Frozen Dough. II. Effects of Freezing and Storing Conditions on the Stability of Yeasted Doughs[1]

K. H. HSU,[2] R. C. HOSENEY, and P. A. SEIB[3]

ABSTRACT

Cereal Chem. 56(5):424-426

Final freezing temperature had a greater effect than the freezing rate on frozen-dough stability. The major damage to frozen-dough stability seems to be the freezing of the yeast cell, but storage conditions also affect frozen-dough stability. In general, frozen doughs were less stable if their storage temperature was lower than their freezing temperature. Thawing or partial thawing of frozen doughs followed by refreezing was harmful to frozen-dough stability.

Studies (Mazur 1967, 1970; Mazur and Schmidt 1968; Nei 1964; Nei et al 1967) on the preservation of microorganisms by freezing have shown that freezing and warming rates affect yeast viability. Slow freezing is generally believed to allow cells to adjust to the freezing environment by transferring intracellular water to the external ice. Fast freezing, on the other hand, causes intracellular freezing because temperatures change much faster than water permeates cell membranes. The small ice crystals formed during intracellular freezing are likely to recrystallize into larger crystals during warming and hence become lethal to the cells.

Most research on frozen doughs has concentrated on formulation changes and processing techniques, but the effects of freezing and warming rates on the stability of frozen doughs have been largely ignored. Lorenz (1974) speculated that freezing and thawing conditions affected the quality of frozen doughs, but no data were available to support the speculations.

We report the effects of cooling rates and final freezing temperatures on the quality of frozen doughs and effects of thawing and refreezing on the stability of the frozen doughs.

MATERIALS AND METHODS

Short-Time Dough Method

This improved short-time dough formula (Hsu et al 1979) was used: 100 g of flour (14% moisture), 3 g of sugar, 1.5 g of salt, 3 g of shortening (Crisco), 3 g of yeast, 1 g of malt, 100 ppm (based on flour) of ascorbic acid, 10 ppm (based on flour) of potassium bromate ($KBrO_3$), and an optimum amount of water.

Procedure

Each dough was mixed to optimum development in a National pin mixer (National Mfg. Co., Lincoln, NE). After fermentation in a cabinet maintained at 30° C and 90–95% rh for 40 min, the dough was sheeted through sheeter rolls set at 5/16-in. opening and was either frozen or molded. Molding was with a drum molder. The molded dough was panned and proofed (30° C, 90% rh) to a height of 7.5 cm, and the proof time was recorded. Loaf weight and volume were measured immediately after baking at 218° C (425° F) for 24 min. Volume was determined by rapeseed displacement.

Freezing

Doughs were frozen in rectangular slabs, approximately 7 1/2 × 3 × 1/2 in. The slabs were obtained by passing the doughs through sheeter rolls set at 5/16-in. opening. Doughs to be frozen in a homestyle, upright freezer were wrapped in aluminum foil and placed directly on the freezer shelf. Doughs to be frozen by submersion freezing were wrapped in plastic pouches and submerged in a temperature-controlled bath; after freezing completely, the doughs were transferred to a storage freezer at −18° C.

Thawing

For thawing, dough pieces were held for 1 hr in a fermentation cabinet maintained at 30° C and 90% rh. Because the doughs were still wrapped, there was no condensation problem. Dough temperatures after thawing were 26 ± 1.5° C. Thawed doughs were processed as described in the procedures (starting at the molder).

Reproducibility

Duplicate samples or more were run for each treatment. Standard deviations were calculated to be 11.6 cc, and 3.93 min for the loaf volume and poof time, respectively.

RESULTS AND DISCUSSION

Effect of Freezing Temperature

After 40 min of rest, mixed doughs were wrapped in plastic bags and submerged in a bath maintained at the desired freezing temperature. A thermocouple was placed at the geometric center of the dough, and dough temperature change was recorded at 1-min intervals. The freezing was considered complete when no change in dough temperature was detected. The frozen dough was transferred to a storage freezer maintained at −18° C (0° F) for one week before testing.

[1]Contribution 78-392-j, Department of Grain Science and Industry, Kansas Agricultural Experiment Station, Kansas State University, Manhattan, KS 66506.
[2]Present address: SCM Corp., Dwight P. Joyce Research Center, 16651 Sprague Road, Strongsville, OH 44136
[3]Graduate research assistant, professor, and professor, respectively.

