Effects of Sucrose Ester, Dough Conditioner, and Storage Temperature on Long-Term Textural Stability of Shelf-Stable Bread

Ann Barrett,[1,2] Armand Cardello,[3] Paul Maguire,[1] Michelle Richardson,[1] Gonul Kaletunc,[4] and Larry Lesher[5]

ABSTRACT

Cereal Chem. 79(6):806–811

The effectiveness of a dough conditioner containing an amylase enzyme, surfactants, and a reducing compound on preserving the textural stability of shelf-stable bread was compared with that of sucrose ester. Military-specification Meal, Ready-to-Eat bread was formulated to contain sucrose ester alone, the dough conditioner alone, both in combination, or neither additive. Samples were also stored at 4, 21, and 38°C for 12 weeks. Instrumental texture, as determined by uniaxial compression and mathematically fitted stress-strain relationships, and sensory texture, as determined by a trained texture panel, were assessed periodically between 0 and 12 weeks. Both sucrose ester and the dough conditioner yielded stored samples that were softer than the control; sucrose ester was slightly more effective than the dough conditioner in preserving instrumental texture, and the additive combination yielded the lowest firmness parameters. Thermal analysis results were consistent with mechanical and sensory evaluations in showing slightly increased recrystallization of starch in the no-additive formulation. Panelists perceived the samples containing sucrose ester to be much closer to an "ideal" texture compared with those containing the dough conditioner. A partial substitution of the lower cost dough conditioner for higher cost sucrose ester may be possible.

Bread produced for the military has more stringent shelf-life requirements than does commercial bread. Sealed pouches of standard-issue Meal, Ready-to-Eat bread are expected to be biologically stable and acceptable to consumers for up to six months at 38°C storage or three years at 27°C storage. Such bread is formulated to have a relatively low water activity, and textural effects due to reduction of moisture are partially mitigated by the presence of humectants and other ingredients.

One such additive presently incorporated to preserve texture, the emulsifier sucrose ester, is a relatively high-cost ingredient. Our objectives were to compare the effectiveness of this additive with that of a lower-priced "dough conditioner" that contains multiple ingredients, including an enzyme (fungal α-amylase), reducing agents (cysteine hydrochloride and ascorbic acid), an oxidant (azodicarbonamide), and surfactants (DATEM, mono- and di-glycerides). Sucrose esters have increased bread compressibility (reduce resistance to compression) after one day of storage (Pomeranz 1994) and five days of storage (Xu et al 1992), retarded amylopectin recrystallization within the first two weeks of storage (Rao et al 1992), and increased loaf volume (Chung et al 1976). The crumb softening effect of emulsifiers in bread have been attributed to a number of mechanisms including protein interactions that serve to modify the gluten structure (Grosskreutz 1961; Krog 1981) and complexation with amylose (Krog 1981). Starch-degrading enzymes soften crumb during brief storage periods (Akers and Hoseney 1994; Martinez-Anaya and Jimenez 1997; Gil et al 1999; Hug-Iten et al 2001). Proposed mechanisms for this softening include the inhibition of starch-protein complexation by dextrins resulting from enzymatic hydrolysis (van Dam and Hille 1992), and inhibition of amylopectin crystallization (Hug-Iten et al 2001). Reducing agents, including cysteine hydrochloride, increased dough extensibility (Meredith and Hlynka 1964). However, none of these studies investigated the textural stability of bread over the course of several months.

[1] Combat Feeding Program, US Army Natick Soldier Center, SBCCOM, Natick, MA 01760-5018.
[2] Corresponding author. E-mail: Ann.Barrett@natick.army.mil.
[3] Product Optimization and Evaluation Team, US Army Natick Soldier Center, SBCCOM.
[4] Department of Agriculture and Biological Engineering, The Ohio State University, Columbus, OH 43210.
[5] Geo Centers, Inc., Natick, MA 01760.

Publication no. C-2002-1002-06R.

Our investigations involved assessing the effects of using either sucrose ester or the dough conditioner alone, using both ingredients combined, or eliminating both ingredients from the formulation for bread rolls. Textural stability, as assessed by the increase in mechanically determined parameters as well as by changes in the ratings of sensory characteristics, was evaluated over the course of 12 weeks of storage. The rolls were also maintained at three different temperatures to determine effects of storage conditions, and of interactions between storage conditions and formulation, on firming behavior and sensory ratings. Some researchers (Lorenz and Dilsaver 1982) have reported lower firmness in bread maintained at higher temperatures during short periods of storage.

Relationships between sensory and instrumental properties were also determined.

MATERIALS AND METHODS

Formulation and Baking

Bread rolls were produced according to the formulations shown in Table I. Formulation 1 contains sucrose ester but no dough conditioner; formulation 3 contains dough conditioner but no sucrose ester; formulation 2 contains both additives; and formulation 4 contains neither additive.

