

Effects of Prolonged Storage at Freezing Temperatures on Starch and Baking Quality of Frozen Doughs

W. Lu¹ and L. A. Grant^{2,3}

ABSTRACT

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The effects of prolonged frozen storage on the starch, rheological, and baking properties of doughs were investigated. Four hard red spring (HRS) wheat cultivars exhibiting consistently different gluten characteristics were used. Gelatinization properties of starches isolated from fresh and thawed frozen doughs over 16 weeks of frozen storage were examined using differential scanning calorimetry (DSC). Significance of results varied with cultivar, but all cultivars showed a significant increase in ΔH with increased frozen storage time, indicating water migration and ice crystallization. The amount of freezable water in frozen doughs increased for all cultivars with frozen storage, but the rate of increase varied. Glupro

showed a consistent increase in freezable water during frozen storage (41.6%), which may be associated with its high protein content and strong gluten characteristics. Rheological strength of the frozen doughs which was determined by decreases in extensigraph resistance and storage modulus (G'), declined throughout frozen dough storage. Proofing time increased from 45 min for fresh doughs to an average of 342 min for frozen doughs stored 16 weeks. Concomitantly, loaf volumes decreased from an average of 912 cm³ for fresh doughs to an average of 738 cm³ for the frozen doughs. Longer proof times and greater loaf volume loss were obtained for the cultivars exhibiting greater gluten strength characteristics.

Water, as an important structural and chemical component of frozen dough, plays a significant role in frozen dough quality. Freezable water is the water that can form ice in a dough system when subjected to freezing and frozen storage (Davies and Webb 1969). Ice crystallization and recrystallization are closely related to water movement in the dough during freezing, frozen storage, and transportation of the frozen dough to bakery outlets. Effects of ice crystals on yeast stability, as well as the gluten network, have been proposed and examined (Kline and Sugihara 1968, Van Den Berg 1968, Varriano-Marston et al 1980, Berglund et al 1991).

Berglund et al (1991) studied the ultrastructural features of frozen dough using low-temperature scanning electron microscopy (LT-SEM). They indicated that after 24 weeks of frozen storage, water had separated into pools causing less free water to be distributed throughout the doughs. In addition, the gluten matrix appeared less continuous and more ruptured, which would explain the poor gas retention and decreased loaf volume of the resultant bread.

Wolt and D'Appolonia (1984) investigated differences in starch obtained from breads baked from frozen doughs. Highly significant positive correlations were found between amylose-amylopectin ratio, proof time, and loaf volume. Amylose-amylopectin ratios were also negatively correlated with frozen dough storage time.

Autio and Sinda (1992) studied gelatinization properties of starch in frozen doughs using differential scanning calorimetry (DSC). They observed that the onset temperature of starch gelatinization increased after the doughs were frozen and then thawed at 4°C. They also reported that prolonged storage at 4°C (>23 hr) further increased the onset temperature. They attributed the increase to either a delay in the diffusion of water into the starch granules or to increased growth of ice crystals in the frozen doughs.

The effects of frozen storage and freeze-thaw cycles on dough rheology and baking properties have been extensively studied (Kline and Sugihara 1968; Wolt and D'Appolonia 1984; Inoue and

Bushuk 1991, 1992; Autio and Sinda 1992; Inoue et al 1994). Recent studies of Inoue and Bushuk (1991, 1992) focused on the decline in frozen dough strength and baking quality deterioration. They indicated that frozen dough had a significant decrease in extensigraph maximum resistance after several freeze-thaw cycles and one week of frozen storage. They also reported that frozen doughs made with strong gluten flour showed better baking quality than conventional breadmaking wheats.

Although the factors involved in the deterioration of frozen dough quality are still not fully understood, it is generally agreed that the loss of dough strength and poor baking quality of frozen doughs may be attributed to decreased number of viable yeast cells and weakened gluten structure.

The objectives of this study were to 1) investigate certain physicochemical properties of the original wheat starches and starch isolated from frozen doughs, 2) measure the changes in rheological properties of frozen doughs as affected by frozen storage, 3) quantitatively determine changes in freezable water in frozen dough as frozen storage increased, and 4) examine the baking characteristics of frozen doughs over 16 weeks of frozen storage.

