Studies on Frozen Doughs. I. Effects of Frozen Storage and Freeze-Thaw Cycles on Baking and Rheological Properties[1]

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Cereal Chem. 68(6):627-631

ABSTRACT

The effects of frozen storage for one week and of freeze-thaw cycles during the storage period on rheological and baking properties of yeasted dough were studied. Two oxidant additions (ascorbic acid without and with potassium bromate) were used. A modified extensigraph procedure was used to measure the stretching properties of fermented doughs. Extensigraph resistance of thawed doughs decreased significantly after frozen storage for one week and with an increasing number of freeze-thaw cycles. A highly significant positive correlation was obtained between loaf volume and maximum extensigraph resistance ($r = 0.935$–0.976, $P < 0.05$), and a highly significant negative correlation was obtained between final proof time to a fixed height and maximum resistance ($r = -0.969$–-0.987, $P < 0.05$). A combination of ascorbic acid and potassium bromate, compared with ascorbic acid alone, strengthened the doughs and improved the baking potential of frozen dough. This result indicated that freeze damage to dough was dependent on the strength of the original dough. On the other hand, extensigraph resistance of nonyeasted doughs did not change after the first freeze-thaw cycle but decreased incrementally after the second and third cycles. Comparison of the extensigraph results for yeasted and nonyeasted doughs suggests that the gluten structure of yeasted doughs may be more vulnerable to the effect of freezing (e.g., ice crystallization) than that of nonyeasted doughs.

The quality of bread baked from bread flour by the frozen dough method depends largely on the activity of the yeast after thawing. Merritt (1960) clearly demonstrated that to achieve yeast stability during frozen storage, it is necessary to minimize or eliminate yeast activity before freezing. It also has been shown that slow dough-freezing at −20°C is better than freezing at −40°C (Hsu et al 1979b, Lehmann and Dreese 1981). However, the slow freezing seems to cause more damage to the dough structure than a quicker freezing; the reason for the difference has been attributed to ice crystallization (Potter 1986). According to Varriano-Marston et al (1980), the structure of gluten in frozen dough could be damaged by formation of ice crystals. However, details regarding these adverse effects, as well as adverse effects of reducing compounds leached from dead yeast cells (Kline and

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Sugihara 1968), are still not clear.

We used rheological measurements to study changes in thawed doughs after frozen storage. Although many researchers (Kline and Sugihara 1968, Varriano-Marston et al 1980, Bruinsma and Giesenschlag 1984, Wolt and D'Appolonia 1984) reported a weakened and slackened appearance of thawed dough pieces, only Varriano-Marston et al (1980) and Wolt and D'Appolonia (1984) measured the changes in dough properties objectively, with the extensigraph. Contrary to the subjective observations, both groups found that extensigraph resistance increased and extensibility decreased with storage time or repeated freeze-thaw cycles. Both groups used the standard extensigraph procedure (AACC 1983) developed for nonfermenting doughs. Kilborn and Preston (1982) found that the standard extensigraph procedure was generally unsuitable for studying rheological properties of fermented doughs and developed a modified procedure for such doughs.

The objective of our investigation was to study the rheological properties of thawed frozen bread doughs using the modified extensigraph procedure of Kilborn and Preston (1982) to determine whether the changes in rheological properties can be used to predict the changes in baking performance.

MATERIALS AND METHODS

Flour Sample

The flour used was milled from a commercial sample of No. 1 Canada western red spring wheat (1989 crop) on the Canadian International Grains Institute pilot mill. Analytical and farinograph data of the flour are given in Table I.

Yeast Sample

Compressed baker's yeast was obtained from Fleischmann's Yeast Ltd. (Toronto, ON) and used within one week of receipt.

Baking Study

The formulation of the short-time dough procedure of Kilborn and Tipples (1972) was modified (Table II). This formulation was considerably leaner (designed to show more effectively the response of flour strength to freeze damage) than commercial frozen dough formulations (Merritt 1960).