Dry ingredients were premixed in a Hobart blender operated at low speed. Shortening and then water plus glycerol were added. Batches weighing 5 kg were produced. The dough was mixed at medium speed to development (≈10 min), allowed to relax for 15 min, and then formed into 70-g round rolls using a Fortuna A4-9670 dough divider. The rolls were proofed at 95% rh and 30°C for 40 min and then baked at 175°C for 40 min in a rotary oven.

TABLE I
Bread Formulations (%)

	Formulation			
Ingredient (Supplier)	**1**	**2**	**3**	**4**
Flour (ConAgra)	53	52	53	54
Water	31	31	31	31
Shortening (TemTex)	9	9	9	9
Yeast (Saf-instant)	2.4	2.4	2.4	2.4
Salt (Morton)	1.5	1.5	1.5	1.5
Gum arabic (Kelco)	0.6	0.6	0.6	0.6
Calcium sulfate (ADM Arkady)	0.3	0.3	0.3	0.3
Xanthan gum (Kelco)	0.4	0.4	0.4	0.4
Glucono-delta lactone (BalChem Corp.)	0.7	0.7	0.7	0.7
Encapsulated Potassium Sorbate (BalChem)	0.1	0.1	0.1	0.1
Sucrose Ester (Ryoto)	1.0	1.0	0.0	0.0
Control S (ADM Arkady)	0.0	1.0	1.0	0.0

The product was cooled to <50°C and packaged in trilaminate pouches with Multisorb Oxygen scavengers, and then maintained at –10°C until analysis or commencement of accelerated storage.

Storage and Pulls

The rolls were maintained at 4, 21, and 38°C and evaluated after 0, 2, 6, and 12 weeks for mechanical testing and after 0, 6 and 12 weeks for sensory testing. Prior experiments (Barrett et al 2000), in which firmness parameters versus storage interval were fitted to an asymptotic function, showed that firmness at 12 weeks was close to the fitted asymptotic, or "ultimate", firmness; most of the changes in texture occurred within the first few weeks of storage.

Thermal analysis samples were maintained at 21°C and evaluated after four weeks.

Mechanical Testing

Samples were evaluated in a manner similar to that described by Barrett et al (2000). A cork borer was used to extract specimens 20 mm in diameter, which were trimmed to a height of 20 mm. The center sections of the rolls, with no crust attached, were used for sampling.

A texture analyzer (TA.XT2, Texture Technologies, Scarsdale NY), operated at 3 mm/sec was used for compression testing. Specimens were compressed to 50% deformation. Data was automatically obtained at 25 points/sec.

Mechanical properties were computed using a Sigma Plot program (Jandel Scientific). Deformability modulus was determined using stress-Hencky strain data up to 20% deformation. The entire set of compression data were additionally fitted to the function (Swyngdau et al 1991):

$$y = [C1 \times x]/[(1+(C2 \times x)) \times (C3 - x)]$$

where y = stress in kPa, and x = Hencky strain. The parameter C1 was taken as an index of firmness.

TABLE II
Sensory Attributes and Definitions

Firmness (first bite). Perceived force required to compress the sample between the molar teeth, prior to compacting.

Denseness (first bite). Perceived amount of bread material per unit volume during a single compression with the molar teeth.

Springiness (partial compression). Perceived degree (time and extent) to which the sample returns to its original shape (thickness) after a 50% compression between the thumb and forefinger.

Chewiness (mastication). Perceived total effort required to repeatedly compress the sample through five chews.

Moistness (mastication). Perceived degree of moisture in the sample.

Cohesiveness (mastication). Degree to which the sample holds together as a single mass during chewing.

Six replicates (two specimens from each of three rolls) were used for compression testing. Statistical software from Minitab was used for stepwise analysis of variance (ANOVA) to determine significant effects of formulation, storage temperature, storage time, and interactions on mechanical properties.

Sensory Testing

The magnitudes of sensory attributes of the samples were judged before storage and after six and 12 weeks of storage by a trained descriptive panel consisting of 11 individuals. The panelists had received instruction in the use of the General Foods texture profile method (Brandt et al 1963) and in the method of modulus-free magnitude estimation to judge attribute intensities (Stevens 1953; Moskowitz 1977). All panelists had participated as members of an

