Texture Changes in White Bread: Effects of Processing and Storage

ULLA STÖLLMAN AND BIRGIT LUNDGREN[1]

ABSTRACT

Cereal Chem. 64(4):230–236

Eight judges evaluated the texture attributes of the crust and crumb of white bread produced under four different sets of time-temperature conditions during preparation and fermentation of the dough, and stored from zero to seven days at room temperature (20° C). Hardly any sensory texture differences could be observed between the production lines in the freshly baked loaves that were evaluated after 2 hr. During the first two days of storage, however, the crust of bread made on the slowest production line (the longest times and the lowest temperatures) was significantly more brittle, and the soft core of the loaf was larger than in bread made on the faster production lines. Later during storage these differences disappeared, overshadowed by the effect of storage time. Storage at room temperature in aluminum foil wrapping had a more marked effect on the crust than on the crumb. The brittleness of the crust decreased drastically during the first 24 hr of storage. At the same time the crust got tougher, with maximum toughness after about 24 hr of storage. The effects of increased storage time on the crumb were a decrease in softness, the ability to roll it into a ball, and an increase in crumbliness and dryness. Maximum springback of the crumb was seen at one day of storage, and maximum stickiness to teeth after from one to three days of storage. Instrumental compression measurements of the crumb also were made using the Instron universal testing machine. Significant effects of both fermentation conditions and storage time were observed.

During the past two or three decades, the Swedish bakery industry has evolved from many small local bakeries to a few large-scale bakeries. Today 60% of all bread is produced by three industrial bakeries. A consequence of large-scale production is a process design that is sometimes controlled by requirements other than the best possible aroma, taste, and textural properties. The need to serve large distribution areas has created demands for better keeping quality. The objective is bread that keeps its freshly baked aroma and texture longer than today's products.

The overall changes taking place in bread during storage, generally termed staling, have been investigated for several decades. Attempts have been made to retard the staling process by changing the product formulation, the processing technique, or the packaging.

The various factors that influence the staling process have been reviewed by Maga (1975), Kulp and Ponte (1981), Kim and D'Appolonia (1977), and D'Appolonia and Morad (1981). Processing conditions and their influence on the staling rate have been reported by Waldt (1968), Kirk (1965), and Kulp (1979).

Axford and co-workers (1968) studied the effect of loaf volume on the rate of staling and found that a smaller specific volume increased the staling rate, whereas higher volumes had a reducing effect. Maleki and co-workers (1980) also found that bread with a larger loaf volume was softer initially and stayed softer during storage than did bread with smaller volume. The relationship between specific volume and firmness of the crumb has also been investigated by Wasserman and Vogt (1977).

Sensory evaluation techniques are widely used to describe the textural properties of bread. The most commonly used method is quantification of the overall impression of texture (Orr et al 1982). The texture profile method was reported by Elgedaily (1982). Using a profile of 15 descriptors, he characterized the influence of added soy protein on the textural properties of bread. Descriptive sensory analyses of bread texture have also been performed by Marsh and Pierson (1980). They used 11 terms to describe textural differences in commercial white bread. Seven descriptive words described crumb texture and four described crust texture.

Instrumental compressibility measurements of bread crumb to measure staling caused by treatment and storage are described in many papers. Maleki and Seibel (1972) compared the panimeter and the penetrometer as instruments for measuring the rate of staling. They found that the results from the penetrometer are well correlated to the sensory analyses. The penetrometer was used to measure the influence of α-amylase, fat, emulsifiers, and different wheat varieties on bread staling.

Instrumental techniques have also been used to study the influence of other properties, such as loaf volume, moisture content, protein quality, and storage conditions on the staling process. Such studies have been carried out by Waldt (1968), Wassermann (1973), Maleki and Seibel (1974), Thomas and Juretko (1973), Knorr et al (1976), Zaussinger and Scheiblauer (1978), Maleki et al (1980), Neukom and Rutz (1981), Lorenz and Dilsaver (1982), and Roewe et al (1982).

The aim of this project was to study the effect of different time-temperature conditions during preparation and fermentation of the dough on the sensory aroma, flavor, and texture of white bread, and on the keepability of the bread during storage at room temperature. The results of the aroma and flavor study are presented elsewhere (Stöllman 1986), and the results of the texture evaluations are reported in this paper. To complement the sensory evaluations, instrumental texture measurements of the crumb were also carried out.