Doughs were mixed to just beyond peak development, as indicated by the mixing curve, on a Grain Research Laboratory (GRL)-200 mixer equipped with a GRL energy-input meter (Kilborn 1979). The final dough temperature was 23.5 ± 0.5°C. The dough was removed from the mixer, divided into two 160-g pieces, rounded, and rested for 20 min in a fermentation cabinet at 28°C and 95% rh. Dough pieces were molded on a GRL sheeter-molder (Kilborn and Irvine 1963). Fifteen identical pieces were prepared for each type of dough. Three pieces were panned and proofed in a fermentation cabinet for 45 min. The heights of the dough pieces were measured. The average height of the three dough pieces was used as the standard proofing height for the analogous frozen dough pieces. After final proofing, dough pieces were baked at 218°C for 25 min. After 30 min of cooling, loaf volume was determined by rapeseed displacement.

Immediately after molding, the other 12 dough pieces were placed in an upright freezer at −20°C and frozen until the core temperature of the doughs reached −5°C. After freezing, the dough pieces were placed in polyethylene bags, vacuum-sealed, and stored in a chest freezer at −20°C for one week. During this frozen-storage period, three dough pieces were subjected to one, two, or three additional freeze-thaw cycles (Fig. 1). Doughs were thawed in a retarder at −2°C for approximately 15 hr, panned, and final-proofed in the fermentation cabinet until the dough height reached the predetermined proofing height. The average of the proof times of three replicate dough pieces was recorded as the final proofing time. The doughs were baked and cooled, and their loaf volumes were measured as described above.

Extensigraph Measurements

For the extensigraph measurements, doughs were prepared using the same formulation and mixing procedure as for the baking study. The dough pieces (150 g) were first molded on the GRL molder, then molded by hand into dough cylinders 15.5 cm long, clamped into the modified extensigraph holder, proofed in the

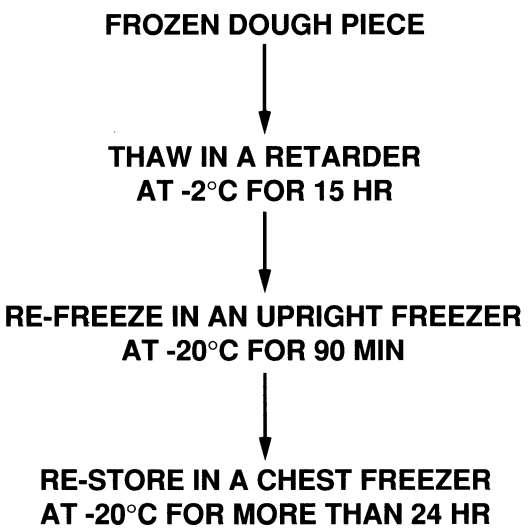

Fig. 1. Procedure for subjecting frozen doughs to additional freeze-thaw cycles.

TABLE I
Analytical and Farinograph Data for Flour Sample (14.0% mb)

Data	Value
Analytical	
Protein (N × 5.7), %	13.72
Ash, %	0.52
Starch damage, Farrand units	23.00
Farinograph	
Absorption, %	63.50
Dough development time, min	6.50

TABLE II
Bread Dough Formulas

	Ascorbic Acid	Ascorbic Acid + Potassium Bromate
Flour	200 g	200 g
Yeast	10 g	10 g
Sugar	5 g	5 g
Salt	2 g	2 g
Shortening	3 g	3 g
Ascorbic acid	100 ppm	100 ppm
Potassium bromate	0	30 ppm
Water	Optimum	Optimum

TABLE III
Effect of Frozen Storage and Freeze-Thaw Cycles on Baking Characteristics of Yeasted Dough[a,b]

	AA		AA + KB	
Freeze-Thaw Cycles	Proof Time (min)	Loaf Volume (cc)	Proof Time (min)	Loaf Volume (cc)
Nonfrozen	45	782	45	807
0[c]	73[d]	733	71	770
1	76	700	77	745
2	88	695	87	742
3	91	675	94	723

[a] Mean of three replicates.
[b] AA = ascorbic acid (100 ppm), AA + KB = ascorbic acid (100 ppm) plus potassium bromate (30 ppm).
[c] One week frozen storage.
[d] Time to read same height as nonfrozen dough.

fermentation cabinet for the predetermined proofing time used for the baking test, and stretched.

