An Optimum Compression Depth for Measuring Bread Crumb Firmness

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ABSTRACT

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Bread firmness evaluation with the Instron universal testing machine was performed on two distinctly different bread formulations and over a period of time in order to evaluate the sensitivity of various compression depths. The standard AACC method 74-09 was modified so that the firmness was measured at 5, 10, 15, 20, 25, and 30% of the 25-mm thick sample. A 3×2×2 factorial design was used, and the data were analyzed for variance and significant differences. As the degree of compression increased, so did the variability. This can be interpreted to mean increased sensitivity to changes in crumb firmness. Further analysis revealed that the 25% compression depth was most effective in detecting significant differences in firmness due to staling and bread formulation. The characteristics of the resulting compression curve are also discussed.

The importance of measuring bread crumb firmness or staling has long been recognized by the scientific community. Platt (1930), reported on a simple device that would quantitatively measure the physical changes (compressibility) of bread crumb. As the capabilities of these types of instruments increased through the years, so did the number of parameters controlling the test. These parameters typically include sample size, characteristics of deforming cell, rate of deformation, depth of deformation, and product storage temperature and time.

Many researchers have studied the effects of these parameters, agreeing on the necessity of standardizing and reporting the measurement conditions (Breene 1975, Bourne and Comstock 1981, Lorenz and Dilsaver 1982, Redlinger et al 1985, Baker et al 1986). In response to this need for standard conditions, the American Association of Cereal Chemists (1983) developed a method for use with the Instron universal testing machine (Baker and Ponte 1987) to determine the firmness of white pan bread crumb.

Baker et al (1986) determined that a 25% compression of a 25-mm thick slice of bread gave better firmness results than a 50% compression. Based on these results, a 25% compression of the 25-mm-thick sample was recommended for use in the standard AACC method. However, a compression less than 25% could prove to be more reliable or sensitive than the 25% compression. This study examines the effect of 5, 10, 15, 20, 25, and 30% compression depths on the sensitivity of the data and the characteristics of the Instron curve.

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MATERIALS AND METHODS

Bread Formulation

Two variations on a typical straight dough bread formula (Table I) were evaluated in this study. Formula 1 included 0.5% (based on flour weight = 100%) of sodium stearoyl lactylate (SSL) and an emulsified (mono- and diglycerides) shortening. Formula 2 bread was made with an all-purpose, nonemulsified shortening and without any SSL.

After baking, the loaves from both formulas were cooled for 1 hr, weighed, and volumes were measured by rapeseed displacement. The loaves were stored until tested, double wrapped in polyethylene bags, under ambient conditions.

Compression Test

Bread firmness was measured with an Instron universal testing machine (UTM, model 1000) according to the American Association of Cereal Chemists (AACC) standard method 74-09. The method was modified in that the firmness (amount of force required) was measured at 5% (1.25 mm), 10% (2.5 mm), 15% (3.75 mm), 20% (5.0 mm), 25% (6.25 mm), and 30% (7.5 mm) compression of the 25-mm-thick slice. The bread was evaluated one, four, and seven days after baking.

On each test day, two loaves from each formula were mechanically sliced 12.5 mm thick, both end slices discarded, and two consecutive slices stacked to form the 25-mm-thick sample. Seven samples were tested from each loaf. The center of each sample was compressed by approximately 40% (10.0 mm), allowing the compression curve to be drawn out beyond the 30% compression depth. The firmness values were then measured from a line extended down to the baseline from the first slope of the curve. This eliminated the area of the curve that represented an uneven loading of the crumb on the plunger surface.