MATERIALS AND METHODS

Materials

Three cultivars of hard red spring wheat grown in North Dakota during 1995 were chosen for this study according to their farinograph characteristics. The cultivars (Glupro, Grandin, and Prospect) exhibited very strong, medium, and weak gluten properties, respectively. In addition, one extremely strong gluten cultivar (Glenlea) obtained from Manitoba, Canada, was also included in the study. The wheats were tempered to 15.5% moisture 24 hr prior to milling into straight-grade flour on a pilot mill (Buhler Miag Co., Minneapolis, MN) according to established procedures.

Proximate Analysis

Moisture, ash, and protein were determined by Approved Methods 44-15A, 08-01, and 46-13, respectively (AACC 1995).

Methods

Wet gluten content and gluten index were determined by Approved Method 38-12 (AACC 1995), using the Glutomatic 2200 to obtain the quantity of wet gluten. The wet gluten ball was then centrifuged using a Glutomatic 2015 centrifuge equipped with a special sieve for 1 min, and then weighed. The percentage of wet gluten remaining on the sieve was defined as the gluten index. A low value indicates a weak gluten.

¹ Graduate research assistant, Department of Cereal Science, North Dakota State University, Fargo, ND 58105. Present Address: Byrnes and Kiefer Co., Callery, PA 16066.

² Research chemist, USDA-ARS Hard Red Spring/Durum Wheat Quality Laboratory, Fargo, ND 58105. Mention of vendor or proprietary product does not constitute a guarantee or warranty of the vendor or product by the USDA, and does not imply its approval to the exclusion of other vendors or products that may also be suitable.

³ Corresponding author. E-mail: lgrant@badlands.nodak.edu Fax: 701-239-1377.

Farinograms were obtained by Approved Method 54-21 (AACC 1995). A constant flour weight and a 50-g bowl was used for all flours. Data obtained from the farinograms included absorption, peak time and dough mixing stability.

At zero weeks (control) and at each four-week interval of frozen storage thereafter, extensigraph measurements were made on the thawed, frozen doughs following the procedure described by Inoue and Bushuk (1991). Previously frozen, thawed dough pieces (160 g) were molded into cylinders (16.0 cm), proofed in a fermentation cabinet maintained at 30°C and 85% rh to a predetermined height, and stretched using the extensigraph. The predetermined proofing height for the frozen doughs was established on the unfrozen control dough of each flour after 45 min of fermentation under the same proofing conditions.

Total starch and damaged starch contents were determined on the flour samples using enzyme assay kits (Megazyme International Ireland Ltd. C., Wicklow, Ireland) and Approved Methods 76-13 and 76-31 (AACC 1995), respectively.

The dough ball washing method of Walden and McConnell (1955) was used to isolate starch from the four flour samples and from the thawed frozen doughs (three for each cultivar) after each four-week interval of frozen storage. Water-binding capacity was determined on the starch isolated from the four flour samples using the method of Medcalf and Gilles (1965).

Intrinsic viscosity was determined on the starch isolated from the four flour samples according to the method of Leach (1963), using a Cannon-Ubbelohde semi-micro-viscometer (International Research Glassware, Kenilworth, NJ) equipped with an automatic viscosity timer (Jupiter Instruments, Jupiter, FL). Starch (0.05 g) was dissolved in 1N NaOH according to the method of Lansky et al (1949). Flow times of the starch solution diluted to four different concentrations (0.125, 0.167, 0.25, and 0.5%) were measured at 25°C and used to calculate intrinsic viscosity, which was reported as inherent viscosity versus concentration.

TABLE I
Analytical and Rheological Data of Flours

	Glupro	Grandin	Glenlea	Prospect
Analytical ^a				
Protein (%)	16.6a ^b	14.2b	12.1c	12.8c
Ash (%)	0.46a	0.51a	0.45a	0.41c
Total starch (%)	68.5b	69.4b	72.9a	71.3a
Damaged starch (%)	4.6b	4.2b	5.4a	4.0b
Wet gluten (%)	45.4a	39.6b	32.0d	35.8c
Gluten index (%)	87.3b	79.0c	99.1a	57.1d
Farinograph				
Absorption (%)	64.1a	63.0a	60.0b	61.0b
Peak time (min)	11.5b	8.0c	24.5a	5.5d
Stability (min)	48.5a	11.0c	25.8b	8.0d
Extensigraph				
Max. resistance (BU)	816b	353c	960a	169d

^a Expressed on 14% mb.

