Texture Characteristics of Reheated Bread[1,2]

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ABSTRACT

Bread slices were reheated in a conventional oven, microwave oven, or steam chamber. Samples were evaluated for toughness subjectively and objectively, using a method developed for the Instron universal testing machine. Toughness was not simply a function of moisture content of the bread after reheating, but rather depended upon the method of reheating. The solubility of gluten protein from bread and gluten balls was determined in 1% sodium dodecyl sulfate containing various amounts of mercaptoethanol. Steamed bread and gluten samples gave lower solubilities than did the other samples at low levels of mercaptoethanol, indicating that they were more highly cross-linked by disulfide bonds.

Many consumers refreshen (heat) aged bread to reverse the "staling" phenomenon. The physicochemistry of such refreshening is not understood (Ghiasi et al 1984, Rogers et al 1988). With microwave ovens now in more than half of U.S. households (Schiffmann 1987), it would be desirable to use them for reheating bread. It is well known, however, that a slight amount of overheating causes a pronounced toughening. The mechanism of the toughening is unknown.

Several reports have been published on bread, pizza, cake, and pastry production using microwave ovens for either baking or reheating. However, most of those do not mention the texture characteristics of the final product (Fetty 1966, Decareau 1967, Chamberlin 1973, Lorenz et al 1973, Schiffmann et al 1979, Martin and Tsen 1981, Pei 1982).

Measuring the texture changes (toughening) that occur during microwave heating is difficult. Platt and Kratz (1933) used tensile strength to determine toughness in sponge cakes, and the same method has been applied for analyzing microwave-baked cakes (Neuzil and Baldwin 1962). Tensile strength is commonly used as a measurement of toughness in meats (Bouton et al 1975, Purslow 1985).

Another method often used for examining meat toughness is the Warner-Bratzler shear (Bouton et al 1975, Moller and Vestergaard 1987). Hill and Reagan (1982) applied this test for measuring toughness of cakes. Jones et al (1985) used a punch and die system to examine rubberiness in beefburgers.

Voisey (1977) characterized the deformation of bread using a Kramer shear-compression cell. First introduced by Kramer et al (1951) and later modified with semifloating angled blades (Voisey 1972), the shear-compression cell is used to analyze many different types of food products (Voisey 1977, Voisey and Kloek 1981, Karl and Schreiber 1985, Timbers et al 1985).

Only a few studies detail the changes in protein functionality related to microwave heating. When soy proteins were heated in a microwave, solubility in deionized water decreased from 80 to 17% (Hafez et al 1985). Dorfer and Eckert (1980) studied the effect of graduated microwave treatment on wheat flour. They found that when the flour was heated to temperatures over 80°C, its gluten-forming ability was lost. A decrease in protein solubility of 50% was noted. Accompanying those changes was a significant decrease in the number of thiol groups and an increase in disulfide groups.

Studies by Schofield et al (1983) showed that gluten proteins polymerize during conventional heating. The major changes in the glutenin fraction occur between 55 and 75°C. Above 75°C, the gliadin fraction also was affected. There was no increase in the number of disulfide groups, suggesting that the polymerization is the result of thiol-disulfide interchange.

One group (Higo et al 1981a,b, 1982, 1983a,b) attributed the toughening of bread heated in a microwave to the starch fraction. They found an increase in the degree of starch gelatinization, extractability of starch, and multiple changes in the shape and size of starch granules. Lipid extractability from microwaved samples was less than that from conventionally heated samples. All testing was done on model systems of starch or flour mixtures.

The purposes of this research were to study the changes in bread that occur during reheating with different methods, to develop a quantitative method for measuring such changes, and to try to determine mechanisms behind such changes.

MATERIALS AND METHODS

The flours used in this study were donated by Cargill Flour Milling Division, Wichita, KS. They had protein contents of 11.3 or 11.5% and ash contents of 0.44 or 0.46%. The gluten was 68% protein and 0.71% ash and was donated by Midwest Grain Products, Inc., Atchison, KS. Fermipan instant yeast was donated by Gist-Brocades, U.S.A., Charlotte, NC. Bread was baked by the standard straight dough pup loaf procedure (AACC 1983, method 10-10B), using 180 min of fermentation and 55 min proof. Other bread was purchased from local supermarkets.

Microwave-baked bread for the protein solubility study was also prepared by the pup loaf procedure (AACC 1983, method 10-10B). The dough was not molded but rather punched at 5/16 in. and placed as a slab onto a coated paperboard strip. After proofing for 55 min, the dough was microwaved 2 min, using a 700 W Sharp model R9360.

Gluten balls were made by mixing 10 g of gluten and 10 ml of water for 1 min on a micro-pin mixer (TMCO-National Mfg, Lincoln, NE).