TABLE IV
ANOVA Results for Modulus Values

Parameter	df	*F*	*P*
All data			
Formula (F)	3	155	<0.001
Temperature (Tp)	2	22	<0.001
Time (Tm)	3	171	<0.001
F × Tp	6	11	<0.001
F × Tm	9	21	<0.001
Tp × Tm	6	7.3	<0.001
F × Tp × Tm	18	6.0	<0.001
1 vs. 2 vs. 3			
Formula (F)	2	12	<0.001
Temperature (Tp)	2	24	<0.001
Time (Tm)	3	191	<0.001
F × Tp	4	5.1	0.001
F × Tm	6	4.2	0.001
Tp × Tm	6	4.7	<0.001
F × Tp × Tm	12	5.1	<0.001
1 vs. 2			
Formula (F)	1	7.3	0.008
Temperature (Tp)	2	11	<0.001
Time (Tm)	3	220	<0.001
F × Tm	3	7.0	<0.001
Tp × Tm	6	7.6	<0.001
F × Tp × Tm	6	2.8	0.014
1 vs. 3			
Formula (F)	1	6.7	0.011
Temperature (Tp)	2	22	<0.001
Time (Tm)	3	123	<0.001
F × Tp	2	5.3	0.006
F × Tm	3	5.2	0.002
Tp × Tm	6	4.1	0.001
F × Tp × Tm	6	5.0	<0.001
2 vs.3			
Formula (F)	1	18	<0.001
Temperature (Tp)	2	16	<0.001
Time (Tm)	3	96	<0.001
F × Tp	2	6.3	0.003
Tp × Tm	6	4.3	0.001
F × Tm	6	6.1	<0.001

TABLE III
Modulus Values (kPa)[a]

	Formula			
Time/Storage Temperature	1	2	3	4
Initial	0.79 (0.06)	0.88 (0.21)	1.10 (0.24)	2.38 (0.46)
2 weeks/4°C	3.45 (0.29)	3.93 (0.83)	7.95 (1.88)	11.6 (4.21)
2 weeks/21°C	5.77 (0.64)	6.46 (0.55)	7.31 (2.39)	12.5 (2.83)
2 weeks/38°C	3.64 (0.87)	3.88 (0.83)	3.80 (1.77)	8.99 (3.35)
6 weeks/4°C	6.48 (1.36)	6.62 (1.56)	6.02 (2.04)	30.3 (10.4)
6 weeks/21°C	6.64 (1.24)	4.88 (1.41)	10.1 (2.41)	14.6 (3.28)
6 weeks/38°C	6.04 (1.28)	4.33 (1.54)	4.57 (2.03)	13.4 (5.04)
12 weeks/4°C	6.25 (0.46)	4.89 (1.02)	7.08 (1.71)	14.2 (2.63)
12 weeks/21°C	7.16 (1.12)	4.81 (1.05)	5.68 (2.61)	10.8 (2.45)
12 weeks/38°C	5.23 (0.90)	5.61 (1.41)	4.47 (1.48)	10.4 (3.01)

[a] Standard deviation values are in parentheses. Average of all temperatures and pulls: formula 1, 5.15; formula 2, 4.63; formula 3, 5.81; formula 4, 12.9. Average of all formulas and pulls: 4°C, 9.06; 21°C, 8.05; 38°C, 6.20.

TABLE V
Index of Firmness Values(C1)[a]

Time/Storage Temperature	Formula 1	2	3	4
Initial	2.02 (0.70)	2.30 (0.81)	2.42 (0.68)	3.53 (1.13)
2 weeks/4°C	5.56 (1.29)	8.11 (3.40)	17.2 (7.00)	23.5 (12.1)
2 weeks/21°C	20.7 (0.64)	18.0 (0.55)	15.1 (2.39)	29.3 (2.83)
2 weeks/38°C	6.36 (2.61)	7.65 (2.37)	5.61 (2.60)	12.6 (6.55)
6 weeks/4°C	16.3 (6.89)	14.9 (9.31)	18.5 (9.78)	65.0 (21.5)
6 weeks/21°C	14.5 (8.09)	10.1 (4.02)	17.3 (6.63)	30.5 (16.2)
6 weeks/38°C	12.8 (6.71)	8.56 (4.86)	6.08 (3.23)	31.3 (14.5)
12 weeks/4°C	21.7 (13.7)	17.0 (9.95)	20.3 (10.7)	36.4 (16.3)
12 weeks/21°C	17.8 (8.62)	12.1 (6.39)	11.7 (7.59)	26.5 (13.3)
12 weeks/38°C	9.56 (1.76)	13.7 (5.02)	7.01 (2.83)	23.1 (13.3)

[a] Standard deviation values are in parentheses. Average of all temperatures and pulls: formula 1, 12.7; formula 2, 11.2; formula 3, 12.1; formula 4, 28.2. Average of all formulas and pulls: 4°C, 22.0; 21°C, 18.6; 38°C, 12.0.