MATERIALS AND METHODS

Bread and Experimental Variables

White bread was made according to the following dough formulation, which is a commonly used basic recipe in large-scale bakeries in Sweden: 100 parts (weight basis) wheat flour (11.9% protein); water, 59; yeast, 5; salt (NaCl), 1.5; sucrose, 2; and margarine, 2. All ingredients were poured into a Bjorn Varimixer 30/15 and mixed for 7 min (2 min at 80 rpm and 5 min at 200 rpm). The dough was bulk-fermented in a cabinet with a bowl of water placed at the bottom to give off some humidity. It was then divided into six pieces of 450 g each, which were allowed to rest for 5 min before they were molded into loaves in a long molder (Glimek LM-1; Glimakra, Sweden). The loaves were proofed in a chamber (Lillnord; Dahlén International, Sweden) at approximately 85% rh, placed on the stone in a stone hearth oven, and baked for 25 min (230° C). Steam was injected into the oven during the first 90 sec. Four samples were produced, referred to as production lines I through IV, by varying the time and temperature conditions during dough preparation and treatment according to the data given in Table I. This investigation was one part of a larger project where the different production lines were primarily chosen in order to study the influence of fermentation and proofing conditions on formation of flavor compounds in bread. Therefore, four fixed fermentation temperatures were chosen, from very low, 25° C, to very high, 45° C, and two in between. On the bases of these temperatures, adequate times to get proper loaves were chosen. Production line II corresponds to processing conditions commonly used by large-scale bakeries in Sweden. After baking, the bread was allowed to cool at room temperature for 2 hr, after which each loaf was wrapped in aluminum foil and placed in a temperature-controlled storage room (20° C). Samples were then

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[1] SIK, The Swedish Food Institute, P.O. Box 5401, S-402 29 Goteborg, Sweden.

removed for texture analyses after 2 hr (= 0 days), 1, 2, 4, and 7 days of storage.

Sensory Evaluation

Sensory method. Sensory texture evaluations were made on bread slices according to a descriptive technique developed jointly by the panel leader and panel members during introductory sessions preceding the actual experiment. Because the list of attributes considered necessary to describe the samples became very long, the evaluation was divided into two parts; procedures A and B (Fig. 1). Procedure A involved manual evaluation of the crumb (compression and "kneading") and oral evaluation (biting and chewing) of the crust; procedure B involved manual evaluation of a whole slice and oral evaluation (biting and chewing) of the crumb. The intensity of each attribute was judged using a scale consisting of a 10-cm unstructured line. The judges were allowed to indicate intensity anywhere long the line. Anchor terms were given at both ends of the scale (1 cm from the end points). They are given within parentheses in Figure 1.

Sample Preparation and Presentation

Using a manual slicer (model Brutus, Nils-Johan), slices about 16-mm thick were cut from each loaf and the ends discarded. To minimize drying, the bread was not sliced until just before a sensory session (15–30 min before). The slices were put in racks and placed in odor-free, 4,000-ml plastic boxes (one box/judge) that were kept shut at all times, except when a slice was removed. Two loaves per experimental sample were used for each session.

Because only one production line could be produced per day, samples of the same age but of different lines could never be presented together in the same sensory session. For this reason, a sample production plan was developed to provide samples of different production lines but with approximately the same age range (i.e., both fresh and stale bread) to each session, and ensure that one replicate of all 20 experimental samples (4 production lines × 5 storage times) was completed before the next one commenced. A total of three replicates was performed. The time order of the four production lines was randomized within each replicate. The judges were to receive three experimental samples in each session. They first received one set of three samples to evaluate according to procedure A, then another set of the same three samples (in a different order and with different code numbers) to evaluate according to procedure B. A sample consisted of one slice, and the two slices given to one judge for procedures A and B, respectively, were always taken from the same loaf. All samples were given two-digit random code numbers and were presented in random order.

Judges. Eight judges, five of whom were staff members, participated. Most of them had experience in sensory testing of food, however, not with bread. All eight judges participated in the introductory test sessions.

Statistical treatment. All intensity evaluations were transformed into scores 0.0–10.0 by measuring the length in centimeters from the left end of the scale to the mark made by the judge. The measurements were made with a digitizer (Hewlett Packard, 9111A). For each attribute, the score was subjected to a three-way analysis of variance, ANOVA, with the following variables: production lines (L), storage time (S), and judges (J), and the interactions L × S, L × J, S × J, and L × S × J. When the ANOVA showed a significant main effect for L or S, a Duncan's multiple range test was applied to determine which sample averages were significantly different.

The size of the soft center of the bread slice indicated by the judge (Procedure B, Attribute 9) was measured by using the above-mentioned digitizer and a computer program for calculating areas. Averages were calculated and transferred to relative values (in %) by dividing the average value by the area of the pictured slice on the form (which was almost natural size). The same ANOVA as mentioned above was performed for the area values.

TABLE I
Dough Processing Conditions

	Production Line			
Condition	I	II	III	IV
Dough temp., °C	22	26	30	33
Bulk fermentation time (min)/temp., °C	45/25	30/30	25/30	20/35
Proofing time (min)/temp., °C	50/33	40/38	35/40	25/45

Instrumental Texture Measurements

Compression measurements were made on crumb samples with an Instron universal testing machine (model 1122) provided with a 50 newton load cell. A cylindrical crumb sample (diameter 46 mm, height 16 mm), cut from the middle of a bread slice, was placed between two parallel plates that were larger than the sample. The sample was compressed to 50% of its original height at a deformation speed of 50 mm/min, and the compression curve was recorded. At this deformation level, the crosshead was stopped, and the force relaxation curve was recorded during 60 sec. The sample was then unloaded at the same speed as before. This

PROCEDURE A

You will be given three coded samples of sliced bread. For each sample you are asked to do the following:

Crumb

Attribute 1 Place the slice flat on the bench. Press down on the bread crumb in the center of the slice gently with your middle finger, remove the finger, and watch how the bread returns to its original shape. Evaluate the speed of springback (scale anchors: slow and fast).