Extensigraph test pieces of nonyeasted doughs were prepared in the same way, except that the test piece was 14.5 cm long, and the final proofing times were 45 min for the nonfrozen doughs and 70 min for the thawed frozen doughs. After these times, both nonfrozen and thawed doughs were the same temperature (28°C) and gave the same extensigraph resistance at 5-cm extension (results not shown). The nonyeasted doughs were tested by the standard extensigraph procedure (AACC 1983).

The lengths of yeasted and nonyeasted dough test pieces used were found to be the most suitable for two extensigraph procedures. Variation of the length did not alter the pattern of rheological changes due to freezing and thawing or to frozen storage (results not shown).

RESULTS AND DISCUSSION

Baking Results

Results of baking tests (Table III) show that the final proofing time increased and loaf volume decreased during frozen storage and with increasing number of freeze-thaw cycles; these results are generally similar to those reported by Hsu et al (1979b). Although no significant difference was found in the final proofing time for doughs with the two different oxidants—ascorbic acid (AA) and AA plus potassium bromate (KB)—the decrease in loaf volume was less for the AA + KB doughs than for the AA doughs. Similar superiority of the combination of AA + KB over KB alone for frozen dough had been reported by Hsu et al (1979a), Varriano-Marston et al (1980), and Dubois and Blockcolsky (1986).

Definite differences in external and internal appearance between breads from doughs subjected to more than one freeze-thaw cycle and those from the control doughs were observed (Fig. 2). As the number of freeze-thaw cycles increased, loaf volume decreased, and the tops of the loaves became flatter. In addition, prominent blisters appeared on the crust surface, and the crumb structure became more open. The AA + KB loaves retained acceptable shred even after three additional freeze-thaw cycles, whereas the AA loaves lost the normal shred after two additional freeze-thaw cycles. The combined AA + KB loaves improved in external appearance compared with those that had AA alone.

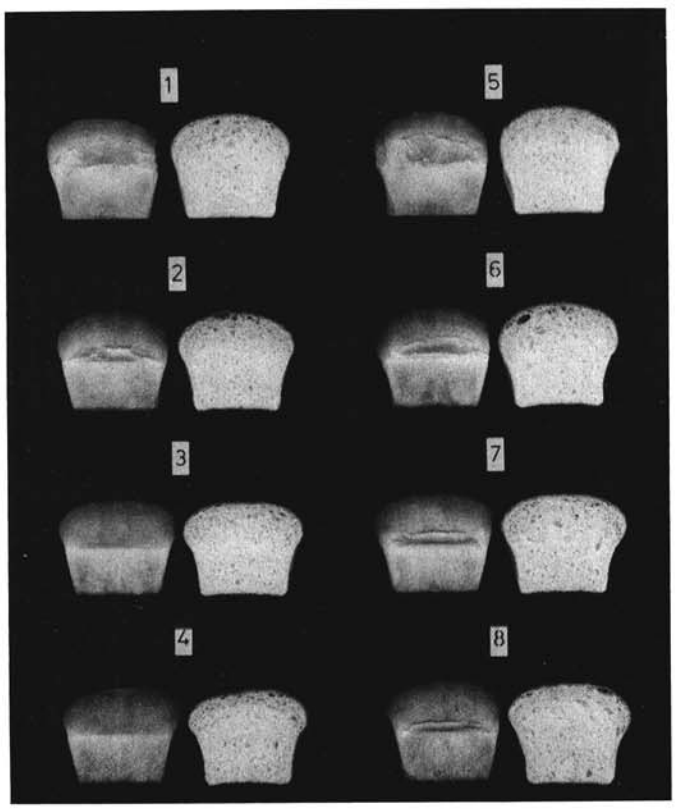

Fig. 2. Effect of additional freeze-thaw cycles on external and internal appearances of breads. 1 = ascorbic acid (AA), 0 cycles; 2 = AA, 1 cycle; 3 = AA, 2 cycles; 4 = AA, 3 cycles; 5 = AA + potassium bromate (KB), 0 cycles; 6 = AA + KB, 1 cycle; 7 = AA + KB, 2 cycles; 8 = AA + KB, 3 cycles.