TABLE VI
ANOVA Results for Index of Firmness Values (C1)

Parameter	df	*F*	*P*
All data			
Formula (F)	3	40	<0.001
Temperature (Tp)	2	17	<0.001
Time (Tm)	3	54	<0.001
F × Tp	6	2.9	0.010
F × Tm	9	7.5	<0.001
Tp × Tm	6	6.1	<0.001
1 vs. 2 vs. 3			
Temperature (Tp)	2	17	<0.001
Time (Tm)	3	44	<0.001
F × Tp	4	2.6	0.035
Tp × Tm	6	5.8	<0.001
1 vs. 2			
Temperature (Tp)	2	7.4	0.001
Time (Tm)	3	36	<0.001
Tp × Tm	6	6.6	<0.001
1 vs. 3			
Temperature (Tp)	2	15	<0.001
Time (Tm)	3	29	<0.001
Tp × Tm	6	3.8	0.002
2 vs. 3			
Temperature (Tp)	2	12	<0.001
Time (Tm)	3	25	<0.001
F × Tp	2	3.6	0.029
Tp × Tm	6	3.0	0.008

in-house laboratory and descriptive texture profile panel. The range of time that the test panelists had served on the panel varied from 3 to 15 years. All had participated in descriptive analysis of a wide range of bread and snack products and all had prior experience in the use of magnitude estimation scaling.

Evaluation involved partial compression of the samples with the molar teeth and mastication up through swallowing. Panelists used the psychophysical method of modulus-free magnitude estimation to judge the perceived magnitude of attributes listed in Table II. These attributes and definitions were developed during pretest evaluations of the products. The magnitude estimation procedure involved assigning a number to the first sample to represent the perceived magnitude of each attribute present in that sample. Subsequent judgments of attribute intensities were made relative to the first sample. For product development guidance, panelists also assigned an "optimal" magnitude estimate for each attribute so that an "ideal" sensory profile for the products could be constructed. Although such judgments are typically reserved for consumer tests, consumers often have difficulty making these judgments (Cooper et al 1989). Data for these ideal estimates were subjected to the same transformation-normalization procedures used for attribute magnitude estimates.

A maximum of five samples were evaluated during one session. At each withdrawal period, three sessions were convened within two consecutive days. Each session contained a sixth, common sample that was used to normalize magnitude estimates across sessions. All testing was replicated twice.

Statistical Analysis

Sensory data were normalized using modulus equalization (Moskowitz 1977) to accommodate differences in the range of magnitude estimates used by the panelists. Normalization involved calculating geometric means across all samples and subjects for each attribute and session. Magnitude estimates for each subject were multiplied by the ratio of the grand mean to the panelist mean for each attribute and session, thus producing a common scale for all the data.

The sensory data were analyzed by conducting a set of multiple regressions to assess the effect of formulation and storage parameters on each sensory attribute. The parameters included were the presence or absence of sucrose ester, the presence or absence of dough conditioner, the sucrose ester-dough conditioner interaction, time of storage, temperature of storage, and the time-temperature interaction. Each parameter range was normalized to extend between 0 and 1 to compare the relative magnitude of effects, indicated by the beta values (slopes) of the regressions.

Treatments were furthermore ranked according to the statistical correlation between the sensory profiles obtained under the specified conditions and the (averaged) ideal sensory profile. Profiles obtained from all specimens obtained using a specific treatment (i.e., all specimens from a specific formula but stored at different temperatures or for different time periods, or all specimens stored at a specific temperature or for a specific time but made from different formulas) were averaged.

Minitab and SPSS programs were used for all statistical analyses.

Differential Scanning Calorimetry (DSC)

DSC (model 2920, TA Instruments) was used to monitor the thermally induced transitions in the stored bread samples. Specimens (30–40 mg) were heated in hermetically sealed sample pans at a scanning rate of 7.5°C/min. Thermograms were recorded from –40 to 130°C. After scanning to 130°C and cooling, a second scan was performed to determine the reversibility of the transitions in the initial scan. In each case, a distinct irreversible transition occurred at ≈65–75°C, consistent with melting of recrystallized starch (Rao et al 1992). The enthalpy of this starch melting endotherm was determined after subtracting the second scan from the first scan.

RESULTS AND DISCUSSION

Mechanical Property Results.

