Measurements of Bread Firmness Using the Instron Universal Testing Instrument: Differences Resulting from Test Conditions

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ABSTRACT

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The Instron universal testing instrument (IUTM) was used to evaluate bread firmness as influenced by sample location, loci of compression, slice thickness, IUTM depth of compression, and presence of a crust. Crusted or crustless slices 13, 25, or 50-mm thick, cut from the center or 25 or 50 mm from the end of the loaf, were compressed 4 or 8 mm at the top, center, or bottom of the slice. Bread firmness measurements were influenced by slice thickness, depth of compression, presence of crust, and location of measurement. Deeper compression always gave higher firmness values regardless of the other factors. The larger value supposedly indicates firmer breads. Consistently, the thinnest slice (13 mm) had a higher firmness measurement when compressed 8 mm compared to 4 mm. When the two compression depths were compared, significant differences in firmness were found for both crusted and crustless slices 13 and 25 mm thick, regardless of location of measurement. The crust imparted resistance during compression, particularly when a compression depth of 8 mm was used with thin slices, and resulted in high firmness readings. No differences were noted in locations of measurement when the crust had been trimmed before compression. However, crusted samples cut 50 mm from the end of the loaf and compressed at the bottom exhibited higher values. A difference in firmness detected by the IUTM may have resulted from conditions of measurement rather than inherent differences within the loaf.

Firmness is an important sensory attribute of bread. Bice and Geddes (1949) concluded that firmness and crumbliness are related closely to the organoleptic assessment of staleness. Generally, bread softness is measured instrumentally with a Baker Compressimeter, or more recently with the Instron universal testing instrument (IUTM) (Bashford and Hartung 1976, Bourne 1979, Kamel et al 1984).

Research studies have illustrated that bread firmness is influenced by a variety of factors, including formulation (Marston and Short 1969, Short and Roberts 1971, Stutz et al 1973, McDermott 1974, Tenney 1978). Increased skim milk solids, for example, significantly increased the softness of the crumb (Platt and Powers 1940). Lorenz and Dilsaver (1982) showed that slice thickness and storage temperature affect compressibility. Short and Roberts (1971) and McDermott (1974) found that crumb firmness varies throughout the loaf, with the firmest crumb at the center of the loaf. Platt and Powers (1940) and Ponte et al (1962) reported that the center slice of the loaf has a firmer crumb than slices near the end of the loaf, but Platt and Powers warned that slices toward the end tend to be the most irregular in compressibility. They noted, further, that the softest part of a slice usually is found approximately one third the distance from the bottom, near the center of the slice.

The objectives of this study were to examine IUTM bread firmness measurements as influenced by sample location within the loaf, locus of compression within the slice, slice thickness, depth of IUTM penetration or compression, and presence of a crust.

MATERIALS AND METHODS

Standard loaves of unsliced white pan bread, packaged in plastic bags, were obtained 1 hr after baking from the American Institute of Baking. All loaves for one replication were from the same bake. A sponge and dough (60:40 ratio) procedure was used. The sponge was prepared with 60% enriched flour (11.5% protein, 14% mb), 33.6% water, 2.5% yeast, and 0.5% bromated mineral yeast food, and held at 24°C for 4 hr. The remaining ingredients: 40% flour, 24.15% water, 11.25% high-fructose corn syrup (42% conversion, 71% solids), 2% soy-whey milk replacer, 2% soy oil, 0.25% sodium stearoyl lactylate, 0.25% calcium propionate, 30 ppm ascorbic acid, and 2% sodium chloride (added at the end of the mixing) were mixed with the sponge for 7–8 min to optimal dough development using a commercial horizontal dough mixer. The dough temperature was 27°C and had a floor time of 25 min. Scaling weight was 0.55 kg (19.5 oz) before proofing at 43°C at 83 ± 3% rh to constant height. Loaves were baked in a Chubco (Bakers Equipment Winkler) 10-tray single lap oven for 21 min at 210°C. Wrapped breads were stored 12 hr at 21 ±2°C before sampling. Slices 13, 25, or 50 mm thick were cut from the loaf location specified in the experimental plan (Fig. 1). A separate loaf of bread was used for each slice. When the crust was removed, the bottom of the slice was marked with a red felt-tip pen. Three hours were required to slice, weigh, code, and repackage the bread samples. IUTM measurements were begun 16 hr after baking and required 2.5–3 hr to complete. Samples within each replication (bake) were measured at random to eliminate any biases which might arise because of the lapse of time between baking and measuring.