Attribute 2-3 Remove the crust with the knife provided. Compress the remaining crumb with your finger to about half of its original height (5-8 mm) and evaluate the softness of the crumb, (2) in the center of the slice, and (3) at the upper part of the slice, i.e., just below where the crust has been (scale anchors: little and much).

Attribute 4 Tear a piece of the crumb from the center. Crumble it between your fingers and evaluate its crumbliness (scale anchors: little and much).

Attribute 5 Take another piece of crumb from the center. Try to knead the material into a ball and evaluate how easy it is to do this (scale anchors: difficult and easy).

Crust

Attribute 6-7 Bite through a piece of the crust with your front teeth (use only one layer of the crust; not several layers), and evaluate (6) the difficulty to bite through (scale anchors: easy and difficult), and (7) the brittleness of the crust (scale anchors: little and much).

Attribute 8 Chew another piece of the crust with your molars and evaluate its toughness (scale anchors: little and much).

PROCEDURE B

You will be given three coded samples of sliced bread. For each sample you are asked to do the following:

Whole Slice

Attribute 9 Place the slice flat on the bench. Feel the whole surface of the slice. Indicate the size of the soft center area(s) of the slice by drawing a contour line on the "map" of a bread slice on the form.

Attribute 10 Lift the slice, compress it from "top to bottom" between your thumb and forefinger and evaluate its softness. (Scale anchors: little and much).

Crumb

Attribute 11-12 Cut the slice into halves with the knife. Bite through the crumb with your front teeth from the center of the slice and evaluate its softness (11) and dryness (12) at the first bite (scale anchors: little and much.)

Attribute 13 Continue to chew the sample (or take another sample of the remaining half). Evaluate how much the sample sticks to your teeth (scale anchors: little and much).

Fig. 1. Procedures and instructions to the panel for sensory evaluation of bread samples.

deformation cycle was repeated once with the same sample. The following texture parameters were determined from the force/deformation curves: the initial compression force of the first cycle, denoted F1; the force after 60 sec of relaxation, F(60); and the compression force of the second cycle, F2. A rough estimate of the degrees of elasticity was obtained by calculating the ratio: 100× F(60)/F1 (Peleg 1979). The deformation energy for cycles 1 and 2 was measured as the area below the compression curve for cycles 1 and 2, respectively (W1 and W2).

The measurements were made on five slices from one loaf, and a total of three replicates from each production line and storage time were investigated. The determinations were performed at the same time as the sensory evaluations. These data were subjected to the same statistical analyses as the sensory data.

TABLE II
Results of Sensory Analyses: Three-Way Analyses of Variance

	Significance Level for Variable[a]		
Sensory Attribute	Production Line (df = 3)	Storage Time (df = 4)	Production Line × Storage Time (df = 12)
Procedure A			
Crumb (manual)			
1. Springiness	ns	0.001	ns
2. Softness (center)	ns	0.001	ns
3. Softness (upper part)	ns	0.001	0.05
4. Crumbliness	ns	0.001	0.001
5. Kneading into a ball	ns	0.001	0.01
Crust (oral)			
6. Difficulty to bite through	ns	0.001	ns
7. Brittleness	0.001	0.001	0.001
8. Toughness	ns	0.001	ns
Procedure B			
Whole slice (manual)			
9. Area of softness	0.001	0.001	0.05
10. Softness (whole slice)	ns	0.001	0.01
Crumb (oral)			
11. Softness (center)	ns	0.001	0.01
12. Dryness	ns	0.001	ns
13. Stickiness to teeth	ns	0.001	ns

[a] The third variable was judges. ns Denotes a significance level >0.05.

Loaf Volume

The loaf volume was measured by rapeseed displacement. Three replicates from each production line and storage time were investigated. The specific volume of a loaf was calculated by dividing the volume by its weight.

RESULTS AND DISCUSSION

Sensory Evaluation

The results of the sensory evaluation are shown in Figures 2–5, and of the three-way ANOVAs in Table II. A highly significant effect of storage time was obtained for all attributes, implying that there was at least one significant difference among the five overall averages for the experimental variable storage time (S) given in Table III. For several attributes (Table II), the data showed a significant interaction between production line and storage time (L × S), implying that the effect of storage time was different on the different production lines. However, with two exceptions (7 = brittleness of the crust, and 9 = softness area), there seems to be no consistent interaction pattern: the curves for the four production lines I–IV (Figs. 2–5) appear to cross each other in a random way. It was therefore concluded that there was no real interaction. One important exception is the attribute brittleness of the crust, where production line I bread generally was perceived most brittle during