Reheating of Breads or Gluten Balls

Loaves were cut into 1.27-cm thick slices. The center four slices from each pup loaf were used. Bread was microwave reheated by placing a single slice on an inverted styrofoam bowl, such that the bottom of the slice was 5 cm above the oven floor. The microwave oven was a 700W Sharp model R9360. This oven had a rotating carousel, which had been marked so that all samples were placed in the same position. Samples were heated on the highest power setting for the desired time and cooled on a covered wire rack at room temperature for 3 min prior to evaluation.

Bread was steamed by placing slices on a wire mesh supported over boiling water inside a turkey roaster. After the desired time, the slices were removed and cooled to room temperature on a covered wire rack before evaluation.

Bread was conventionally reheated by placing the slices on the grate of an air oven at 130°C. After heating for the desired time,

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the samples were immediately placed in Ziploc bags and cooled to room temperature before evaluation.

Slices of purchased bread were air-dried on wire racks for various times to provide a moisture series. Slices then were reheated to approximately 85°C in oven browning bags and allowed to cool before being tested.

The same reheating procedures were applied to gluten balls. Whole gluten balls were steamed or microwaved for various times.

Bread or Gluten Toughness

An untrained panel tested the samples of bread or gluten balls for their organoleptic properties, particularly first bite characteristics and resiliency with continued mastication.

The Instron universal testing machine was used in compression mode, with a 50-kg load cell and Kramer shear-compression cell attachment. The crosshead speed was 5 cm/min and the chart speed was 25 cm/min. A 4.13 × 5.72 cm rectangle was cut from the center of each bread slice after treatment. Gluten balls were pressed flat between two Teflon-coated boards for 1 hr. The gap between the boards was fixed at 6 mm, and bricks were used as weights. Samples were cut from the flattened gluten ball with a 2.85-cm i.d. cookie cutter. Peak force and shoulder force were measured from each tracing from the universal testing machine. Data reported are average values for at least four samples.

Samples of the bread or gluten that passed through the blades of the Kramer shear-compression cell were immediately weighed for a two-stage moisture analysis (AACC 1983, method 44-15A).

Protein Solubility

Flour or flour with minor bread ingredients was slurried or mixed into a developed dough and then lyophilized. Protein was extracted from lyophilized ingredients, dough, or crumb by solubilizing 1 g (14% moisture basis) in 30 ml of 1% (v/v) sodium dodecyl sulfate (SDS). Protein was extracted from lyophilized gluten doughs by the same procedure, using 0.5-g samples. Between 0 and 1.5% mercaptoethanol (ME) based on SDS volume was added.

The sample plus solvent was stirred at low speed (60 rpm) for 1 hr. Samples were centrifuged for 20 min at 3,000 × *g*, and the supernatant was decanted. In early studies, 10- or 20-ml aliquots of the bread supernatant or 3-ml aliquots of the gluten supernatant were pipetted directly into microKjeldahl flasks. Samples were dried overnight in an air oven at 130°C. Protein was determined by microKjeldahl analysis (AACC 1983, method 46-13). In later studies, the entire supernatant was decanted into Kjeldahl flasks, and protein was determined by Kjeldahl analysis (AACC 1983, method 46-10). The amount of soluble protein in the samples were expressed as percentage of the protein present in the gluten or bread crumb. All reported values are the averages of at least four replicates.

RESULTS AND DISCUSSION

Bread Texture Analysis

Three methods of reheating bread (steaming, convection oven, and microwaving) were studied. Steaming of bread slices for 15–75 min caused an increase in the moisture content from 42% (unheated) to as high as 54%. The eating characteristic of the steamed bread could best be described as noncohesive, i.e., the binding forces appeared to short-ranged, and the bread was easily masticated.

Reheating slices of bread in an air oven for 15–60 min decreased the moisture content to a range of 28–37%. The bread was dry on the surface, but gave no indication of toughness.

Microwaving bread slices for 5–30 sec also decreased the moisture content to a range of 33–39%, which overlaps the range of the conventionally heated samples. The microwaved bread could best be described as tough and rubbery; samples were very resistant to bite. There appeared to be long-range forces within the bread, and even with continued mastication, the bread remained cohesive. The crumb broke down into adhesive "balls" during mastication. Therefore, changes occur during microwave reheating that differ from those occurring during steaming or air-drying.

In tests of the one set of samples with the Kramer shear-compression cell, the first peak seemed related to organoleptic firmness of the bread. The shoulder seemed related to organoleptic toughness of the bread (Fig. 1). This quantitative method for bread toughness then was applied to two methods of reheating, using bread purchased at a local supermarket.