The IUTM (model 1122, with a 3.5-cm diameter head) compressed samples with crosshead and chart speeds of 200 mm/min and a full-scale load of 0.2 (20 kg). Intact slices with or without crust were compressed either 4 or 8 mm at the top, center, or bottom as shown in Figure 1. The IUTM was cycled to give three successive measurements (corresponding to peak heights 1, 2, and 3) for each sample.

Statistical Design and Analysis

A 2 × 2 × 3 × 4 treatment combination (with or without crust, compression depth, slice thickness, and sample location within the loaf, respectively) was used with a randomized complete block design to compare measurements from the different locations within the loaf on slices of varying thickness. Because the number of loaves available from the same bake was limited, a separate analysis was used to compare loci of compression on a slice. A split plot design with a 2 × 2 × 3 × 2 treatment combination (with or without crust, compression depth, slice thickness, and loci of compression within the slice, respectively) was used.

Three replications of the entire experiment were made, and data were tested using analysis of variance. When significant differences were found, least square means were calculated (SAS, 1982).

RESULTS AND DISCUSSION

In this study, bread firmness measurements differed depending upon test conditions: thickness of the slice, depth of compression, presence of crust, sample location, and loci of compression. An

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interaction ($P < 0.01$) among slices for thickness, compression depth, and crust was indicated by analysis of variance (Table I) when sample locations within the loaf were compared. All factors (slice thickness, location, compression, and crust) interacted ($P < 0.01$, Table II) when loci of compression were considered. Differences in firmness among loaves should have been minimal, since all breads of each replication were from the same bake and held under like conditions before firmness was measured. The differences in firmness which were observed may have been a function of the measurement conditions (compression depth, IUTM load, presence of crust, slice thickness) or may be attributed to sample location within the loaf.

Effect of Crust, Slice Thickness, and Depth of Compression

As one might expect, the crust influenced the degree of resistance exhibited by the sample being compressed, especially the bottom crust. The short depth of compression in relation to thickness of slice resulted in less "pulling" of the crust than the longer compression depth. As noted in Table III, mean peak heights of bread samples with crust 13-mm thick compressed 8 mm (62% compression) were significantly lower (indicated by unlike upper case letters on left, Table III) than for samples without crust; but 8 mm compression of 50-mm thick (16% compression) crusted samples resulted in significantly higher readings than for crustless samples compressed 8 mm. In this instance, the depth of compression was relatively slight compared to overall slice thickness; thus, the resistance imparted by the crust was somewhat less important than when the compression percentage was greater.

The mean peak heights given in Table IV (significance indicated by vertical line between means) show that, in general, the greater compression depth (8 mm) gave a higher reading, indicating greater firmness, than a compression depth of 4 mm. Resisting forces resulting from testing conditions that contribute to the higher IUTM values included the ratio of compression depth to slice thickness and the density of the crumb beneath the probe. Thus, the thinnest slice of bread compressed 8 mm gave a significantly higher sample firmness reading. A 13-mm thick slice compressed 8 mm was compressed 62%; consequently, the crumb under the probe was more dense than a sample compressed 16%. The denser crumb offered greater resistance to the downward force exerted by the compression probe. Resistance values for the thick (50mm) crustless slices compressed 4 mm (8%) in the center were not significantly different from those compressed 8 mm (16%).