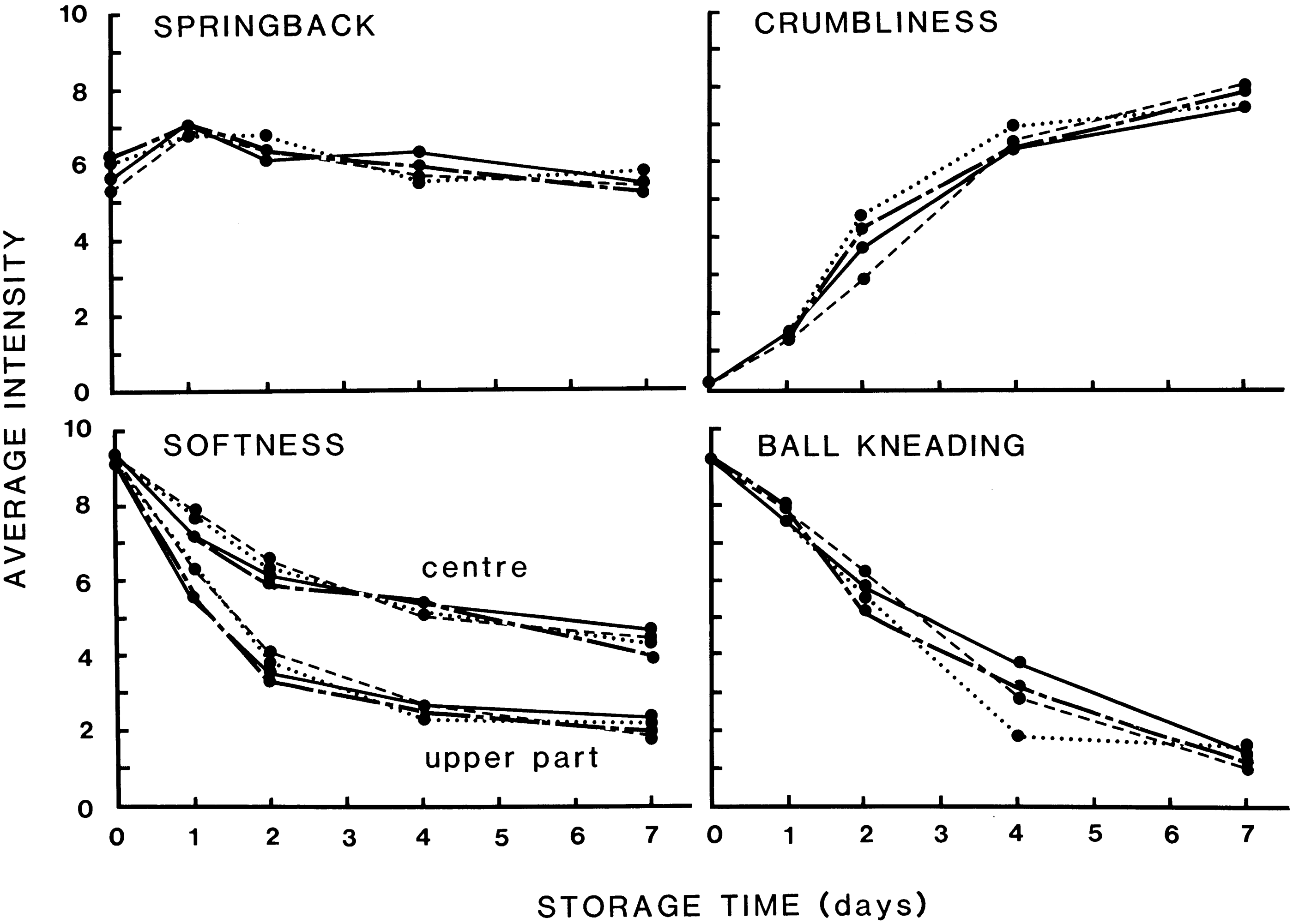

Fig. 2. Results of manual texture evaluations of bread crumb. Procedure A, average intensity vs. storage time (n = 8 judges × 3 replications).

storage, particularly after 1–2 days of storage (Fig. 3). A supplementary two-way ANOVA, performed on the 1-day-old bread samples, showed that production line I gave a significantly ($P < 0.001$) more brittle crust than the other three production lines, which did not differ significantly from one another. The same result was obtained for 2-day-old samples. The area of softness, the second important exception, also showed that production line I was significantly different from the other lines. The soft center remained larger during storage than in the three other, nondiscriminable production lines. To the consumer, and also according to the present data, a brittle crust and a soft crumb are signs of freshness in white bread. It is therefore concluded that production line I, the slowest proofing, retains the freshness of the bread better than the other production lines, and it is thought that this type of bread would be preferred by the consumer. According to the present data, a change from production line II to I would give bread that keeps fresh longer, whereas a change to production