0009-0352/79/000067$3.00/0

The freezing curves are shown in Fig. 1. Initial freezing started at about −4° C. Freezing curves at −20, −40, and −78° C show two eutectic points, one at about −12° C and another at about −35° C. For comparison, the freezing curve of yeast slurry (100 g of compressed yeast and 27 g of water) frozen at −78° C in a glass jar is presented in Fig. 2. The initial freezing point was difficult to locate; however, a major change in slope was observed at about −8° C, with a minor slope change at about −33° C. Most of the water probably was frozen at −8° C, but freezing (of the system) might not have been complete until the temperature went below −33° C. We speculate that the minor change of slope at about −33° C was due to the freezing of yeast cells. Dough is a much more complicated system than is yeast slurry, but Figs. 1 and 2 show similarities. Sugars and other dough ingredients depress the initial freezing point of dough to −4° C, with most of the water frozen by −12° C, and the yeast cells might not have frozen until the temperature dropped below −35° C. Doughs frozen at −10° C were thus believed not to be completely frozen.

Freezing curves at −40 and −78° C overlapped until the temperature reached −15° C. This is reasonable because the thermocouple was at the center of the dough and the phase change took place from the outside of the dough piece; therefore the driving force for heat loss between the ice front and the position of the thermocouple was kept fairly constant during the freezing process. With such a steep slope in that region of the freezing curve, few differences could be detected.

Differences in the freezing rates were obtained by submerging the dough in different freezing temperatures. When the change in the temperature at the location of the slowest freezing rate (Fig. 1, center) was used to calculate the cooling rate, cooling rates of 0.57, 1.94, and 5.0° C per minute were obtained for freezing at −20, −40, and −78° C, respectively. The freezing rate is many times faster on the surface of the dough than that at the center. A freezing rate as fast as 200° C per minute can be achieved by directly immersing dough at −78° C (Mazur and Schmidt 1968).

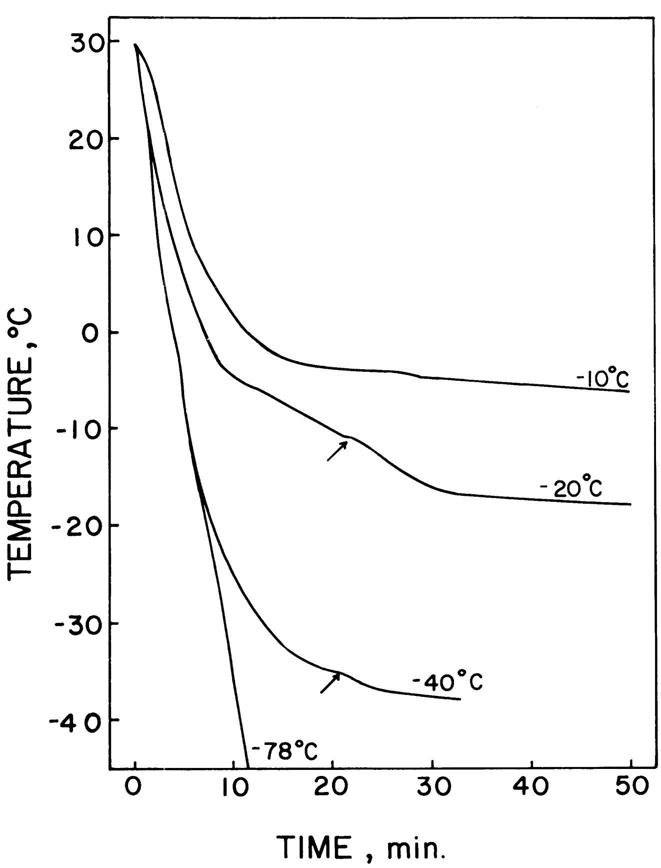

Fig. 1. Freezing curves of bread doughs submerged in temperature-controlled baths at indicated temperatures. Arrows indicate eutectic points at about −12° C and −35° C.