Steaming for 15 min slightly increased the moisture of the bread (Table I). Most of the increase appeared to be on the surface, as judged by the organoleptic gumminess and the large Kramer shoulder force. There was evidence of wet crumb sticking on the Kramer blades and cell. Steaming for 60 min raised the moisture level considerably and generally softened or shortened the bread texture, reducing the peak force. This agreed with previous organoleptic analyses.

Microwaving the bread decreased the moisture. Both the peak force (firmness) and the shoulder force (toughness) were increased. The question arose as to whether the decrease in moisture confounded the interpretation of the data, or if toughness was indicated by increases in both the peak and shoulder forces.

Influence of Bread Moisture on Kramer Analysis

The peak force decreased with steaming of the bread. It is known that reheating in sealed conditions in a conventional oven decreases the force required to compress a slice of bread (Ghiasi et al 1984). The bread used in the previous study had been purchased, and, therefore, its history was not known. We were interested in minimizing the effects of reheating or refreshening.

For bread slices dried for various times and reheated, an increase in peak force was observed as moisture decreased (Table II), but no real changes occurred in the shoulder force. Some moisture was lost even when the bread slices were not first air-dried, and a slight increase in peak force occurred simultaneously. Therefore, the Kramer shear-compression cell test differentiated between firmness, indicated by peak force, and toughness, indicated by shoulder force. The peak force relates directly to the bread's moisture content, whereas the shoulder force does not. The microwave-induced toughness was not due to decreasing moisture content.

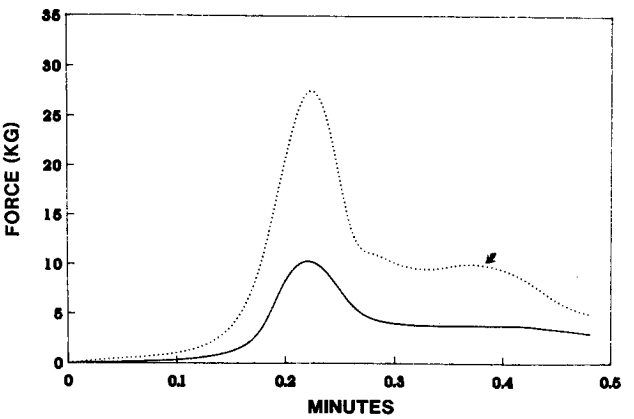

Fig. 1. Kramer shear-compression cell tracing of control bread (—) and tough bread (- - -). Arrow indicates shoulder force reading.

TABLE I
Initial Shear-Compression Cell Analysis of Bread[a]

Sample	Peak[b] (kg)	Shoulder[c] (kg)	Moisture (%)
Control	11.7	4.3	42.3
Steam			
15 min	7.7	12.7	45.5
60 min	6.0	4.6	54.5
Microwave 10 sec	21.7	18.8	35.4

[a]Commercial bread brand A.
[b]LSD 0.05 = 1.74.
[c]LSD 0.05 = 0.74.

Gluten Ball Texture Analysis

Because the continuous phase of bread is gluten, a study of how isolated (wet) gluten reacts to different forms of heating was undertaken. Steaming of gluten balls decreased the shoulder force, although the peak force was increased (Table III). The steamed gluten was very resilient to the first bite but had little extensibility. The gluten failed rather than extended when pulled. This behavior would be consistent with a more highly cross-linked material (Jeanjean et al 1980, LeGrys et al 1981).

Both peak force and shoulder force were increased by microwaving. When gluten was microwaved for even a short period of time, it became more elastic. Chewing the gluten ball that had been microwaved for 30 sec was like chewing a piece of rubber.

Both organoleptic and instrumental methods easily distinguished between gluten that had not been heated (control) and those that had been steamed or microwaved. Apparently most, if not all, of the changes observed during heating of bread are associated with changes in the gluten.

Protein Solubility of Gluten Balls

The physical properties of the gluten balls indicate that the gluten fraction is likely to be involved in the toughening of bread during heating in a microwave. Therefore, we measured the solubility of gluten in SDS solvents containing various amounts of ME. If the gluten were cross-linking by disulfide bonds during heating, then more ME would be required to solubilize the gluten. If the gluten were being cross-linked by other bonds, then the level of ME should not affect its solubility.

Mixing gluten into a dough increased the solubility in SDS (Table IV). Most of the samples were essentially 100% soluble in 0.5% ME. When short microwave heating time was used (10 sec), the protein solubility was identical to that of the unheated gluten. With increasing microwave heating time, solubility in 1% SDS decreased, indicating some additional cross-linking was occurring. However, upon addition of 0.5% ME to the SDS, all of the protein was soluble.

Steaming the gluten had a much greater effect. With short steaming times (15 min), only 33% of the protein was soluble in SDS. With 90-min steaming, the SDS-soluble protein decreased to 14%. Even 0.5% ME was not able to solubilize all of the protein. Virtually all of the protein was solubilized with 1% ME, indicating that the solubility decreased because of disulfide cross-linking.