^b Values followed by the same letter in the same row are not significantly different ($P < 0.05$).

TABLE II
Chemical and Physical Properties of Flour Starch Isolates

	Glupro	Grandin	Glenlea	Prospect
Analytical				
Water-binding capacity (% dwb)	85.8a ^a	80.4b	88.9a	78.5c
Intrinsic viscosity (η)	1.521b	1.491b	1.770a	1.447b
Amylose content (%)	27.1a	26.8a	24.7b	26.7a
Thermal properties				
Onset temperature (°C)	56.1a	56.0a	54.9b	54.2b
Peak temperature (°C)	61.1a	60.9a	59.9b	59.3b
Enthalpy (J/g)	10.9a	11.0a	10.2a	11.0a

^a Values followed by the same letter in the same row are not significantly different ($P < 0.05$).

Percent amylose content was estimated on the starch isolated from the four flour samples using the procedure of Williams et al (1970).

Thermal properties of starches isolated from the four flours and from thawed frozen doughs were analyzed using a differential scanning calorimeter (DSC 7, Perkin-Elmer Corp., Norwalk, CT) according to the procedure of White et al (1989). Starch (3.5 mg, dwb) was weighed directly into aluminum DSC pans, followed by the addition of 8 μ L of purified, deionized distilled water. The pans were hermetically sealed and allowed to equilibrate at room temperature overnight. Samples were heated from 40 to 130°C at a scanning rate of 10°C/min. The thermal transition of the starches was recorded as onset (T_o) and peak (T_p) transition temperatures. Enthalpy of gelatinization (ΔH) was expressed as J/g. An average of at least three thermograms was used for each starch.

Frozen Dough Preparation

Doughs were prepared using a no-time straight-dough procedure as described by Kamman (1979). By definition, a straight-dough method is one in which all the ingredients are placed in the mixer and mixed in a one-step process. A no-time dough is one that is taken from the mixer directly to the divider with no more than 15 min of rest time. Due to reduced fermentation, a typical no-time dough has several formula adjustments (Kamman 1979). For our frozen dough study, we used increased levels of oxidation, yeast, and shortening, and decreased levels of salt and water. The formula consisted of flour (100%), compressed yeast (5.0%), shortening (4.0%), sugar (4.0%), salt (1.5%), ice water (based on farinograph absorption – 4%), ascorbic acid (100 ppm), and potassium bromate (50 ppm). Flour (300 g) was blended thoroughly with the sugar and salt and placed in the mixer. The shortening and crumbled yeast was added and blended with the dry ingredients. Oxidants and ice water were added, and the dough was mixed to optimum dough development. Temperature was kept <20°C by using ice water in the formula and keeping all ingredients cold before mixing. After the dough was mixed, it was immediately scaled into three 160-g pieces, rounded, and placed in stainless steel bowls in a fermentation cabinet held at 25°C and 85% rh for a 10-min rest. The doughs were then molded on a laboratory-scale molder and placed into baking pans.

TABLE III
Correlation Coefficients of Starch Properties^a

	Damaged Starch	Water-Binding Capacity	Intrinsic Viscosity	Total Starch	Amylose Content
Damaged starch	1.000	0.793** ^b	0.919**	0.475	-0.723**
Water-binding capacity		1.000	0.720**	0.177	-0.517
Intrinsic viscosity			1.000	0.538	-0.671*
Total starch				1.000	-0.831**
Amylose content					1.000

^a Triplicate analysis of four starch samples, $n = 12$.

^b *,** = Significant at $P < 0.05$ and 0.01 , respectively.

TABLE IV
Correlation Coefficients Between Differential Scanning Calorimetry (DSC) Starch Gelatinization and Other Starch Properties^a

	Onset Temperature	Peak Temperature	Enthalpy of Gelatinization
Damaged starch	0.087	0.071	-0.378
Water-binding capacity	0.235	0.254	-0.305
Intrinsic viscosity	-0.191	-0.166	-0.410
Total starch	-0.662** ^b	-0.754**	-0.310
Amylose content	0.310	0.412	0.664

^a Triplicate analysis of four starch samples, $n = 12$.

