig. 1. Texture attributes and corresponding sensory definitions, references, and scores used in evaluating bread texture. HBR = Holzofen Brot rye bread (Dillon's Bakery, Hutchinson, KS); WW = Wonder white bread (Interstate Baking Co., Kansas City, MO); FB = Farmer's bread (Rubschlager Baking Corp., Chicago, IL); BSR = Beefsteak soft rye bread (Interstate Baking Co., Kansas City, MO).

TABLE I
Sensory Texture Attributes of Commercial Breads

Bread	Firmness	Springiness	Cohesiveness	Adhesiveness
Honey cocktail	13.7c[a]	1.40a	2.83a	1.08a
Rye cocktail	13.1c	2.01a	4.02b	1.41a
Pumpernickel	6.86b	9.81bc	9.30c	8.54b
Rye	6.30b	11.0c	11.7d	11.4bc
Whole wheat	3.60ab	8.62b	11.8d	11.8bc
White	1.93a	13.0d	13.7e	13.8c

[a] Values followed by the same letter are not significantly different ($P < 0.05$).

TABLE II
Mechanical Analysis (MA) of Commercial Bread at 50 mN

Bread	D[a] (mm)	S1 (mm/min)	S1 × R[b] (mm/min)	S2 (mm/min)	R	S1 × S2[c] (mm/min)^2
Honey cocktail	0.11e[d]	1.3a	0.81b	–0.0015a	0.64bc	–0.0015b
Rye cocktail	0.13d	1.1a	0.51a	–0.0068b	0.45a	–0.0078a
Pumpernickel	0.56b	4.5c	3.0e	0.017c	0.62b	0.079d
Rye	0.19c	2.3b	1.7c	0.0096c	0.74c	0.022c
Whole wheat	0.93a	5.3cd	2.4d	0.041d	0.44a	0.18e
White	0.74b	5.1d	3.0e	0.036d	0.58b	0.21e

[a] D is point A – point B on the MA curve.
[b] Slope 1 (S1) × recovery (R), where R = (C – B)/(A – B) from the MA curve.
[c] Slope 1 (S1) × Slope 2 (S2).
[d] Values followed by the same letter are not significantly different ($P < 0.05$).

TABLE III
Mechanical Analysis (MA)[a] of Commercial Bread at 600 mN

Bread	S1 (mm/min)	S2 (mm/min)	R	S1 × S2 (mm/min)^2
Honey cocktail	6.02b[b]	0.021a	0.66e	3.98d
Rye cocktail	7.26b	0.023a	0.72e	5.23d
Pumpernickel	11.8c	0.50d	0.23c	2.68c
Rye	13.2d	0.46d	0.36d	4.69d
Whole wheat	7.52b	0.24c	0.11b	0.826b
White	4.85a	0.098b	0.061a	0.296a

[a] R = (C – B)/(A – B) from the MA curve. Slope 1 (S1) × recovery (R).
[b] Values followed by the same letter are not significantly different ($P < 0.05$).

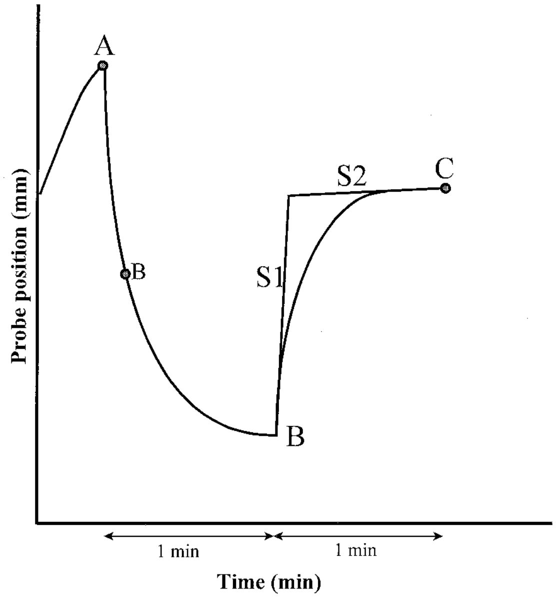

Fig. 2. General mechanical analysis creep-recovery curve of bread sample.

law, and the dashpot is considered an ideal fluid element obeying Newton's law. Connected in various ways, they can portray the behavior of viscoelastic materials (Steffe 1996). Elastic and viscous components are generally expressed by spring and dashpot components in most of the models. However, the bread crumb system was far more complicated, which was beyond the simplified Burger's model, a combination of the Maxwell and Kelvin models, recommended for describing viscoelastic material (Steffe 1996).