Deformability modulus values (averages of replicates) are shown in Table III, and stepwise ANOVA results are shown in Table IV. C1 values (averages of replicates) are shown in Table V, and stepwise ANOVA results are shown in Table VI. Formulation significantly

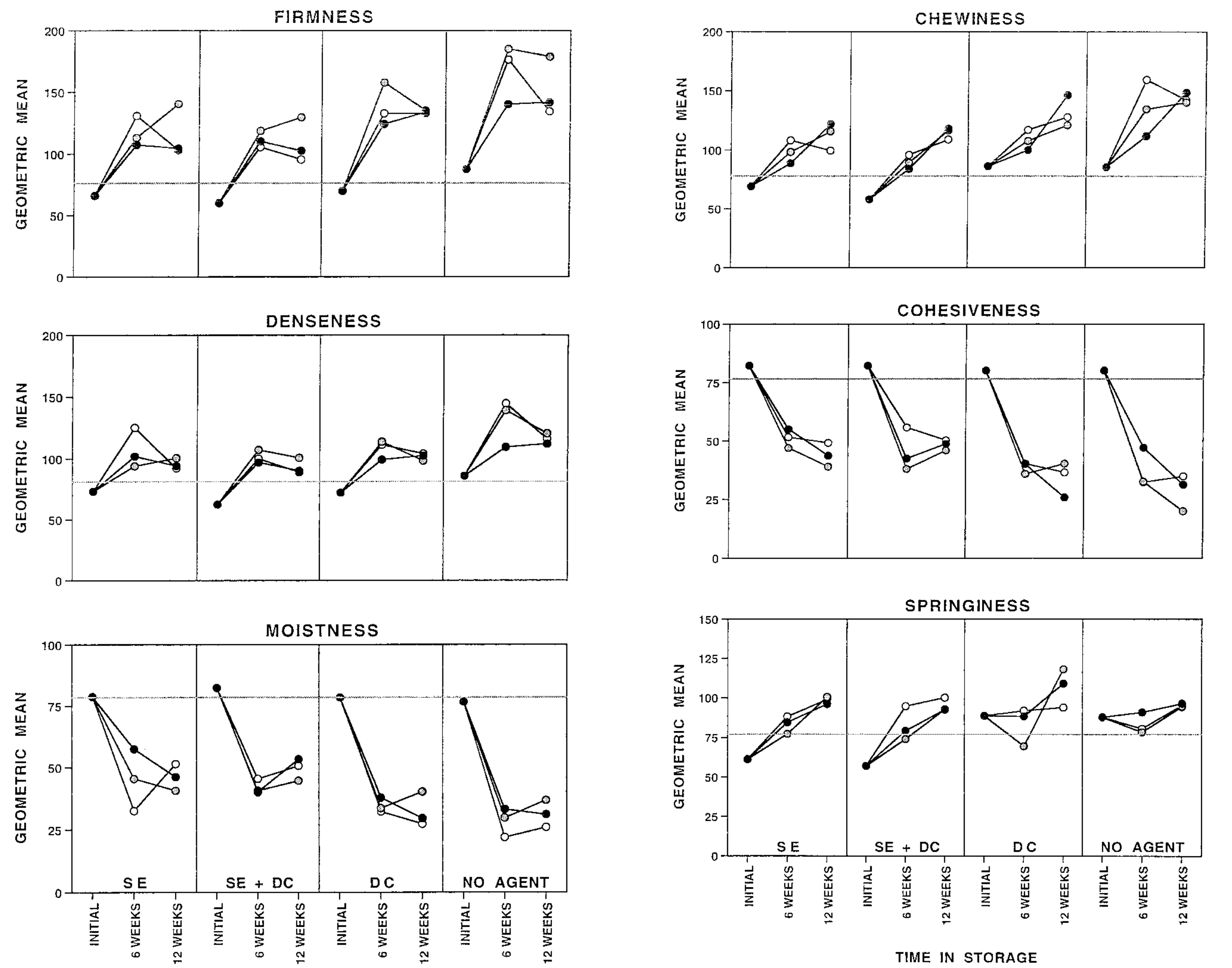

Fig. 1. Mean magnitude estimates of sensory properties through time and according to storage temperatures: 4°C (black circles); 21°C (shaded circles); 38°C (white circles). Line indicates average of "ideal" ratings.

affected ($P < 0.05$) both parameters when all formulations were compared, primarily because of the much greater firming of formulation 4 (no-additive sample). Formulation also significantly affected modulus in comparisons of samples 1, 2, and 3 (excluding the no-additive formula), and in comparisons of samples 1 v. 2 and 2 v. 3 (showing a moderate benefit of a sucrose ester-dough conditioner combination compared with addition of either additive singly). Differences in C1 were only significant in comparison of all four formulations together. Either parameter demonstrates that the greatest effect on texture was brought about by incorporation of either sucrose ester or dough conditioner. Slight additional softening may result from using both additives together.

Both temperature and time were also significant factors in all analyses. The firmness of the rolls increased with decreasing storage temperature, consistent with observations of Lorenz and Dilsaver (1982) and, as expected, was higher for stored samples (Tables III and V). All interactions significantly affected modulus in analysis of all formulations together; all two-by-two interactions significantly affected C1 in analysis of all formulations together.