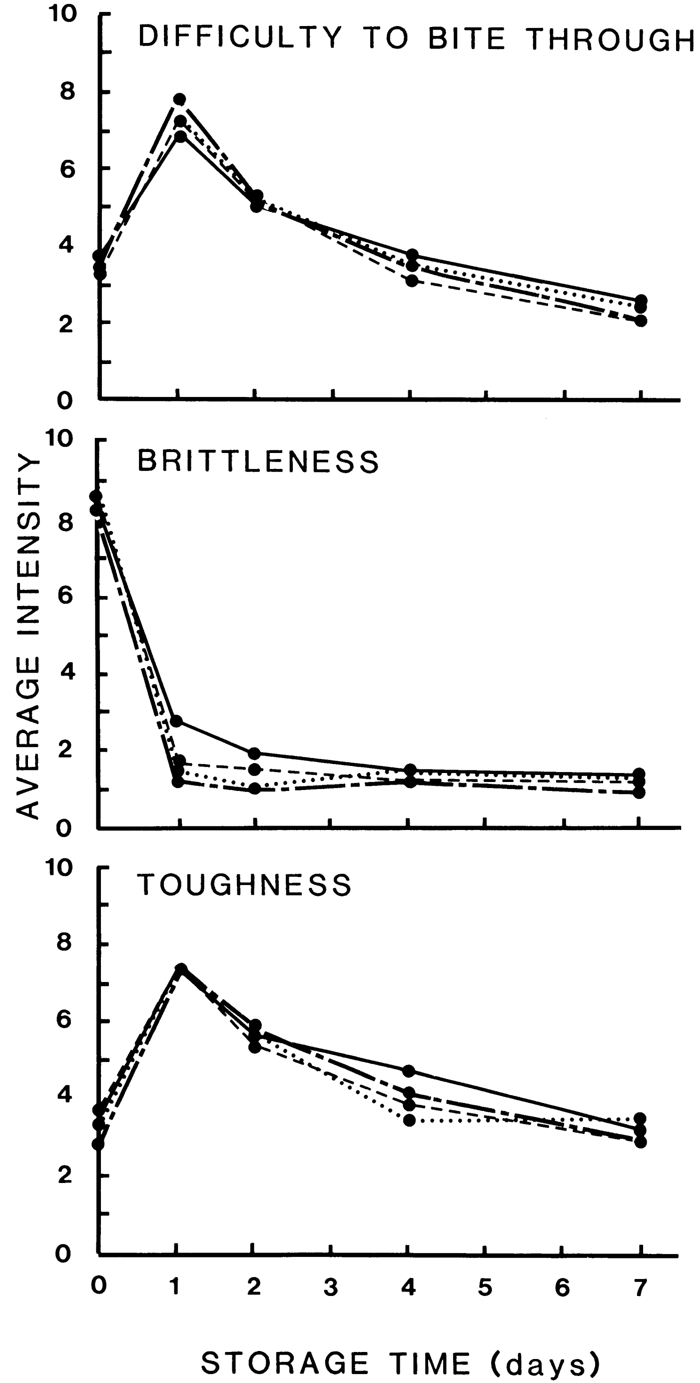

Fig. 3. Results of oral texture evaluations of bread crust. Procedure A, average intensity vs. storage time (n = 8 judges × 3 replications).

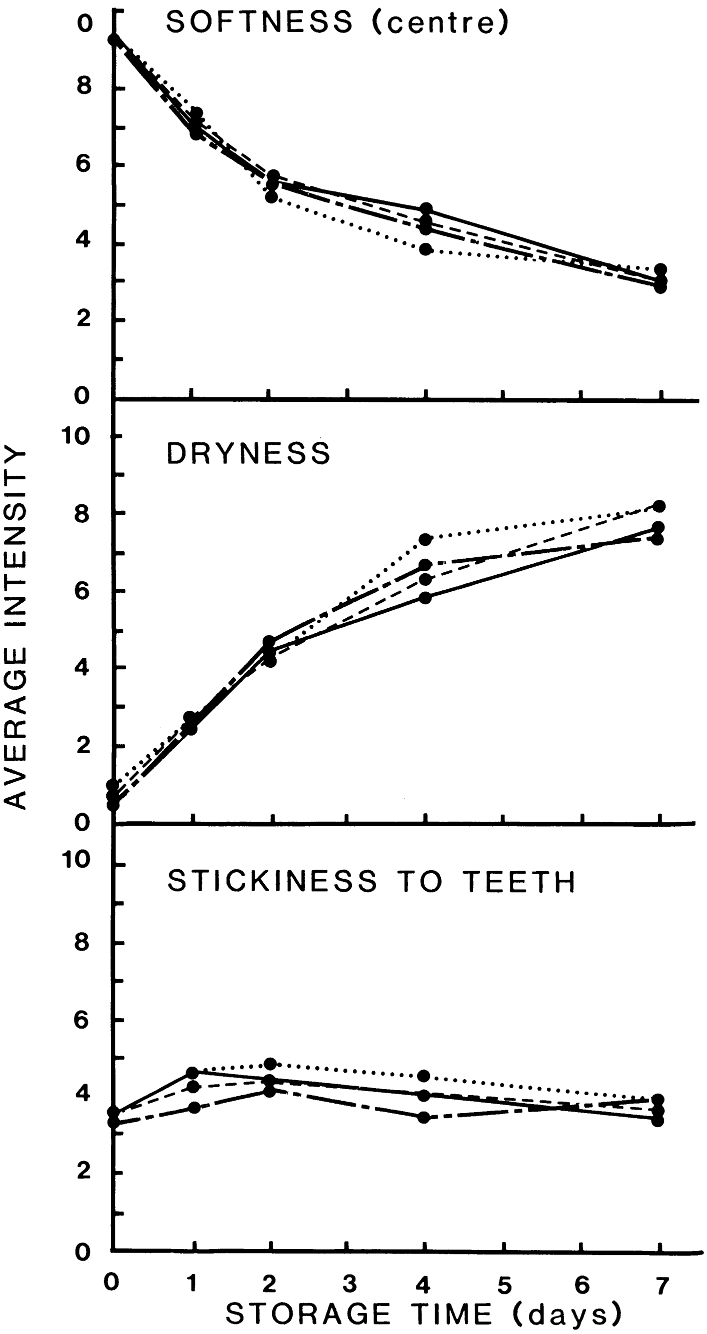

Fig. 4. Results of oral texture evaluations of bread crumb. Procedure B, average intensity vs. storage time (n = 8 judges × 3 replications).