In the creep-recovery test at the beginning of a given constant force, the bread had an instantaneous change in strain from point A to B′ (Fig. 2) because of the elastic components. Then the bread started to creep at an exponential rate because of viscous and elastic components. After a certain time, the bread crept slowly because of the increase in energy potential stored in the elastic components and the reduction in energy potential stored in the elastic components which was absorbed by the viscous components. As the force became small or was removed completely, the bread recovered instantaneously because of the elastic components, resulting in the first slope. Then the bread continued to recover slowly (slope 2) because of an elastic retardation contributed by the elastic components. The viscous response from the viscous components caused a permanent deformation in the bread crumb.

The creep of the bread from point A to B (Fig. 2) can be used to indicate firmness. A firm bread such as honey cocktail offered more resistance from the elastic components, resulting in a small creep; thus, the displacement of the MA probe was small. In contrast, for a soft bread such as whole wheat, the resistance offered from the elastic components were small so the displacement of the MA probe was large. Therefore, bread firmness was defined as the displacement from point A to B from the MA curve. As the distance increased, bread firmness decreased.

At a small probe force in the linear viscoelastic portion such as 50 mN, the bread sprang back first because of the elastic components but was held back by the viscous components, resulting in slope 1 (S1) (Fig. 2). For a more springy bread, S1 would be larger, and for a less springy bread, S1 would be smaller because of the combined effects of the elastic and viscous components. The amount recovered at point C is also important in bread springiness. If the bread is more springy, meaning that either the complex elasticity is larger or the complex viscosity is smaller, the recovery distance from point B to C would be larger. Therefore, springiness of the bread was defined as a combination of S1 and recovery (R), where R is defined as the ratio of recovery (distance from B to C) to creep (distance from A to B).

TABLE IV
Relationships and Correlation Coefficient (r^2) Between Mechanical Analysis (MA)[a] and Sensory Results

	Linear		Nonlinear	
MA Measurement	r^2	**Model**	r^2	**Model**
50 mN probe force				
Firmness (Fm)	0.71	$Fm = -11.601\ (D) + 0.3597$	0.77	$Fm = 15.02 - 28.44\ (D) + 17.156\ (D)^2$
Springiness (Sp)	0.75	$Sp = 3.82\ (S1 \times R) + 0.3597$	0.82	$Sp = -3.93 + 10.59\ (S1 \times R) - 1.863\ (S1 \times R)^2$
600 mN probe force				
Cohesiveness (Co)	0.98	$Co = -15.9\ (R) + 14.545$	0.988	$Co = 3.818 - 9.64\ (R) - 7.83\ (R)^2$
Adhesiveness (Ad)	0.89	$Ad = -18.545\ (R) + 14.598$	0.9	$Ad = 13.178 - 6.321\ (R) - 15.3\ (R)^2$

[a] D = point A – point B on the MA curve. S1 = Slope 1 × recovery (R), where R = (C – B)/(A – B) from the MA curve.

At a large probe force in the nonlinear viscoelastic portion (600 mN), as the bread was pressed firmly, the crumb cells collapsed. If the bread is sticky or cohesive, the sticky force from the viscous components would be larger than that from elastic components, and the viscous components would inhibit the bread recovery, resulting in smaller S1, S2, and R. Therefore, cohesiveness of a bread could be expressed to some extent by the combination of S1, S2, and R.

Correlation Between MA and Sensory Measurements

Sensory texture results are shown in Table I. Honey cocktail and rye cocktail breads were the most firm, and white bread was the least firm. Distinguishing between high-firm and low-firm breads was easy. However, breads in the medium-firm range like whole wheat, rye and pumpernickel were difficult to differentiate by sensory analysis because of minute differences. Similar phenomena were observed in the analyses of springiness, cohesiveness, and adhesiveness. Breads with high firmness were less springy, cohesive, and adhesive. Breads like honey cocktail and rye cocktail had a tight, small cell structure, resulting in a dense and firm texture, whereas white bread had an open, bigger cell structure, resulting in a spongy, soft, and springy texture. White bread had the highest cohesiveness and adhesiveness. It interacted greatly with saliva and was so adhesive and cohesive that it rolled into a tight ball during mastication; some panelists even found it difficult to remove it from their palates. On the other hand, not only did the honey cocktail bread adhere poorly to the palate when compressed by the tongue, it also resulted in loose masses in the mouth. However, the panelists noted fewer chews and shorter time were needed to get to the extreme point of mastication for the white bread than for the honey cocktail bread. This indicates that the white bread may absorb saliva faster and dissolve faster in the mastication process. Formulation and baking conditions were the major causes of these texture differences and were beyond the scope of this study.

Features extracted from MA measurements at 50 mN and 600 nM are presented in Tables II and III. At 50 mN, the deformation from point A to B decreased as bread firmness increased. For breads with a large difference in firmness, such as honey cocktail (hard), rye (medium), and white bread (soft), sensory analysis was in good agreement with the MA measurements. However, for breads with similar firmness, such as white and whole wheat, the agreement between sensory and MA measurements was poor. In the latter case, sensory results varied among panelists because of the difficulty in differentiating between these similar breads (Table I). Nonlinear correlation ($r^2 = 0.77$) was higher than linear regression (Table IV).