Sensory Results

Figure 1 illustrates the effects of formulation and storage parameters on each sensory attribute, with a line indicating the ideal level (average from all panels) of each attribute. Table VII shows the significance of these effects. In general, only unstored samples had sensory scores close to "ideal" levels. Storage time had a large and statistically significant effect on all sensory attributes, with the standardized beta values (slopes from regression of normalized parameter values) indicating increased firmness, denseness, chewiness, and springiness, but decreased moistness and cohesiveness with time. The addition of sucrose ester produced moderate and significant decreases in firmness, chewiness, and denseness, and an increase in the cohesiveness of the samples. The addition of the dough conditioner only decreased perceived denseness and chewiness.

The largest effects of storage time occurred between the initial evaluation and either of the two storage intervals (six and 12 weeks). To assess the effects of formulation on stored samples only, the same analysis was made excluding time 0 data. The statistically significant effects from this analysis are shown in Table VIII.

Excluding time 0 data, the only statistically significant effects of storage interval were for chewiness and springiness, where increased storage time from six to 12 weeks resulted in large increases in the magnitude estimates of both properties. Sucrose ester, evaluating only stored samples, moderately and significantly reduced ratings for firmness, denseness and chewiness, and concomitantly increased ratings for cohesiveness and moistness. The dough conditioner, evaluating only stored samples, reduced magnitude estimates of denseness and chewiness—as was observed for the analysis including time 0 samples—and of firmness.

Sensory results thus corresponded to mechanical results in showing a significant benefit due to addition of either sucrose ester or the dough conditioner, and also (at least in the case of modulus

TABLE VII
Significance Results for Sensory Characteristics (including time 0)

Attribute	Formulation Parameter	Beta Value	*t*-ratio	*P*
Firmness	Sucrose Ester	–0.46	–3.3	0.002
	Time (weeks)	0.70	3.5	0.001
Denseness	Sucrose Ester	–0.42	–2.7	0.010
	Dough Conditioner	–0.43	–2.5	0.020
	Time (weeks)	0.57	2.6	0.016
Moistness	Time (weeks)	–0.77	–4.1	<0.001
Chewiness	Sucrose Ester	–0.47	–5.7	<0.001
	Dough Conditioner	–0.24	–2.6	0.016
	Time (weeks)	0.92	7.6	<0.001
Cohesiveness	Sucrose Ester	0.23	2.1	0.045
	Time (weeks)	–0.92	–5.8	<0.001
Springiness	Time (weeks)	0.73	3.7	0.001

TABLE VIII
Significance Results for Sensory Characteristics (excluding time 0)

Attribute	Formulation Parameter	Beta Value	*t*-ratio	*P*
Firmness	Sucrose Ester	–0.79	–4.6	<0.001
	Dough Conditioner	–0.48	–2.5	0.023
Denseness	Sucrose Ester	–0.71	–5.1	<0.001
	Dough Conditioner	–0.67	–4.3	0.001
	Temperature	1.06	3.0	0.008
Moistness	Sucrose Ester	0.78	4.8	<0.001
Chewiness	Sucrose Ester	–0.76	–7.9	<0.001
	Dough Conditioner	–0.49	–4.5	<0.001
	Time (weeks)	1.03	7.4	<0.001
	Temperature	1.27	5.2	<0.001
	Time × Temperature	–1.37	–5.1	<0.001
Cohesiveness	Sucrose Ester	0.74	3.9	0.001
Springiness	Time (weeks)	0.86	3.1	0.007

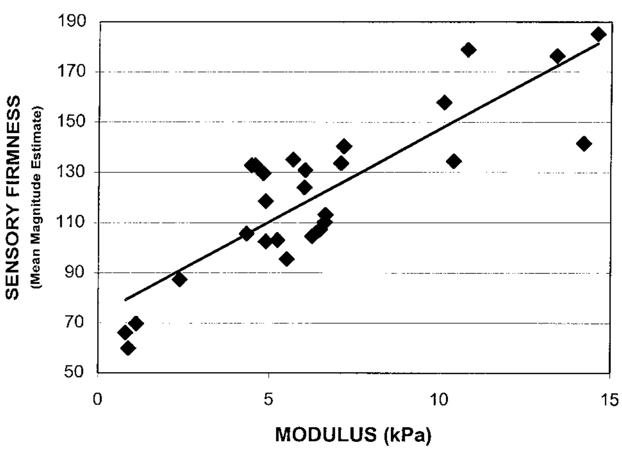

Fig. 2. Relationship between sensory firmness and deformability modulus.