TABLE I
Straight Dough Formulation[a]
(% flour weight basis)

Ingredients	Formula 1	Formula 2
Flour (11.2% protein)	100	100
Water	65	65
Compressed yeast	3.5	3.5
Salt	2	2
Sugar	6	6
Nonfat dry milk	2	2
SSL[b]	0.5	...
Shortening	(Emulsified) 3	(Nonemulsified) 3

[a]Mix time = 13 min (225 rpm, Union Glen Mixer); dough temperature = 90° F; floor time = 20 min; scaling weight = 19½ oz. (AMF divider, model 2 PKT); intermediate proof = 10 min (AMF no. 1022); Crossgrain molder (Marion Corp.); proofed 54 min, batch 1, and 61 min, batch 2; baked 16 min at 450° F (Middleby Marshall reel oven); specific volume: batch 1 = 5.49 cm^3/g and batch 2 = 5.29 cm^3/g.
[b]Sodium stearoyl lactylate.

Statistical Analysis

The resulting firmness data were analyzed via analysis of variance as a 3 × 2 × 2 factorial using PROC ANOVA in the Statistical Analysis Systems manual (SAS 1982). The firmness values were also plotted by day and by degree of compression in order to determine the effect of each depth on the compression force.

RESULTS AND DISCUSSION

Mean Values

The mean firmness values of both bread formulations for each degree of compression and by each day evaluated are given in Table II. For both formulas 1 and 2, as the bread aged, the crumb firmness increased, and the amount of increase was about the same for all degrees of compression. The firmness values for the formula 2 bread (without crumb-softening agents) were significantly higher than the corresponding values for the formula 1 bread. For each day tested and for each bread formulation, the crumb firmness increased as the percent compression increased.

These changes in crumb firmness over time are graphically illustrated in Figure 1. The increase in firmness for the formula 1 bread over the seven-day shelf life was basically linear, but the changes in the formula 2 bread included both linear and quadratic effects, showing more rapid changes between days 1 and 4 than between days 4 and 7. Figure 1 clearly shows that as the degree of compression increased, the amount of force required increased, regardless of the day or formula.