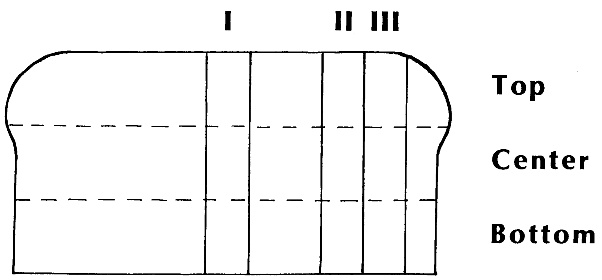

Fig. 1. Slices 13-, 25-, or 50-mm thick were cut from the three locations shown: center **(I)**, 50 mm from the end **(II)**, or 25 mm from end of loaf **(III)**. Loci of compression were at the top, center, or bottom of the slice. The crust was trimmed from half the total slices. Each slice was taken from a separate loaf, and a separate slice was used for each IUTM measurement.

Effect of Location of Measurement

Table V shows differences in firmness based upon the mean peak height when sample location and point of compression were compared for slices with or without crust. The peak heights of samples cut 50 mm from the end of the loaf and compressed at the

TABLE I

Analysis of Variance with *F* Values Used for Comparisons of Slice Thickness, Location Within the Loaf, Presence of Crust and Depth of Compression[a]

Source	Degrees of Freedom	Instron Measurements: Height 1	Height 2	Height 3	Mean Height
Replication	2	10.39 (0.0001)	9.93 (0.0001)	10.02 (0.0001)	10.21 (0.0001)
Thickness	2	127.49 (0.0001)	111.05 (0.0001)	110.55 (0.0001)	117.81 (0.0001)
Location	1	4.55 (0.0052)	4.18 (0.0081)	4.16 (0.0083)	4.34 (0.0067)
Thickness × location	2	0.90 NS	0.78 NS	0.80 NS	0.83 NS
Compression	1	225.13 (0.0001)	211.92 (0.0001)	215.94 (0.0001)	219.79 (0.0001)
Thickness × compression	2	71.56 (0.0001)	62.01 (0.0001)	60.96 (0.0001)	65.67 (0.0001)
Location × compression	1	1.58 NS	1.62 NS	1.39 NS	1.55 NS
Thickness × location × compression	2	0.63 NS	0.52 NS	0.51 NS	0.56 NS
Crust	1	0.99 NS	1.47 NS	1.35 NS	1.26 NS
Thickness × crust	2	4.59 (0.0126)	4.28 (0.0166)	4.26 (0.0170)	4.42 (0.0146)
Location × crust	1	5.78 (0.0012)	5.53 (0.0017)	5.80 (0.0012)	5.75 (0.0013)
Thickness × location × crust	2	0.71 NS	0.67 NS	0.73 NS	0.71 NS
Compression × crust	1	2.00 NS	1.51 NS	1.58 NS	1.72 NS
Thickness × compression × crust	2	4.94 (0.0091)	4.68 (0.0116)	4.64 (0.0120)	4.80 (0.0103)
Location × compression × crust	1	1.85 NS	1.82 NS	1.98 NS	1.89 NS
Thickness × location × compression × crust	2	0.96 NS	1.02 NS	1.02 NS	1.00 NS

[a] Levels of significance are given in parentheses; NS = not significant. Error mean squares, 94 degrees of freedom, were 0.015, 0.012, 0.010, and 0.012 for heights 1, 2, 3, and mean height, respectively.

bottom of the slice (Location II, Fig. 1) were significantly higher (Table V) when the crust was present than when the crust had been removed. When top and center locations were compared (Table IV), no significant difference was noted in the 25- or 50-mm thick samples with or without crust. Four sample locations are compared on Table V; no differences were noted (indicated by upper case letters on right) for location when the crust had been removed prior to compression. This finding is in contrast with the idea that the actual firmness of the bread differs at various locations in the loaf, and lends support to the conclusion that conditions of measurement alone might result in the differences in firmness reported in the literature. Even though most reported measurements have been made with the Baker Compressimeter, Kamel et al (1984) indicated that similar results were obtained with the IUTM. Earlier reports indicating a firmer crumb in the center of the loaf compared to end slices (Platt and Powers 1940, Ponte et al

TABLE II
Analysis of Variance with *F* Values Used for Comparisons of Slice Thickness, Loci of Compression Within the Slice, Presence of Crust and Depth of Compression[a]