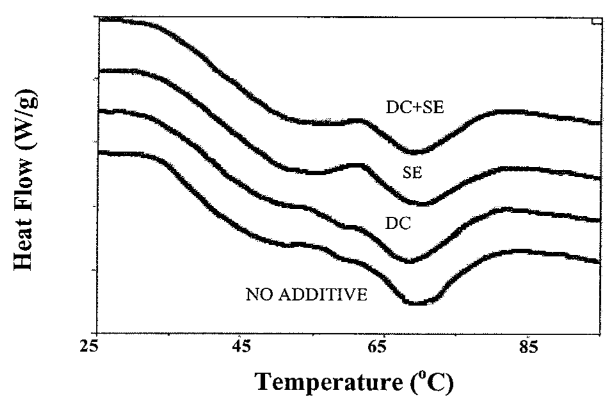

Fig. 3. Differential scanning calorimetry (DSC) thermograms of bread formulations after four weeks of storage at 21°C.

values) in indicating a relatively greater effect of sucrose ester. Panelists, however, perceived effects of temperature on only two properties, chewiness and denseness, and estimated significantly higher magnitudes of these attributes in samples stored at higher temperatures.

Sensory-Instrumental Relationships

Regression analysis revealed several significant relationships (*t*-ratio > 2.0 or < –2.0; $P < 0.05$) between sensory characteristics and mechanical parameters. Sensory firmness, chewiness, and denseness were positively correlated with both C1 and modulus; sensory moistness and cohesiveness were negatively correlated with both C1 and modulus (Table IX). Figure 2 illustrates the relationship between sensory firmness and modulus.

TABLE IX
Significant Sensory-Instrumental Relationships

Relationship	*t*-ratio	*r*	*P*
Sensory firmness-modulus	8.35	0.85	<0.001
Sensory firmness-C1	5.64	0.74	<0.001
Sensory denseness-modulus	7.64	0.83	<0.001
Sensory denseness-C1	5.15	0.70	<0.001
Sensory moistness-modulus	–5.59	0.73	<0.001
Sensory moistness-C1	–45.0	0.65	<0.001
Sensory chewiness-modulus	6.11	0.76	<0.001
Sensory chewiness-C1	6.29	0.77	<0.001
Sensory cohesiveness-modulus	–6.01	0.76	<0.001
Sensory cohesiveness-C1	–5.58	0.73	<0.001

TABLE X
Sample Ranking According to Difference Sums of Squares (SSQ)[a,b]

Treatment	SSQ
Formulation	
Sucrose ester + dough conditioner	4,181a
Sucrose ester	4,850a
Dough conditioner	9,152a
No additive	15,509b
Storage temperature	
4°C	7,658
38°C	9,867
21°C	11,630
Storage time	
None	653a
6 weeks	9,570b
12 weeks	9,866b

[a] Average sensory profile for specific treatments compared to ideal sensory.
[b] Within each treatment parameter (formulation, temperature, or time), values followed by different letters are significantly different at $P \leq 0.05$.

Comparison with the Ideal Profile

Table X shows the difference sums of squares for various treatments relative to the theoretical ideal. For these determinations, average magnitude estimates across treatment or formulation were used, and the average "ideal" level from replicated panels was used.

These results show 1) that specimens containing either sucrose ester, dough conditioner, or both agents were closer to the "ideal" product than was untreated bread; 2) that unstored samples were significantly closer to the "ideal" than were samples stored for either time period, and that six-week samples were not significantly different from 12-week samples; and 3) that there was no significant systematic effect of temperature on how close the samples were to the "ideal".

Calorimetric Results

DSC thermograms for stored rolls are shown in Figure 3. Scans for all the bread formulations contained similar features. Melting of retrograded starch, assessed by subtracting first scans from second scans, in each case occurred around peak temperatures of 69–70°C, and had enthalpies of 1.02, 0.96, 1.10, and 1.20 J/kg for samples containing sucrose ester, the sucrose ester plus dough conditioner, dough conditioner alone, and samples with no additive, respectively. That the starch melting enthalpy of the no-additive bread was ≈20% higher than that of samples containing sucrose ester or sucrose ester plus dough conditioner, and ≈10% higher than that of the sample containing dough conditioner alone, indicated a somewhat lower degree of crystallization in bread containing either additive.

While DSC results are consistent with mechanical measurements, the difference between the stored firmness parameters of no-additive bread compared with those of samples containing sucrose ester—on average 200–300%—is of substantially greater magnitude than the difference between the melting enthalpies of these samples. Thus, while crystallization of starch may contribute to textural changes, other mechanisms (i.e., involving gluten moieties) may predominate.

In each case, an additional, broad, irreversible endotherm was evident at lower temperatures (≈50–60°C), which may have been attributable to the presence of residual, incompletely gelatinized starch in the samples. Furthermore, a reversible transition occurring at ≈44–50°C assumed to be caused by melting of lipid material was observed by Eliasson (1986).