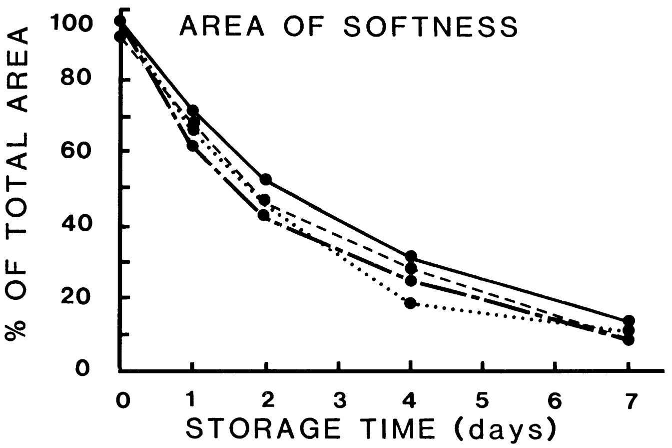

Fig. 5. Results of manual texture evaluations of bread crumb. Average intensity vs. storage time (n = 8 judges × 3 replications).

III or IV would give no perceptible difference. The significantly lower specific volume of production line IV, discussed below, showed that time-temperature changes in the direction of faster proofing give denser bread.

Because only small, and mostly nonsignificant, differences between production lines were shown, the data for the four production lines were pooled into overall averages (Table III), and the effect of storage time was studied for these averages. Storage time generally had a highly significant effect on the texture (Table II), with the following types of relationships (Figs. 2–5 and Table III).

Crust. The brittleness of the crust decreased rapidly with increased storage time, while the difficulty to bite through and toughness attributes had a pronounced peak at about 1 day of storage. The two latter attributes were highly correlated ($r = 0.97$).

Crumb. Both manual and oral evaluations of softness (attributes 2, 3, 10, 11) showed that the softness decreased with increased storage time. The ease to knead it into a ball also decreased, whereas crumbliness and dryness increased. The springback attribute showed a small peak at about 1 day of storage, and the stickiness to teeth a small peak (plateau) at around 1–3 days of storage.

The magnitude of the effect of storage time on softness was different for the the different parts of the bread crumb. The lower left graph of Figure 2 shows that all parts of the crumb were equally soft when the bread was only hours old, and that the center of the bread remained softer (attribute 2) during storage than the part closest to the crust (attribute 3).

The judges also indicated the size of the soft center of the bread (attribute 9). It decreased with increased storage time (Fig. 5). Note that this was not an evaluation of the degree of softness.

High correlation coefficients (r values) were obtained for the

TABLE III

Results of Sensory Analyses: Overall Averages and Results of Duncan's Multiple Range Tests

Sensory Attribute	At Storage Time (days)[a] 0	1	2	4	7	Curve Shape
Procedure A						
Crumb (manual)						
1. Springiness	5.8 a	6.9 c	6.4 b	5.8 a	5.5 a	peak at 1 day
2. Softness (center)	9.4 e	7.5 d	6.2 c	5.3 b	4.4 a	decrease
3. Softness (upper part)	9.2 e	5.9 d	3.7 c	2.5 b	2.1 a	decrease
4. Crumbliness	0.3 a	1.4 b	3.9 c	6.6 d	7.8 e	increase
5. Kneading into a ball	9.2 c	7.7 d	5.7 c	2.7 b	1.3 a	decrease
Crust (oral)						
6. Difficulty to bite through	3.5 b	7.3 d	5.2 c	3.5 b	2.3 a	peak at 1 day
7. Brittleness	8.4 c	1.8 b	1.4 a	1.3 a	1.2 a	decrease
8. Toughness	3.4 a	7.4 d	5.6 c	4.1 b	3.2 a	peak at 1 day
Procedure B						
Whole slice (manual)						
9. Area of softness, %	96 e	67 d	47 c	26 b	11 a	decrease
10. Softness (whole slice)	8.9 e	6.7 d	4.6 c	2.9 b	1.7 a	decrease
Crumb (oral)						
11. Softness (center)	9.3 e	7.2 d	5.6 c	4.4 b	3.1 a	decrease
12. Dryness	0.7 a	2.7 b	4.5 c	6.6 d	7.9 e	increase
13. Stickiness to teeth	3.5 a	4.3 c	4.5 c	4.0 bc	3.7 ab	peak at 1–3 days

[a] Averages of 120 values (4 production lines × 10 judges × 3 replications) and results of Duncan's multiple range test. For each row, averages denoted by the same letter are *not* significantly different ($P = 0.05$).