Extensigraph Results

Extensigraph results for yeasted doughs (Fig. 3, Table IV) showed that maximum resistance decreased significantly after one week of frozen storage and with increasing number of freeze-thaw cycles. Extensibility increased with storage time, but no clear trend was observed with increasing number of freeze-thaw cycles. The reproducibility of the modified extensigraph procedure was very good and was similar to that of Kilborn and Preston (1982).

Highly significant positive correlations ($r = 0.976$; $P < 0.05$ for AA and 0.935, $P < 0.05$ for AA + KB) were obtained between loaf volume and maximum extensigraph resistance. Negative correlations ($r = -0.987$; $P < 0.05$ for AA and -0.969, $P < 0.05$ for AA + KB) were obtained between final proof time and maximum resistance. On the basis of these results, we concluded that the weakening effect of frozen storage and freeze-thaw cycles on the rheological properties of thawed frozen doughs can be measured effectively with the modified extensigraph procedure.

Figure 4 shows the effect of time of proofing on extensigraph maximum resistance of yeasted doughs. There was essentially no change in maximum resistance when proof time was extended from 45 to 90 min for a nonfrozen dough and from 75 to 95 min for frozen dough that had been subjected to three additional freeze-thaw cycles. Accordingly, the observed weakening of the dough was caused by frozen storage and freeze-thaw cycles and not by the small variations in proof time, which we used to obtain the predetermined height of proofed doughs.

Our extensigraph results do not agree with those of previous studies by Varriano-Marston et al (1980) and Wolt and D'Appolonia (1984). In contrast, our studies showed that extensibility increased and resistance decreased after frozen storage and with increasing number of freeze-thaw cycles. The discrepancy is probably due to the different extensigraph techniques used. The previous studies used the standard AACC procedure (AACC 1983) designed for nonfermenting doughs, while we used the modified technique of Kilborn and Preston (1982) developed for fermenting doughs. Additionally, the storage conditions (packaging and time) we used were somewhat different from those used in the earlier studies.

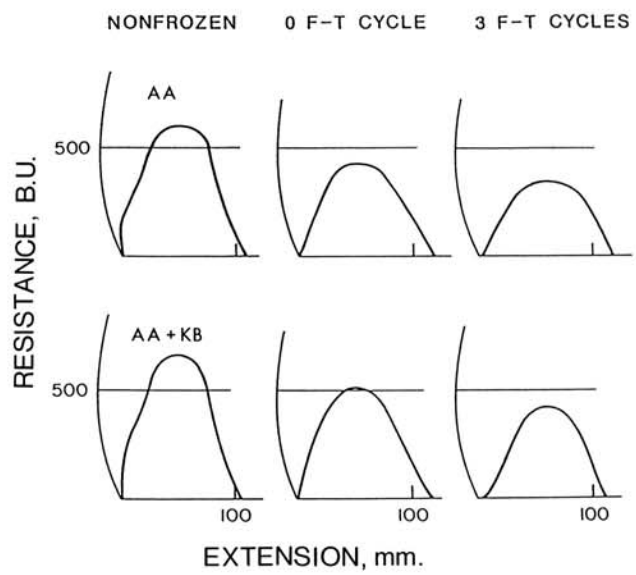

Fig. 3. Extensigrams of frozen and refrozen yeasted doughs. F-T = freeze-thaw, AA = ascorbic acid (100 ppm), AA + KB = ascorbic acid (100 ppm) plus potassium bromate (30 ppm).

TABLE IV
Effect of Frozen Storage and Freeze-Thaw Cycles on Extensigraph Properties of Yeasted and Nonyeasted Dough[a]

Freeze-Thaw Cycles	Yeasted Dough[b]				Nonyeasted Dough			
	AA Max. R (BU)	E (mm)	AA + KB Max. R	E	AA R at 5 cm (BU)	E (mm)	AA + KB R at 5 cm (BU)	E (mm)
Nonfrozen	558 ± 21	109 ± 3	596 ± 19	103 ± 2	723 ± 15	129 ± 10	783 ± 15	124 ± 4
0[c]	393 ± 25	114 ± 3	477 ± 23	114 ± 9	713 ± 28	131 ± 4	785 ± 21	124 ± 2
1	363 ± 6	116 ± 4	453 ± 25	108 ± 3	720 ± 20	131 ± 3	787 ± 12	127 ± 5
2	340 ± 10	118 ± 5	423 ± 15	111 ± 3	665 ± 7	135 ± 4	705 ± 35	133 ± 2
3	307 ± 6	116 ± 3	400 ± 17	109 ± 3	620 ± 28	143 ± 1	630 ± 14	142 ± 1