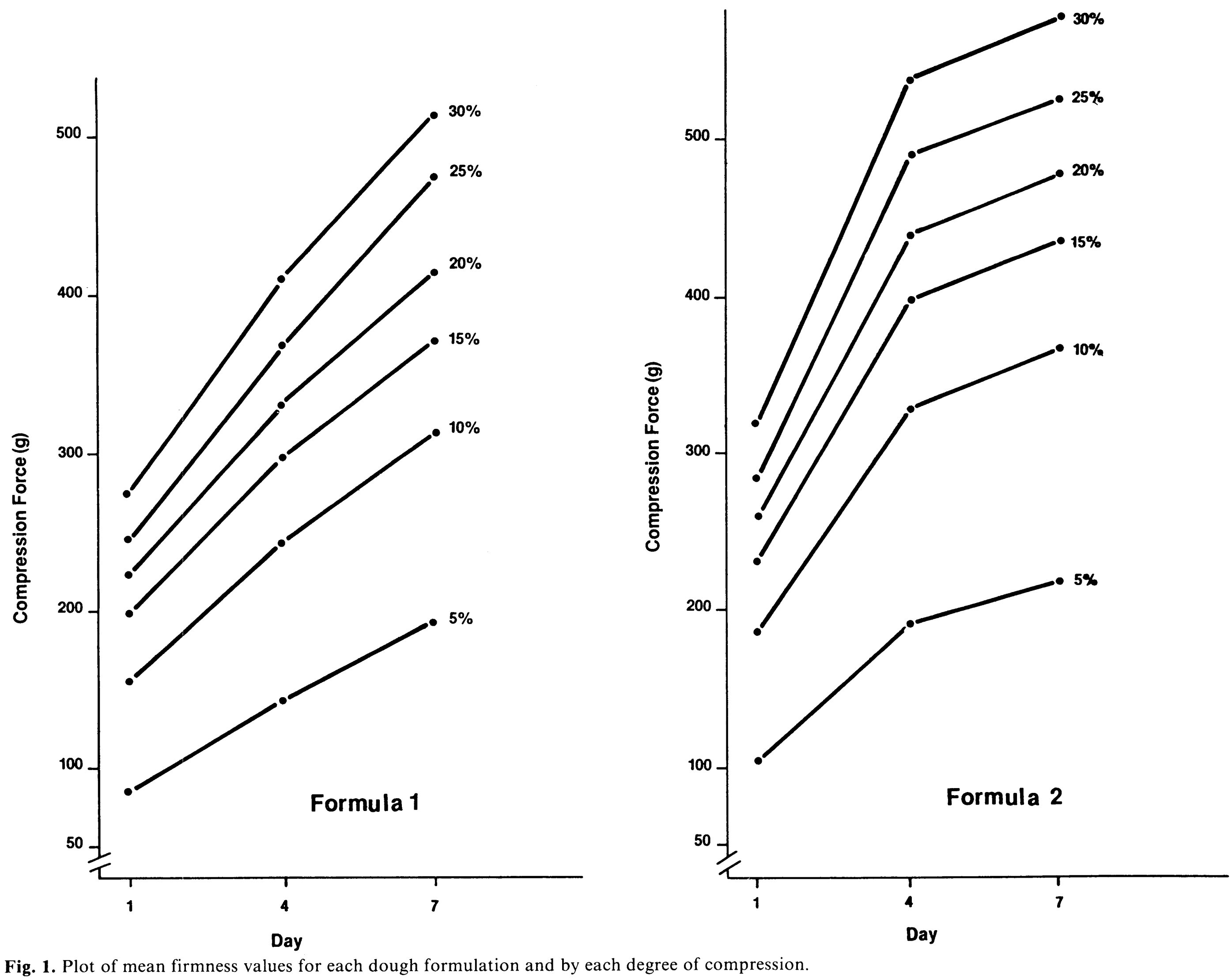

Fig. 1. Plot of mean firmness values for each dough formulation and by each degree of compression.

Analysis of Variance

An analysis of variance table for each degree of compression is given in Table III. The R^2 values for each degree of compression were generally very good, indicating the fit of the statistical model to the actual data was good. Estimates of the variances (σ^2) between the two loaves for each day-formula combination for the different degrees of compression are reported as the mean square error (MSE). The MSE nearly doubled when the compression increased from 5 to 10%. In general, the MSE increased as the degree of compression increased, indicating increasing sensitivity to changes in crumb firmness.

Another indicator of the variability at each compression depth is the coefficient of variation (CV), which describes the amount of variation relative to the mean force. The 5% compression was the highest (14.56). The CV decreased with each increase in compression depth.

The effects of staling (day), dough formulation (formula), and the interaction of these two effects (day × formula) on each degree of compression are also given in Table III. Although the effect of day was significant ($P \leqslant 0.05$) for each of the compression depths, the 20, 25, and 30% compressions were more sensitive to this effect as shown by the higher F values and lower probabilities. The significance of the day effect indicated that the differences between the firmness of the breads as they aged, were discernible with each of the compressions.

At the 95% confidence level ($P \leqslant 0.05$), all of the compression depths were able to detect differences between the two bread formulations. However, the day × formula interaction effect was not significant for any of the compression depths, which indicated that the bread staling rate was relatively uniform for both bread formulations. The 25% compression depth had the highest F value and lowest probability for each of these effects, indicating that this compression was more sensitive in each case.

TABLE II
Mean Firmness[a] For Each Formula by Day

Formula	Day	Degree of Compression (%)[b] 5	10	15	20	25	30
1[c]	1	85.0	155.7	198.9	223.6	245.4	275.4
	4	142.9	243.6	296.1	331.4	368.6	411.8
	7	193.2	313.2	373.2	414.3	465.4	515.4
2[d]	1	103.6	186.4	231.8	259.3	284.6	319.6
	4	192.9	330.4	398.6	440.4	489.6	538.9
	7	228.2	368.6	436.1	478.2	527.1	578.6

[a] $n = 14$.
[b] Percent of total slice thickness of 25 mm.
[c] Bread made with crumb softening agents.
[d] Bread made without crumb softening agents.