Source	Degrees of Freedom	Instron Measurements: Height 1	Height 2	Height 3	Mean Height
Replication	2	2.46 (0.1090)	2.17 NS	2.31 NS	2.33 NS
Thickness	2	28.83 (0.0001)	24.97 (0.0001)	24.06 (0.0001)	26.25 (0.0001)
Location	1	1.84 NS	3.04 (0.0940)	3.78 (0.0638)	2.80 NS
Thickness × location	2	0.29 NS	0.58 NS	0.55 NS	0.45 NS
Compression	1	49.66 (0.0001)	45.55 (0.0001)	45.42 (0.0001)	47.34 (0.0001)
Thickness × compression	2	14.50 (0.0001)	12.53 (0.0002)	11.65 (0.0004)	13.05 (0.0002)
Location × compression	1	0.07 NS	0.07 NS	0.08 NS	0.10 NS
Thickness × location × compression	2	0.91 NS	2.47 NS	3.01 (0.0679)	1.90 NS
Crust	1	0.41 NS	0.62 NS	0.53 NS	0.51 NS
Thickness × crust	2	2.17 NS	2.01 NS	2.06 NS	2.10 NS
Location × crust	1	7.29 (0.0125)	14.12 (0.0010)	14.51 (0.0009)	11.56 (0.0024)
Thickness × location × crust	2	2.11 NS	4.02 (0.0312)	4.18 (0.0276)	3.32 (0.0533)
Compression × crust	1	0.63 NS	0.40 NS	0.46 NS	0.50 NS
Thickness × compression × crust	2	1.74 NS	1.53 NS	1.55 NS	1.62 NS
Location × compression × crust	1	1.53 NS	3.39 (0.0779)	4.19 (0.0517)	2.80 NS
Thickness × location × compression × crust	2	2.98 NS	7.46 (0.0030)	7.13 (0.0037)	5.44 (0.0113)
Crust × replication × thickness × compression[b]		4.93 (0.0001)	10.00 (0.0001)	10.06 (0.0001)	7.93 (0.0001)

[a] Levels of significance are given in parentheses; NS = not significant. Error mean squares, 22 degrees of freedom, used to test all sources of variation above were 0.030, 0.023, 0.020, and 0.024 for heights 1, 2, 3, and mean height, respectively.

[b] Error b mean squares, 24 degrees of freedom, used to test sources of variation below error a were 0.006, 0.002, 0.002, and 0.003 for heights 1, 2, 3, and mean height respectively.

TABLE III
Means[a] Comparing Slice Thickness, Depth of Compression, and Crust

Slice Thickness	Height 1			Height 2			Height 3			Mean Height		
	13 mm	25 mm	50 mm	13 mm	25 mm	50 mm	13 mm	25 mm	50 mm	13 mm	25 mm	50 mm
Without crust												
Depth of compression[b]												
4 mm	d0.212a	d0.118b	d0.135ab	d0.190a	d0.112a	d0.128a	d0.183a	d0.108a	d0.125a	d0.195a	d0.112a	d0.129a
8 mm	D0.989a	D0.276b	D0.216b	D0.837a	D0.248b	D0.202b	D0.791a	D0.242b	D0.197b	D0.872a	D0.255b	D0.205b
With crust												
Depth of compression[b]												
4 mm	d0.267a	d0.153b	d0.194ab	d0.239a	d0.143b	d0.181ab	d0.229a	d0.135b	d0.175ab	d0.245a	d0.143b	d0.183ab
8 mm	E0.803a	D0.336b	E0.317b	E0.685a	D0.308b	E0.293b	E0.648a	D0.296b	D0.281b	E0.712a	D0.313b	E0.297b

[a] Letters on the left are used to compare the four means within a column. Letters on the right are used to compare the three means within a row for each height. Unlike lower case letters on the left indicate a significant difference ($P < 0.05$) between samples with and without a crust when compressed 4 mm. Unlike upper case letters on the left indicate a significant difference ($P < 0.05$) between samples with and without a crust when compressed 8 mm. Unlike lower case letters on the right indicate a significant difference ($P < 0.05$) among slices of varying thickness when compressed 4 mm.