[a]Mean ± SD (eight replicates for nonfrozen dough, three for frozen doughs).
[b]AA = ascorbic acid (100 pm), AA + KB = ascorbic acid (100 ppm) plus potassium bromate (30 ppm), Max. R = maximum resistance, E = extensibility.
[c]One week frozen storage.

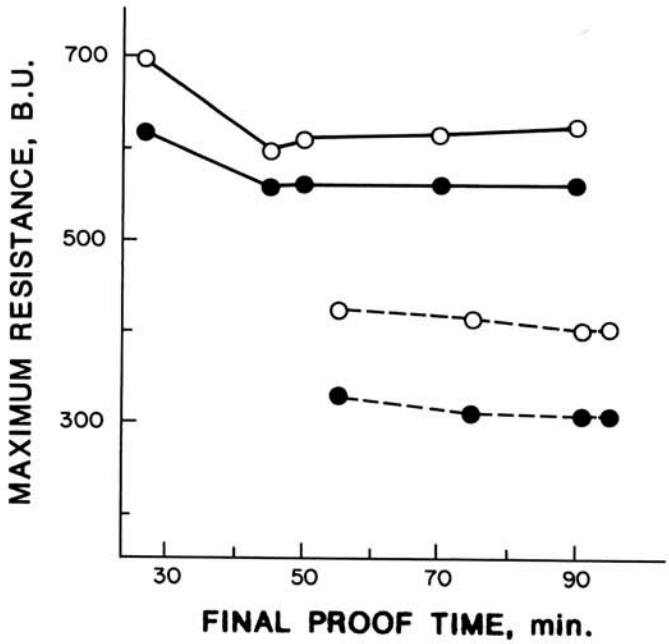

Fig. 4. Effect of final proof time on maximum resistance of ascorbic acid (●) and ascorbic acid plus potassium bromate (○) in yeasted doughs without freezing (solid line) and with three freeze-thaw cycles (broken line).

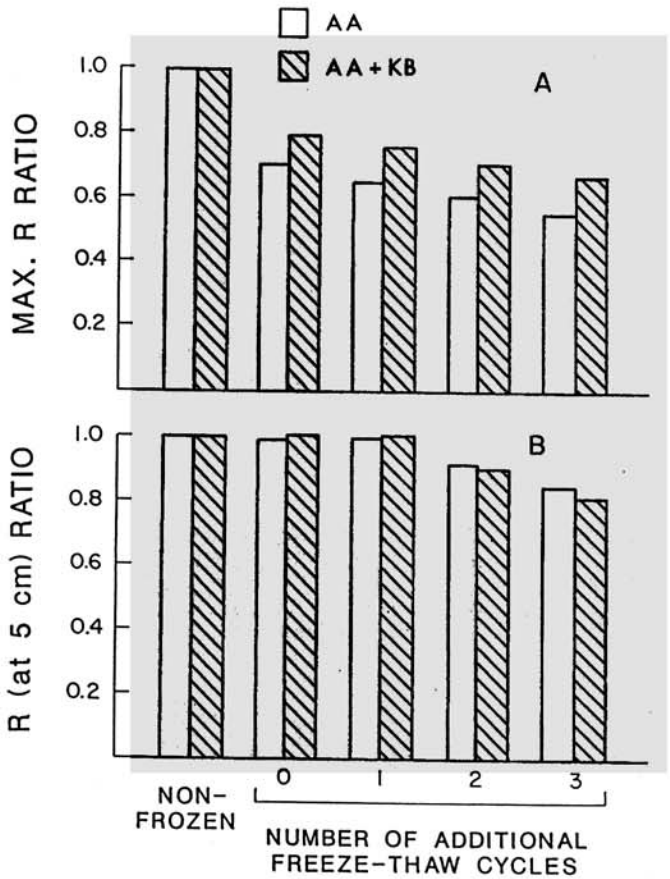

Fig. 5. Effect of frozen storage and freeze-thaw cycles on extensigraph maximum resistance (Max. R) ratio of yeasted doughs (**A**) and R (at 5 cm) ratio of nonyeasted doughs (**B**). Max. R ratio = Max. R. of sample dough/Max. R of nonfrozen dough; R (at 5 cm) ratio = R (at 5 cm) of sample dough/R (at 5 cm) of nonfrozen dough.