Least Significant Difference Test

A least significant difference test (LSD) was performed on the data to determine the significant differences among the three days evaluated (day effect) and among the two bread formulations (formula effect). For this test, the mean firmness values that are not significantly different from the other values within each compression depth are identified with the same letter.

For the day effect (Table IV), only with the 5% compression could all three days be distinguished. However, for the 5% compression, the variation within the values for each day was

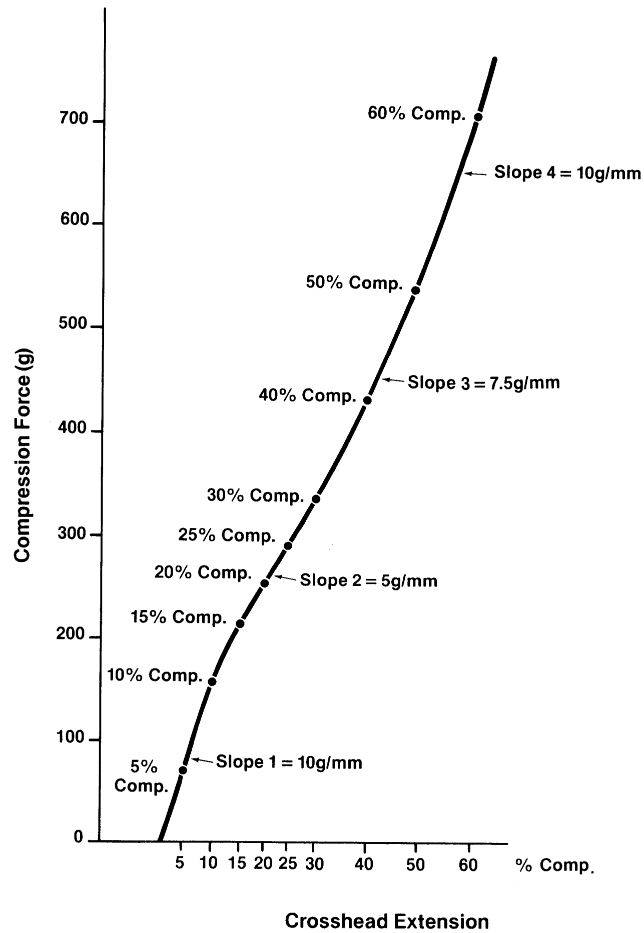

Fig. 2. Universal testing machine compression curve for white pan bread. The position of each degree of compression is identified on the curve, as well as the slopes of each distinct area of the curve.

TABLE III
Analysis of Variance

Statistic	Degree of Compression (%)[a] 5	10	15	20	25	30
R^2	0.91	0.92	0.92	0.92	0.93	0.93
Mean Square Error	527.13	1,049.23	1,401.74	1,485.80	1,662.76	1,989.16
Coefficient of variation	14.56	12.16	11.61	10.77	10.28	10.14
Day						
F Value	26.31	28.71	26.89	29.82	34.05	33.18
Probability[b]	0.0011	0.0008	0.0010	0.0008	0.0005	0.0006
Formula						
F Value	6.78	9.49	9.34	9.76	9.89	9.23
Probability[b]	0.0404	0.0216	0.0223	0.0205	0.0199	0.0229
Day × formula[c]						
F Value	0.47	0.75	0.87	0.92	1.07	0.95
Probability	0.6469	0.5109	0.4656	0.4490	0.3994	0.4389

[a] Percent based on total slice thickness of 25 mm.
[b] Significant if $P \leqslant 0.05$.
[c] Interaction effect between the day and batch effects.

small, causing the LSD value to be small. With the smaller LSD, the differences between the means appeared large, indicating significant differences among all three days for this degree of compression. The other compression depths only distinguished between days 1 and 4 and days 1 and 7, but not between days 4 and 7. All of the compression depths significantly distinguished between formulas 1 and 2 in the LSD test for the formula effect (Table V).