CONCLUSIONS

Both sucrose ester and the dough conditioner softened the crumb during storage and affected sensory properties such as perceived firmness, chewiness, and moistness. In a direct comparison of the effect of the two agents (singly) on mechanical properties, sucrose ester had a slight statistical benefit in reducing modulus. Effects of the two agents on the C1 parameter were statistically equivalent. Differences between the effect of the two agents on the sensory properties of stored samples were somewhat more pronounced: Beta values for the effect of sucrose ester on firmness and chewiness were >50% higher than those for the effect of dough conditioner on these properties. Furthermore, only sucrose ester had a statistical effect on sensory moistness and cohesiveness. However, it is likely that at least partial substitution of sucrose ester with dough conditioner is possible, for production cost reasons, while preserving quality and acceptance.

That both additives were effective, yet through different mechanisms of action, also suggests that firming in bread is a complex phenomenon attributable to more than one physicochemical process.

ACKNOWLEDGMENTS

We would like to thank members of the texture panel for their dedication to this study.

LITERATURE CITED

Akers, A. A. and Hoseney, R. C. 1994. Water-soluble dextrins from α-amylase-treated bread and their relationship to bread firming. Cereal Chem. 71:223-226.
Barrett, A. H., Cardello, A. V., Mair, L., Maguire, P. Lesher, L. L., Richardson, M., Briggs, J., and Taub, I. A. 2000. Textural optimization of shelf-stable bread: Effects of glycerol content and dough-forming technique. Cereal Chem. 77:169-176.
Brandt, M. A., Skinner, E. Z., and Coleman, J. A. 1963. Texture profile method. J. Food Sci. 28:404-409.
Chung, O. K., Pomeranz, Y., Goforth, D. R., Shogren, M. D, and Finney, K. F. 1976. Improved sucrose esters in breadmaking. Cereal Chem. 53:615-626.
Cooper, H. R., Earle, M. D., and Triggs, C. M. 1989. Ratios of ideals—A new twist to an old idea. Pages 54-63 in: Product Testing with Consumers for Research Guidance. L. S. Wu, ed. ASTM: Philadelphia.
Eliasson, A.-C. 1986. On the effects of surface active agents on the gelatinization of starch—A calorimetric investigation. Carbohydr. Polym. 6:463-470.
Gil, M. J., Callejo, M. J., Rodriguez, G., and Ruiz, M. V. 1999. Keeping qualities of white pan bread upon storage: Effect of selected enzymes on bread firmness and elasticity. Z. Lebensm. Unters. Forsch. A. 208:394-399.
Grosskreutz, J. C. 1961. A lipoprotein model of wheat gluten structure. Cereal Chem. 38:336-342.
Hug-Iten, S., Escher, F., and Conde-Petit, B. 2001. Structural properties of starch in bread and bread model systems: influence of an antistaling α-amylase. Cereal Chem. 78:421-428.
Krog, N. 1981. Theoretical aspects of surfactants in relation to their use in breadmaking. Cereal Chem. 58:158-164.
Lorenz, K., and Dilsaver, W. 1982. Comparative efficiencies of bread crumb softeners at varied bread storage temperatures. J. Am. Oil Chem. Soc. 59:484-487.
Martinez-Anaya, M. A., and Jimenez, T. 1997. Functionality of enzymes that hydrolyze starch and non-starch polysaccharide in breadmaking. Z. Lebensm. Unters. Forsch A. 205:209-214.
Meredith, P., and Hlynka, I. 1964. The action of reducing agents on dough. Cereal Chem. 41:286-299.
Moskowitz, H. 1977. Magnitude estimation: Notes on what, how, when, and why to use it. J. Food Qual. 3:195-227.
Pomeranz, Y. 1994. Sucrose esters in baked products. Food Sci. Technol. 62:137-147.
Rao, P. A., Nussinovitch, A., and Chinachoti, P. 1992. Effects of selected surfactants on amylopectin recrystallization and on recoverability of bread crumb during storage. Cereal Chem. 69:613-618.
Stevens, S. S. 1953. On the brightness of lights and loudness of sounds. (Abstr.) Science 118:576
Swyngdau, S., Nussinovitch, A., Roy, I., Peleg, M., and Huang, V. 1991. Comparison of four models for the compressibility of breads and plastic foams. J. Food Sci. 56:756-759.
Van Dam, H. W. and Hille, J. D. R. 1992. Yeast and enzymes in breadmaking. Cereal Foods World 37:245-251.
Xu, A., Chung, O. K., and Ponte, J. G., Jr. 1992. Bread crumb amylograph studies. I. Effects of storage time, shortening, flour lipids, and surfactants. Cereal Chem. 69:495-501.

[Received February 22, 2002. Accepted July 5, 2002.]