The S1 value increased as bread springiness increased. White bread had high sensory springiness breads (Table I) and a large value of S1 × R (Table II). Again, panelists had difficulty in differentiating between breads with similar springiness, resulting in minor disagreement between sensory results and MA measurements. The combination of S1 × R gave the highest correlation between sensory results and MA measurements: $r^2 = 0.75$ for the linear relationship, and $r^2 = 0.82$ for the nonlinear relationship (Table IV).

Slopes 1 and 2 and recovery ratio R extracted from the MA measurements at 600 mN are shown in Table III. The negative value of S2 meant that the bread had less springiness or more cohesiveness, and the recovery of the bread crumb was held by the viscous components. As expected, the MA recovery decreased as cohesiveness increased. Sensory cohesiveness was correlated highly to the R values: $r^2 = 0.98$ for both the linear and nonlinear regressions. The correlation between sensory cohesiveness and S1 × R was ≈0.69 for both linear and nonlinear regressions.

Sensory adhesiveness had a good correlation with R values at 600 mN (Table III): $r^2 = 0.89$ for the linear regression and $r^2 = 0.9$ for the nonlinear regression. Based on the definition of adhesiveness, the MA creep-recovery should not physically measure the stickiness between the bread and surface of the probe and, consequently, would not be able to predict sensory adhesiveness. However, the sensory adhesiveness increased as the sensory cohesiveness increased among the breads tested (Table I), which could be the reason for the high correlation between sensory adhesiveness and R values.

CONCLUSIONS

The creep-recovery of bread as measured by the MA was correlated highly to bread sensory texture attributes. Sensory firmness was correlated to MA creep deformation, sensory springiness was correlated to the MA recovery slope 1 and ratio R, and sensory cohesiveness and adhesiveness were correlated to the MA recovery ratio R. A small MA probe force in the linear viscoelastic portion should be used to measure springiness, and a large MA probe force in the nonlinear viscoelastic portion should be used to measure cohesiveness. Further experiments could be conducted to study the relationship between bread texture attributes and the parameters of viscoelastic models to determine which model can be used to better express the bread crumb system.

LITERATURE CITED

Baker, A. E., Dibben, R. A., and Ponte, J. G., Jr. 1987. Comparison of bread firmness measurements by four instruments. Cereal Chem. 32:486-488.

Bashford, L. L., and Hartung, T. E. 1976. Rheological properties related to bread freshness. J. Food Sci. 41:446-449.

Bourne, M. C. 1978. Texture profile analysis. Food Technol. 32:62-66,72.

Bourne, M. C. 1993. Texture measurements on finished baked goods. Pages 134-151 in: Advances in Baking Technology. B. S. Kamel and C. E. Stauffer, eds. Blackie Academic & Professional: Glasgow, UK.

Brady, P. L. and Mayer, S. M. 1985 Correlations of sensory and instrumental measures of bread texture. Cereal Chem. 62:70-71.

Friedman, H. H., Whitman, J. E., and Szczesniak, A. S. 1963. The texturometer—New instrumentation for objective texture measurements. J. Food Sci. 28:390-392.

Meullenet, J. F., Lyon, B. G., Carpenter, J. A., and Lyon, C. E. 1998. Relationship between sensory and instrumental texture profile attributes. J. Sensory Stud. 13:77-93.

Mohsenin, N. N. 1986. Some basic concepts of rheology. Pages 128-224 in: Physical Properties of Plant and Animal Materials. Gordon and Breach Science: New York.

Murayama, T. 1978. Dynamic mechanical analysis of polymeric material. Elsevier-Scientific: Amsterdam.

Setser, C. S. 1993. Sensory evaluation. Pages 254-291 in: Advances in Baking Technology. B. S. Kamel and C. E. Stauffer, eds. Blackie Academic & Professional: Glasgow, UK.

Steffe, J. F. 1996. Viscoelasticity. Pages 294-349 in: Rheological Methods in Food Process Engineering. Freeman Press: East Lansing, MI.

Szczesniak, A. S. 1998. Sensory texture profiling—Historical and scientific perspective. Food Technol. 52:54-57.

Vodovotz, Y., Hallberg, L., and Chinachoti, P. 1996. Effect of aging and drying on thermomechanical properties of white bread as characterized by dynamic mechanical analysis (DMA) and differential scanning calorimetery (DSC). Cereal Chem. 72:264-270.

Weipert, D. 1997. Determining rheological properties of cereal products using dynamic mechanical analysis in compression mode. Cereal Foods World 42:132-137.

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