The baking results showed that freezing at different temperatures caused different levels of damage to yeast (Table I). Proof times for the frozen doughs were 72, 71, and 132 min for freezing at −10, −20, and−40° C, respectively. Doughs frozen at −78° C showed very little yeast activity after thawing—dough did not proof to height in 6 hr. The freezing rate apparently was responsible for the damage, but two other factors could affect the results. Either the lowest temperature reached or the temperature change from freezing to storage might affect yeast viability.

To differentiate between the effects of the freezing rate and those of the final temperature, dough samples were frozen to −40° C at a slower rate than normally achieved by direct immersion at −40° C. First the dough was frozen at −20° C until the geometric center of the dough was within three degrees of the bath temperature. The temperature was then lowered to and maintained at −40° C by addition of dry ice to the bath. The dough sample was equilibrated

TABLE I
Effect of Freezing Temperature on Frozen Dough Quality[a]

Freezing Temp (° C)	Proof Time (min)	Volume (cc)
−10	72	900
−20	71	925
−40	132	825
−78	>360	···

[a]Stored at −18° C for one week.

TABLE II
Effect of Cooling Rate on Frozen Dough Quality[a]

Freezing Temperature (° C)	Estimated Cooling Rate (° C/min)	Proof Time (min)	Volume (cc)
−20	0.57	71	925
−20 and −40	0.63	180	748
−40	1.94	132	825

[a]Stored at −18° C for one week.

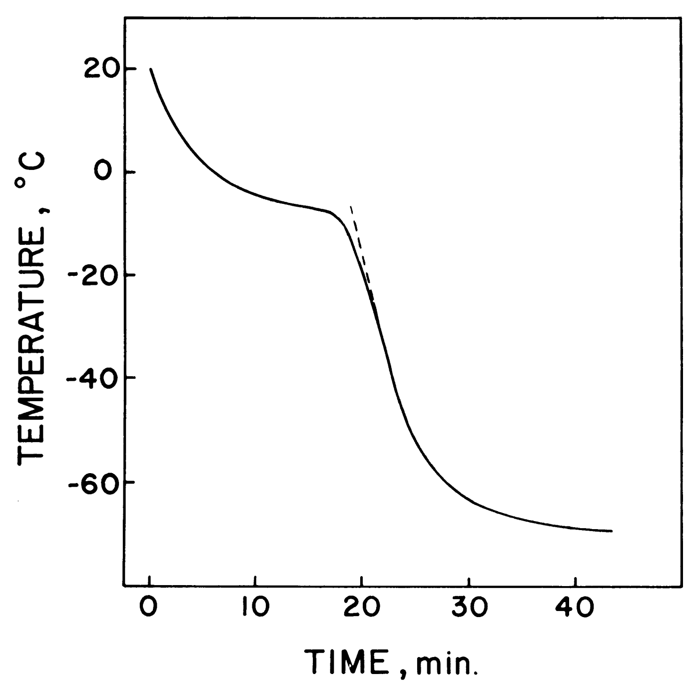

Fig. 2. Freezing curve of a yeast slurry (100 g of compressed yeast and 27 g of water, placed in a glass jar and submerged in a temperature-controlled bath at −78° C.

to within three degrees of the bath temperature and then stored at −18° C. The cooling rate obtained by this slow freezing method was close to that obtained by freezing at −20° C (0.63° C/min vs 0.57° C/min, respectively).

Slow freezing to −40° C was more detrimental to yeast survival than was direct freezing at either −20 or −40° C (Table II). Freezing to a lower temperature and freezing at a slower rate both damaged yeast within the temperatures and rate ranges studied. The lowest temperature reached had a greater effect on the yeast survival than did the freezing rate. These observations were quite surprising when compared with the results reported for freezing isolated yeast cells (Mazur 1967, 1970; Mazur and Schmidt 1968; Nei 1964; Nei et al 1967).

Effect of Temperature Change Between Freezing and Storage

The effect of change in temperature between freezing and storage was studied by maintaining two freezers, one at −18° C and one at −34° C. Thus doughs could be frozen at one temperature and stored at another (Table III). Changes in the temperature between freezing and storage clearly affected yeast viability. Doughs frozen at −34° C and stored at −18° C were damaged less than doughs frozen and stored at −34° C. Storage temperatures lower than freezing temperatures were more harmful than freezing and storing at the same temperature. Yeast activity was significantly lower in samples frozen at −18° C and stored at −34° C than in samples frozen and stored at −18° C. The damage from freezing at −18° C and storing at −34° C was even more pronounced than that from freezing and storing at −34° C. Damage seemed to result from transferring a frozen sample to a lower temperature. Yeast damage caused by slow freezing to −40° C was similar to that caused by freezing at −18° C and storing at −34° C. Both are two-step cooling processes. Change of storage temperature to a higher level did not cause much additional yeast damage (Table III).