Protein Solubility of Breads

The solubilities of dough ingredients and flour, whether slurried or mixed to optimum, were virtually identical. For simplicity, only the ingredients data are shown in Table V. The solubility of protein in SDS was decreased from 67 to 23% for conventionally baked bread, compared with the protein solubility of the dough ingredients. With a low level of ME, the ingredients were virtually all solubilized, although the protein solubility of baked bread remained lower at 68%. All of the bread protein becomes soluble in 1.5% ME (Hoseney et al 1987). Reheating a half-inch slice of conventionally baked bread in the microwave for 10 sec had little or no effect on the protein solubility.

Baking dough to bread in the microwave oven did not decrease the protein solubility compared with the unbaked dough (ingredients). The protein solubility of microwave-baked bread in SDS was almost double that of conventionally baked bread.

The samples steamed for 90 min were slightly less soluble in SDS and 0.5% ME than the conventionally baked bread. This indicates that the steamed samples were more highly cross-linked as a result of the holding time at elevated temperatures. These data are consistent with the report of Schofield et al (1983). Rheologically, higher cross-linking makes the bread shorter, so that it fails in extension.

Clearly, the microwave toughening effect is not the result of cross-linking by disulfide bond formation. If cross-linking had occurred, we would have expected differences in the protein solubilized with the lower concentrations of ME. In addition, all of the protein was solubilized in the presence of ME and SDS. This would not have been the case if covalent bonds other than disulfide bonds had formed during the heating. Hydrogen bond formation can be discounted because those bonds do not exist at temperatures near 100°C. Hydrophobic bonding, if it increases as a result of microwaving, could not be measured in this system because SDS is very effective in solubilizing proteins even at low concentration and would be expected to disrupt all hydrophobic bonds.

TABLE II
Influence of Bread Moisture on Shear-Compression Cell Analysis[a]

Sample	Peak[b] (kg)	Shoulder[c] (kg)	Moisture (%)
Control	6.4	1.1	40.1
Oven reheat	8.3	1.5	38.2
Dried and reheated			
dried 30 min	9.0	1.8	35.1
dried 60 min	10.0	1.2	33.1
dried 90 min	13.1	1.7	30.7
dried 120 min	18.9	1.8	25.0

[a]Commercial bread brand B.
[b]LSD 0.05 = 1.74.
[c]LSD 0.05 = 0.74.

TABLE III
Effect of Heating Gluten Balls on Shear-Compression Analysis

Sample	Peak[a] (kg)	Shoulder[b] (kg)	Moisture (%)
Control	7.6	3.0	52.9
Steam			
15 min	18.7	2.3	54.5
45 min	19.6	2.2	55.4
90 min	17.7	1.4	56.7
Microwave			
10 sec	8.4	3.3	52.2
20 sec	11.9	3.8	49.0
30 sec	16.7	5.2	46.2

[a]LSD 0.05 = 1.16.
[b]LSD 0.05 = 0.61.

TABLE IV
Effect of Heating Gluten Balls on Protein Solubility

Sample	% Soluble Protein[a]		
	0.0% ME[b]	0.5% ME	1.0% ME
Raw gluten	71.2	100.3	97.8
Mixed gluten	80.1	100.6	100.1
Microwave			
10 sec	83.6	102.3	99.0
30 sec	61.2	101.2	100.7
Steam			
15 min	33.6	100.1	96.9
90 min	14.4	89.1	98.7

[a]LSD 0.05 = 3.22.
[b]Mercaptoethanol.

TABLE V
Effect of Heating Bread on Protein Solubility

Sample	% Soluble Protein[a]		
	0% ME[b]	0.5% ME	1% ME
Ingredients	66.5	93.2	93.3
Baked bread	22.8	68.4	95.5
Microwave reheated	22.0	66.8	94.8
Microwave baked	37.2	92.0	97.7
Steam reheated	16.5	39.5	94.8

[a]LSD 0.05 = 3.22.
[b]Mercaptoethanol.

CONCLUSIONS

The Kramer shear-compression cell attachment on the Instron universal testing machine appears to be useful for measuring toughness. It is able to differentiate between firmness and rubberiness as defined by an untrained sensory panel.

There is a definite time-temperature relationship involved in the disulfide cross-linking (as measured by changes in protein solubility) of proteins in both gluten balls and bread dough. The longer the gluten is held at elevated temperatures, the more cross-linking occurs. With microwave heating, the time at high temperature is short, so very few cross-links are formed. Therefore, disulfide cross-linking of the proteins cannot explain the toughening of bread heated or baked in a microwave.

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