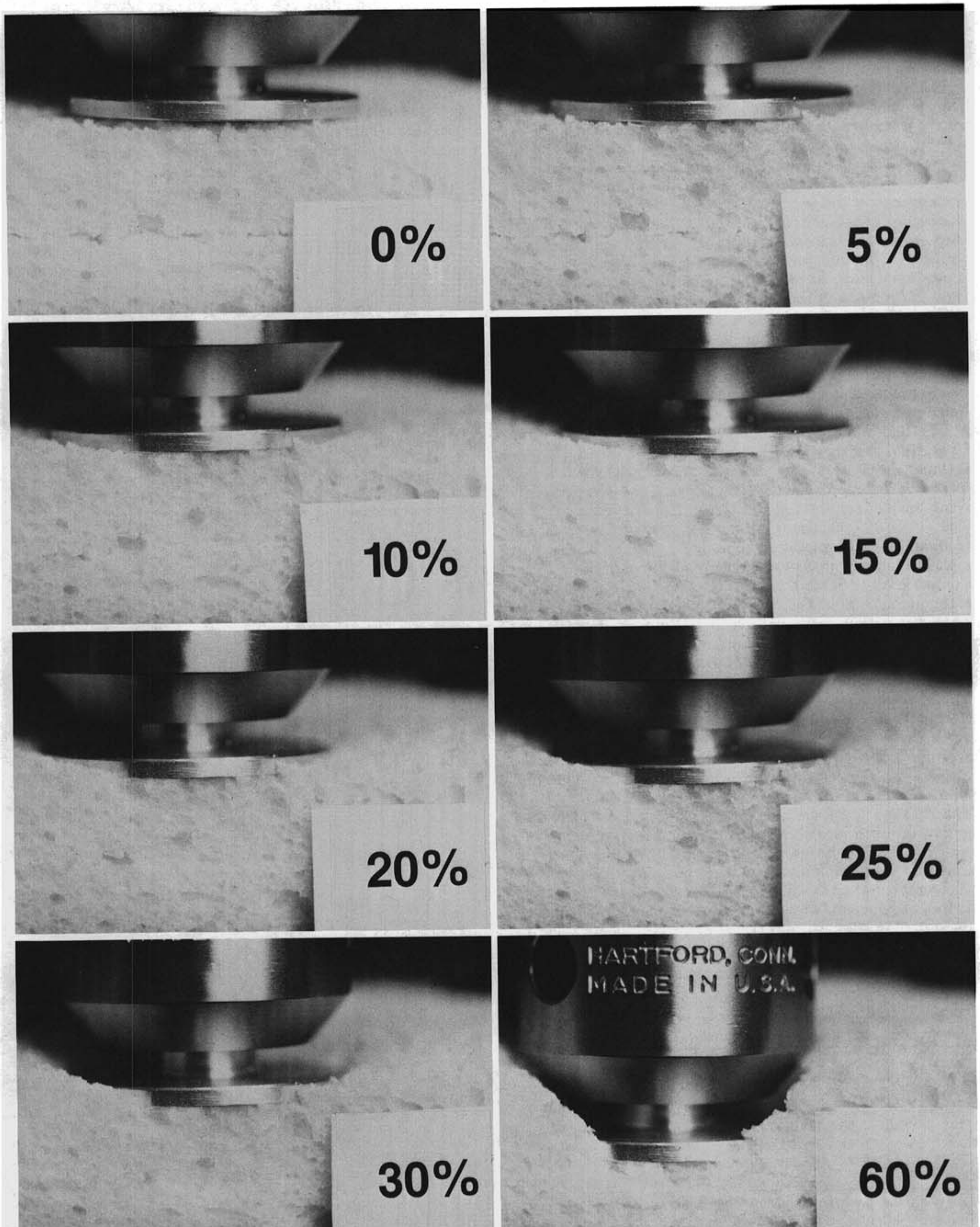

Fig. 3. Photographic series showing white pan bread compressed to different degrees.