The results we obtained are consistent with the practical observations indicating that frozen doughs appear to slacken during storage.

Extensigraph results for nonyeasted frozen doughs (Table IV) show that no significant changes occurred in extensigraph properties during short-term storage. However, the second and third additional freeze-thaw cycles produced a significant decrease in resistance and an increase in extensibility. These results indicate that nonyeasted doughs from strong flours, such as those milled from Canadian hard red spring wheat, were able to resist freeze damage, but they were weakened under severe processing conditions such as additional freeze-thaw cycles. Again, our results are contrary to those of Varriano-Marston et al (1980), which showed that extensigraph resistance of nonyeasted doughs increased and extensibility decreased as the number of freeze-thaw cycles increased. We have no explanation for this discrepancy except that the type of flour, the molding procedures, and the storage conditions used in the two studies were different.

Additionally, our extensigraph results (Fig. 5) show that yeasted doughs appear to be more susceptible to freeze damage than nonyeasted doughs. Furthermore, we found that AA + KB is more effective than AA alone in inhibiting freeze damage (i.e., the maximum resistance ratio is higher for AA + KB doughs than for AA doughs) in frozen yeasted doughs but not in frozen nonyeasted doughs. The reason for this remains to be investigated.

Table V shows that the length of doughs after sheeting is much greater for yeasted than nonyeasted doughs. This observation indicates that the structure of the yeasted dough is weaker (more extensible) than that of the nonyeasted dough. A weakened dough structure would be more vulnerable to freeze damage.

GENERAL DISCUSSION

Kline and Sugihara (1968) postulated that bread dough weakening that occurs during frozen storage results from chemical reduction of gluten disulfide groups by reducing substances released from dead yeast cells. This hypothesis was refuted by Wolt and D'Appolonia (1984), who showed that the sulfhydryl

TABLE V
Length (cm) of Dough Sheet[a,b]

Dough	AA	AA + KB
Yeasted	41.9	40.2
Nonyeasted	35.7	34.8

[a]Mean of duplicates.
[b]AA = ascorbic acid (100 ppm), AA + KB = ascorbic acid (100 ppm) plus potassium bromate (30 ppm).

content of frozen dough does not change significantly during storage. Furthermore, Bruinsma and Giesenschlag (1984) reported that yeast activity in frozen doughs did not change appreciably after consecutive freeze-thaw cycles, while the dough exhibited significant weakening (as assessed subjectively). Destruction of normal dough structure during freezing (presumably by ice crystallization) has been observed by means of scanning electron microscopy (Varriano-Marston et al 1980, Berglund et al 1990).

Our baking and extensigraph results indicate that complete bread doughs were weakened during frozen storage and successive freeze-thaw cycles. Such weakening could result from an increase in reducing substances leached from yeast (which would cause a reduction of gluten proteins) or from redistribution of water caused by a change in the water-binding capacity of flour constituents. Perhaps both of these factors (and others as yet unidentified) are actively involved. Accordingly, to obtain high-quality bread from frozen doughs, the strength of the original dough must be somewhat higher than that required for standard bread production from nonfrozen doughs. In practice, this can be achieved by selecting a stronger flour, adding appropriate oxidants, or adding vital wheat gluten.

ACKNOWLEDGMENTS

We thank R. R. Zillman and P. K. W. Ng for technical assistance, A. R. Tweed for providing the flour sample, and R. H. Kilborn and K. R. Preston for providing the modified extensigraph dough holder. Financial assistance to Y. Inoue from the Japanese Institute of Baking Technology, Tokyo, is gratefully acknowledged.

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[Received October 9, 1990. Accepted May 30, 1991.]