Yeast damage apparently was caused by the freezing of the yeast cell. The freezing curves (Fig. 1) suggested that yeast cells freeze at around −35° C. All doughs frozen at temperatures materially lower than −35° C gave poor quality frozen doughs, regardless of cooling rates. That mode of damage is supported by the results of the two-step cooling tests. When samples were frozen at −10° C and transferred to −18° C (Table I), no severe yeast damage was observed, but when they were frozen at −20° C and transferred to a temperature below −35° C (Table II), the damage became severe.

The effect of thawing rate was not studied because thawing rate data is difficult to interrupt. Thawing frozen doughs overnight in a refrigerator would give long processing times with an unknown amount of fermentation. Yeast performance of such doughs compared with yeast performance of doughs thawed in a proof box would be difficult. Although yeast viability improves greatly by thawing frozen yeast rapidly, those rates probably could not be achieved with a dough system.

TABLE III
Effect of Temperature Change Between Freezing and Storage on Frozen Dough Quality

Temperatures (° C)		Proof Time	Volume
Freeze	Store	(min)	(cc)
−18	−18[a]	69	920
−18	−34[a]	98	855
−34	−34[a]	89	910
−34	−18[a]	80	875
−18	−34, −18[b]	100	880

[a]Samples were frozen at the given temperatures for 20 hr and stored at the given temperatures for one week.
[b]Samples were frozen at −18° C for 20 hr transferred to −34° C for 36 hr, and stored at −18° C for one week.

TABLE IV
Effect on Frozen Dough Quality of Repeated Freeze-Thaw Cycles During Storage[a]

Number of Freeze-Thaw Cycles	Proof Time (min)	Volume (cc)
0	120	810
1	146	748
2	173	733
3	203	733

[a]Frozen and stored at −34° C for 15 days after last freeze-thaw cycle.

Effect of Thawing During Storage

Frozen doughs are often mishandled while being loaded, transported, or kept in display freezers. The dough may be partially or even completely thawed and then refrozen later. Because temperature changes are involved, the quality of the frozen doughs may be affected. To study effects of thawing and refreezing, short-time doughs were prepared and frozen at −34° C; after a short storage period, doughs were removed from the freezer, thawed for 1 hr at room temperature, and then returned to the freezer. Thawing and refreezing damaged yeast viability, as shown by increased proof times (Table IV). Freeze-thaw damage was more severe after longer frozen storage than after short frozen storage. The proof time of the frozen doughs increased proportionally with the number of freeze-thaw cycles. Thus doughs should be kept frozen at all times to minimize yeast damage.

LITERATURE CITED

HSU, K. H., HOSENEY, R. C., and SEIB, P. A. 1979. Frozen Dough. I. Factors affecting stability of yeasted doughs. Cereal Chem. 56:419.

LORENZ, K. 1974. Frozen dough—Present trend and future outlook. Bakers Dig. 48(2):14.

MAZUR, P. 1967. Physical-chemical basis of injury from intracellular freezing in yeast. In: ASAHINA, E. (ed.). Cellular injury and resistance in living organisms. p. 171. Inst. Low Temp. Sci: Sapporo, Japan.

MAZUR, P. 1970. Cryobiology: The freezing of biological systems. Science 168:939.

MAZUR, P., and SCHMIDT, J. J. 1968. Interactions of cooling velocity, temperature, and warming velocity on the survival of frozen and thawed yeast. Cryobiology 5(1):1.

NEI, T. 1964. Freezing and freeze-drying of microorganisms. Cryobiology 1:87.

NEI, T., ARAKI, T., and MATSUSAKA, T. 1967. The mechanism of cellular injury by freezing in microorganisms. In: ASAHINA, E. (ed.). Cellular injury and resistance in living organisms. p. 157. Inst. Low Temp. Sci: Sapporo, Japan.

[Received January 18, 1979. Accepted March 29, 1979]