Examine Figure 2 to better understand how the firmness values were affected by the compression depth. This is a typical firmness curve for a three-day-old sample of a standard (sponge dough) white pan bread, compressed to an extreme of 60% of the 25-mm thickness. This curve and the areas identified on it are characteristic of all bread firmness curves. The position where each compression occurred is marked on the curve.

Since the increase in the compression force was not strictly linear, the slopes of each of the four distinct sections of the curve were measured. The first portion of the curve or slope 1 was 10 g/mm, indicating a rather rapid rise in the force, and included the 5% and possibly the 10% compressions. This area of the first slope occurred from the slice surface to approximately 2.5 mm deep. At this depth, the surface of the bread was barely compressed, and the force value may have actually reflected the amount of surface tension or elasticity (Walker et al 1987) in the crumb instead of a true compression.

The second area of the curve, or slope 2, had a slope of 5 g/mm. This portion of the curve showed a slowing in the rate of force resisting deformation and included the 15, 20, 25, and 30% compression depths. At this point, the elasticity or tension of the surface cells most likely was released or reduced, causing the rate of rise in force to slow down because the crumb resistance (due to a true compression of the crumb directly beneath the plunger) decreased.

Once the true compression ended at about 30%, the next slope (slope 3) occurred at a rate of 7.5 g/mm. Perhaps a shearing and compression of the crumb occurred at this point since the plunger was 8.75–12.5 mm (35–50%) below the surface of the slice. The final portion, or slope 4, had a slope of 10 g/mm, the same as the first slope. The 60% (15 mm) compression occurred in this portion of the curve and represents the compacting of the crumb directly beneath the plunger.

The effect of each compression depth on the bread crumb surrounding the plunger was photographically recorded (Fig. 3). A sample of white pan bread was sliced in half and positioned so that the crumb directly beneath the plunger could be observed during the compression test. The plunger was aligned just above the surface of the slice so that the load readout registered 0 g of force at 0% compression. The plunger was then lowered to each degree of compression and held there only long enough to photograph the effects of each compression depth.

The 5% compression depth (Fig. 3) shows the plunger on the surface of the slice, but not visibly compressing the crumb structure beneath the surface. When the deformation was increased to 10%, the crumb was beginning to be compressed; however, the deformation of the crumb was visibly observed at about 15% compression.

The 20 and 25% compression (Fig. 3) show increasing compression of the crumb beneath the plunger. Although some shearing of the crumb was evident for the 30% compression, the crumb was mostly compressed beneath the plunger. The extreme 60% compression shows some shearing at the edge of the plunger but mostly compaction of the crumb directly beneath the plunger.

Figure 4 shows the position of each compression depth along the compression force curve for each of the days evaluated. Again, these curves (from the formula 2 bread) are characteristic of all bread firmness curves, and are representative of the curves obtained when using the AACC approved method 74-09 (AACC 1983). As the age of the bread increased, the rapid ascent of the first slope of the curve also increased. The 5% compression occurred in this portion of the curve for each of the three days. The 10% compression occurred at the point of inflection in the curve where the slopes are changing or at the release in the elasticity/tension of the crumb. Both the 15 and 30% compressions occurred at the inflection points of the curves on days 4 and 7 because these inflection areas become more pronounced or elongated as the bread aged. The 20 and 25% compressions remained in the slope 2 area throughout the testing period, which indicated that the force readings from these compressions were more reliable.

TABLE IV
Least Significant Difference Test[a] for Day Effect, Both Formulas Combined

Day	Degree of Compression (%)[b]					
	5	10	15	20	25	30
1	94.3 a	171.1 a	215.4 a	241.4 a	265.0 a	297.5 a
4	167.9 b	287.0 b	347.3 b	385.9 b	429.1 b	475.4 b
7	210.7 c	340.9 b	404.6 b	446.3 b	496.3 b	547.0 b
LSD[a]	39.7	56.0	64.8	66.7	70.6	77.2

[a] Means with the same letter within each compression depth are not significantly different at the 95% confidence level, based on the least significant difference (LSD) value given.
[b] Percent based on total slice thickness of 25 mm.