TABLE IV

Average Readings from Instron Measurements of Bread Crumb

Production Line	Storage Time (days)	Parameter Determined from the Compression Curve[a] F1 (N)	F(60) (N)	100 × F(60)/F1 Elasticity	F2 (N)	W1 (Nmm)	W2 (Nmm)
I	0 (2 hr)	2.5	1.5	61	2.1	9.6	6.3
	1	7.4	4.0	54	5.5	34.6	15.8
	2	9.4	4.8	51	6.7	47.7	19.2
	4	16.7	8.0	48	11.3	82.3	27.4
	7	21.6	9.8	45	14.1	117.2	32.6
II	0 (2 hr)	2.8	1.7	63	2.2	11.2	7.0
	1	6.2	3.3	53	4.6	30.5	14.3
	2	8.9	4.5	51	6.3	44.1	18.2
	4	14.7	7.0	47	10.0	78.5	26.0
	7	20.9	9.5	45	13.8	115.9	31.6
III	0 (2 hr)	2.8	1.7	60	2.3	11.3	7.2
	1	7.4	3.9	52	5.5	35.4	16.3
	2	10.8	5.4	50	7.6	55.9	21.3
	4	15.8	7.5	47	10.6	85.7	30.7
	7	20.9	9.5	46	13.6	114.7	32.4
IV	0 (2 hr)	3.0	1.8	60	2.4	11.9	7.6
	1	7.6	4.0	52	5.6	37.2	17.1
	2	11.5	5.7	50	8.0	58.3	22.1
	4	17.1	8.1	47	11.6	89.9	29.1
	7	23.0	10.4	45	15.1	125.7	36.0
Significance levels[b]							
Production lines, L		0.001	0.001	···	0.001	0.001	0.001
Storage time, S		0.001	0.001	···	0.001	0.001	0.001
Interaction L × S		ns	ns	···	ns	ns	ns

[a] The values are averages based on 15 measurements (3 loaves × 5 slices/loaf). N = Newton; Nmm = newton millimeter.

[b] Obtained in two-way ANOVAs (cf. text).

linear relationship between different attributes. The relationship between, e.g., the 20 averages (4 production lines × 5 storage times) for softness, "ball kneading," and crumbliness of the crumb gave numerical r values $\geqslant 0.96$.

High correlation coefficients ($r \geqslant 0.98$) were also obtained between results obtained by the manual (procedure A) and oral (procedure B) evaluations of softness of the crumb, implying that the number of softness attributes could be reduced, e.g., by deletion of the oral evaluation of the softness of the center (attribute 11).

Instron Measurements

The results from the Instron texture measurements of the bread crumb are given in Table IV. The values for all parameters except degree of elasticity increased with increased storage time. On the contrary, the elasticity values decreased during storage. High correlations were obtained between the averages of the different measurements as a consequence of calculation from the same compression curves. Linear correlation coefficients higher than 0.92 were obtained for all comparisons of pairs of averages in Table IV. These marked relationships imply that that conclusions of the statistical significance tests will be the same for all parameters. As a consequence of this, only some of them are discussed below.

The results of the statistical analyses (two-way ANOVAs) generally show a highly significant main effect of both production line (L) and storage time (S) and no significant interaction (L × S). The latter implies that the effect of storage time was the same for all four production lines. The rank order of the total average force values, F1, F2, and F(60), for the four production lines shown in Table V shows that production line II gave the significantly lowest and production line IV the significantly highest force value, with production lines I and III in between. The changes in the compression force (F1) due to fermentation conditions and storage time are illustrated in Figure 6.

Loaf Volume

The average specific volumes (cm^3/g) of the loaves from the different production lines were 5.0 for production line I, 5.1 for line II, 5.0 for line III, and 4.7 for line IV. Only the result from production line IV was significantly lower than the others at the 0.05 level. These results in combination with those given in Table V indicated that the crumb compressibility is influenced by the specific volume of the loaf. The compression force increased with decreasing specific volumes. Similar results were reported by Axford et al (1968), Maleki et al (1980), and Wassermann and Vogt (1977).

Relationship Between Sensory and Instrumental Measurements

The compression force F1 measures the resistance of the bread crumb to the plate and represents a measurement of the firmness or hardness of the crumb. The relationship between this instrumental measurement and the sensory softness evaluations of the same parts of the crumb (center) is shown in Figure 7. As can be seen, there is a strong, negative, nonlinear relationship between the two types of data. The softer the bread was perceived to be, the lower the force value measured with the Instron. Both types of data showed that the bread became harder as an effect of storage time.

The F1 also showed significant differences between production lines, whereas no significant differences were observed in the sensory softness evaluations. This is in agreement with results of Brady and Mayer (1985), who also found significant differences between the Instron data for different bread samples that a panel could not discern. However, a possible reason for the lack of sensory softness differences in the present study may be that samples of different production lines (same age) were not presented together because of a necessary compromise between ideal conditions and feasibility. It is a common experience in sensory evaluations that small differences between samples may pass unnoticed when the samples are not presented simultaneously.

Intuitively, there should be good correlation between the Instron value for elasticity and the sensory evaluations of springiness (attribute 1). However, the correlation coefficient for these data was very low (0.24), implying that the Instron measurement did not mime the sensorially evaluated springiness. The Instron elasticity data were instead highly correlated to sensory softness data, e.g., attribute 10, softness of a whole slice ($r = 0.98$). In a detailed review, Peleg (1983) described several possible reasons for lack of correlation between instrumental and sensory data. One reason mentioned was the misleading similarity in language used by instrumentalists and panelists: they use the same words but measure different properties. This may be the case in the present study.