[b] Significant difference ($P < 0.05$) were found between means for like samples comparing 4 and 8 mm compression depths, with the exception of all 50-mm thick slices without crusts and for peak height 3 of the 50-mm thick slices with crusts. No comparisons were made among peak heights.

TABLE IV
Means[a] Comparing Slice Thickness, Depth of Compression, Crust, and Location of Compression

Slice Thickness Location[b]	Mean Peak Height					
	13 mm		25 mm		50 mm	
	Top	Center	Top	Center	Top	Center
Without crust						
Depth of compression[c]						
4 mm	d0.218a	d0.178A	d0.091b	d0.136A	d0.098b	d0.108A
8 mm	D0.737a	D0.924A	D0.250b	D0.239B	D0.200b	D0.143C
With crust						
Depth of compression[c]						
4 mm	d0.270a	d0.212A	d0.164a	d0.147A	e0.196a	d0.151A
8 mm	D0.719a	E0.560A	D0.321b	D0.268B	E0.346b	E0.282B

[a] Letters on the left are used to compare the four means within a column. Letters on the right are used to compare the six means within a row for each height. Unlike lower case letters on the left indicate a significant difference ($P < 0.05$) between samples with and without crust when compressed 4 mm. Unlike upper case letters on the left indicate a significant difference ($P < 0.05$) between samples with and without crust when compressed 8 mm. Unlike lower case letters on the right indicate that the means for slice thickness within the top location are significantly different ($P < 0.05$). Unlike upper case letters on the right indicate that the means for slice thickness within the center location are significantly different ($P < 0.05$). No comparisons were made among peak heights.
[b] Significant differences were found ($P < 0.05$) between means for the top and center location within the same slice thickness for only 13-mm thick slices compressed 8 mm with or without crust.
[c] Significant differences were found for depth of compression ($P < 0.05$) between means for samples with or without a crust compressed 4 and 8 mm in each instance except the 50-mm thick slices in the center location.

TABLE V
Means[a] for Comparing Location of Measurement and Crust

Sample Location		Height 1		Height 2		Height 3		Mean Height	
Loaf Location	Loci of Compression	With Crust	Without Crust	With Crust	Without Crust	With Crust	Without Crust	With Crust	Without Crust
I	Center	0.309a	0.363A	0.277a	0.318A	0.264a	0.304A	0.283a	0.328A
II	Bottom[b]	0.479b	0.313A	0.423b	0.276A	0.403b	0.263A	0.435b	0.284A
	Center	0.292a	0.315A	0.266a	0.280A	0.252a	0.269A	0.270a	0.288A
III	Center	0.298a	0.306A	0.267a	0.271A	0.256a	0.261A	0.274a	0.279A

[a] Unlike lower case letters on the right indicate a significant difference ($P < 0.05$) between samples with a crust from the four locations. Unlike upper case letters on the right indicate a significant difference ($P < 0.05$) between samples without a crust from the four locations. No comparisons were made among peak heights.
[b] Significant differences ($P < 0.05$) were found between samples with or without a crust within the same location when the bottom of the loaf was compressed.

1962, Short and Roberts 1971, McDermott 1974) or at the center of a slice compared to the bottom or top may need to be re-examined in light of this study.

CONCLUSIONS

Bread firmness measurements were influenced by slice thickness, depth of compression, presence of crust, and location of measurement. Consistently, the thinnest slice (13 mm) had a higher IUTM value when compressed 8 mm (62%) compared to 4 mm (30%). A compression depth of 8 mm gave a higher IUTM value than 4 mm regardless of presence of crust, thickness of slice, or location of measurement. The higher value, indicative of a firmer bread, probably results from greater crumb density under the probe rather than inherent bread firmness. The crust influenced resistance during compression, particularly when a compression depth of 8 mm was used, and augmented the firmness readings. No differences were noted among locations of measurement when crusts had been trimmed from samples before compression. Crusted samples cut 50 mm from the end of the loaf and compressed at the bottom exhibited higher values than crustless samples. The greater firmness was likely due to testing conditions since no significant differences were found in crustless samples, regardless of loaf or compression location.

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