CONCLUSIONS

As the bread crumb aged, the amount of force required to compress the crumb increased. The greatest increase in force over

TABLE V
Least Significant Difference Test[a] for Formula Effect, All Days Combined

Formula	Degree of Compression (%)[b]					
	5	10	15	20	25	30
1	140.4 a	237.5 a	289.4 a	323.1 a	359.8 a	400.8 a
2	174.9 b	295.1 b	355.5 b	392.6 b	433.8 b	479.1 b
LSD[b]	32.4	45.8	52.9	54.5	57.6	63.0

[a] Means with the same letter within each compression depth are not significantly different at the 95% confidence level, based on the least significant difference (LSD) value given.
[b] Percent based on total slice thickness of 25 mm.

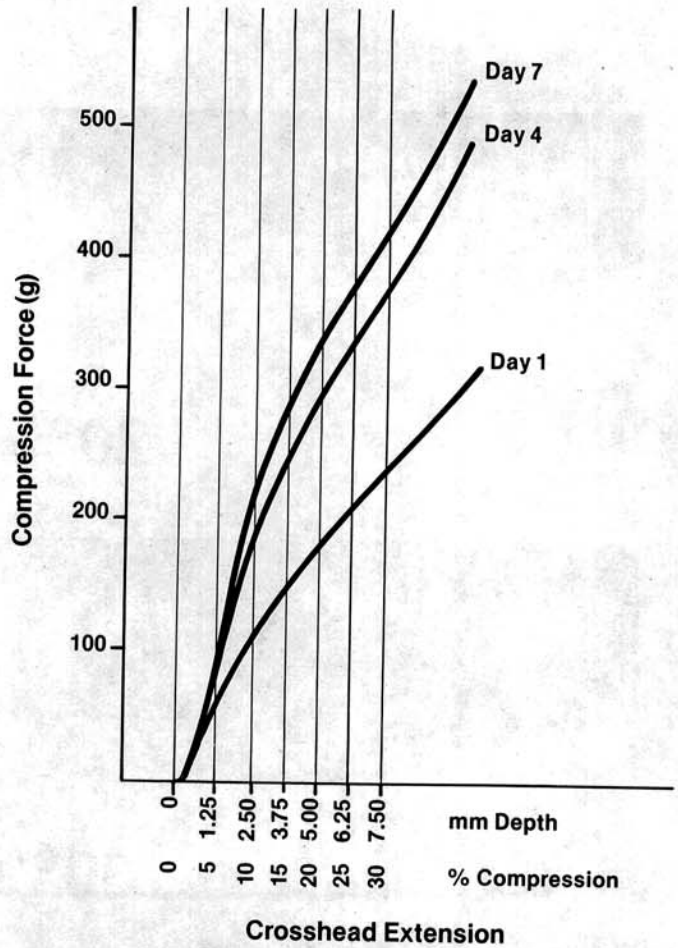

Fig. 4. Universal testing machine compression curves for white pan bread evaluated one, four, and seven days after baking.

the seven-day storage period was between days 1 and 4 after baking. The crumb firmness also increased as the degree of compression increased.

Some variability in the data is desirable since it indicates sensitivity to changes in crumb firmness either due to staling or formulation. However, this should not be the only factor used to determine the appropriate compression depth. The analysis of variance of the data showed that the 25% compression was sensitive, not only because of a high variance (MSE) but also because of the larger *F* values and lower error probabilities for each of the partitioned effects. The AACC method 74-09 specifies a 25% compression depth. Based on the results given here, this compression is an acceptable depth to measure the firmness of bread crumb.

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