There was good correlation between other sensory and instrumental measurements, but their causality was more difficult to explain.

TABLE V
Results of Instron Measurements: Overall Averages and Results of Duncan's Multiple Range Tests

Instron Measurement[a]	Average Reading for Production Line[b] I	II	III	IV
F1	11.5 b	10.7 a	11.6 b	12.4 c
F(60)	5.6 b	5.2 a	5.6 b	6.0 c
F2	7.9 b	7.4 a	7.9 b	8.5 c

[a] For designations, see text.

[b] Averages of 75 values (5 slices × 3 loaves × 5 storage times). Averages denoted by the same letter are *not* significantly different ($P = 0.05$).

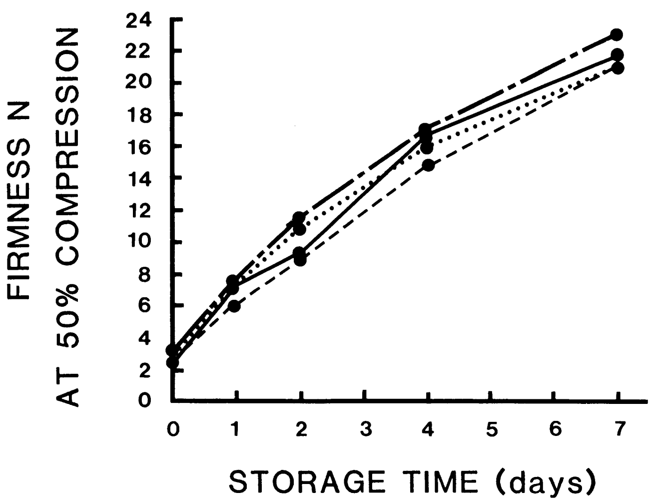

Fig. 6. Results of instrumental evaluations of bread crumb. Average intensity vs. storage time (n = 3 loaves × 5 slices/loaf).

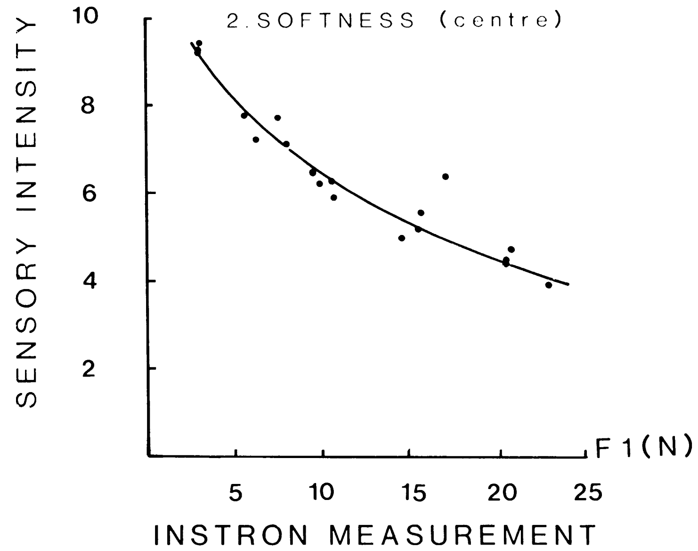

Fig. 7. Relationship between sensory evaluated softness and instrumental measured compression force F1.

CONCLUSION

The sensory evaluations did not show any perceptible texture differences among production lines I–IV for the freshly baked bread (after 2 hr), but differences appeared during storage at 20° C (1–7 days).

The slowest proofing (production line I = lowest temperature and longest time) retained a significantly more brittle crust during storage, particularly after 1–2 days. It also gave a larger core of softness in the bread. No significant differences could be shown between the other three production lines, II–IV.

Storage up to 7 days at room termperature had the most pronounced sensory effect on the texture of the crust. Its initially high brittleness decreased drastically during the first 24 hr of storage. There was a simultaneous increase in toughness, which showed a maximum at around 24 hr of storage. Regarding the crumb, longer storage time resulted in decreased softness and "ease to knead the crumb in a ball," and increased crumbliness and dryness. Maximum springback (by manual evaluation) was seen at around 1 day of storage and maximum stickiness to teeth (oral) after 1–3 days of storage.

The effects of different fermentation conditions and storage times could be evaluated by instrumental texture measurements of the bread crumb. Parameters determined from the force/deformation curves, e.g., F1, F(60), F2, all differed significantly between production lines as well as storage times. Production line II gave the significantly lowest and production line IV the significantly highest force values. Crumb compressibility is also influenced by the specific volume of the loaf. The compression force increases with decreasing specific volumes.

ACKNOWLEDGMENTS

We are greatly indebted to Barbro Karlstrom and Gunilla Torrang-Lindbom for skillful assistance throughout the performance of the work and to Ulla Gustafsson and Marianne Pedersen for making the bread samples.

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[Received July 7, 1986. Revision received February 2, 1987. Accepted February 4, 1987.]