^b *,** = Significant at $P < 0.05$ and 0.01 , respectively.

Dough Freezing and Frozen Storage

The panned dough pieces were placed in a quiescent freezer at -72°C and frozen to a core temperature of -16°C within 90 min (Brummer 1995). At this point, the frozen dough cylinders were removed from the freezer, depanned, double-bagged in polyethylene bags, and stored in a walk-in freezer at -23°C for a total of 16 weeks of frozen storage.

Dough Thawing, Proofing, and Baking

At zero weeks of frozen storage and at each four-week interval thereafter, 12 doughs (three for each cultivar) were placed in greased baking pans and allowed to thaw for 16 hr in a retarder at 4°C , according to the method of Inoue and Bushuk (1991). The doughs were then placed into a fermentation cabinet maintained at 30°C and 85% rh and final proofed to a predetermined height for the nonfrozen control loaves (Inoue and Bushuk 1991). An average of the proofing times of replicate dough pieces for each cultivar was recorded. The loaves were baked at 425°F for 25 min and cooled for 30 min before being weighed. Loaf volume was determined by rapeseed displacement.

Determination of Freezable Water

A differential scanning calorimeter (DSC 220C, Seiko Instruments Inc., Japan) was used to measure the amount of freezable water in thawed frozen doughs at zero weeks of frozen storage and at each four-week interval, according to the method of Davies and Webb (1969). Four samples of dough (5 mg) were cut from the center of a dough cylinder (three for each cultivar) and sealed in tared aluminum DSC pans. A sealed, empty pan was used as a reference. Each sample was cooled to -50°C and then heated at a rate of $10^{\circ}\text{C}/\text{min}$ to $+50^{\circ}\text{C}$ once, with the endotherm being presented as a peak. The ΔH of the freezable water endothermic transition was recorded.

Dynamic Rheometer Measurements

The storage modulus (G') of the thawed, frozen doughs was tested using a parallel plate dynamic rheometer according to the method described by Zang (1997) at zero weeks of frozen storage

and at each four-week interval. The rheometer (designed and built by the Kansas State University physics department) consisted of several small pieces of electronic equipment. A detailed description and schematic diagram of the parallel plate dynamic rheometer for dough stress-strain testing, similar to the one used in our study, has been reported by Faubion et al (1985). For the test, a 40-g piece of thawed, frozen dough was flattened by hand with minimal stretching, placed in a bowl, covered with a wet towel, and allowed to rest for 30 min at 25°C . The dough piece was removed from the bowl and carefully placed on the bottom plate of the rheometer. The top plate was placed above the sample, and the two plates were pressed together by hand and tightened with a screw. The excess dough was trimmed using a razor blade. The exposed sides of the dough were coated with grease (Kendall Super Blu, Witco Corp., Bradford, PA) to prevent drying. The dough was allowed a 5-min rest before testing.

Statistical Analysis

Four flour samples were used to evaluate frozen dough quality over an extended period of frozen storage. Freezable water, thermal properties, rheological properties, and baking quality were determined on doughs at 0, 4, 8, 12, and 16 weeks of frozen storage. The doughs were prepared using a factorial design incorporating the four cultivars, six tests, and five storage periods. All analyses were performed in triplicate. Analysis of variance, Duncan's new multiple range test, and Pearson's correlation were used to analyze the data using the Statistical Package for the Social Sciences (SPSS) system. Values with $P > 0.05$ and 0.01 were considered significant and highly significant, respectively.

RESULTS AND DISCUSSION

Analytical and Rheological Properties of Flours

The proximate composition and rheological properties of the four flour samples are summarized in Table I. The cultivars chosen for this study had flour protein contents ranging from 16.6 to 12.1%. Although Glenlea had the lowest protein and wet gluten contents (12.1 and 32.0%, respectively) of the four flours, this cultivar had a significantly higher gluten index value and exhibited extremely strong farinograph mixing characteristics. This flour has an overly strong gluten character that was also evident with an extensigraph maximum resistance value of 960 BU.

Flour with such overly strong gluten characteristics is generally unsuitable for conventional baking but does perform better in frozen dough procedures (Inoue and Bushuk 1992). Glupro had the highest protein content of the four flour samples, as significantly demonstrated by its wet gluten content. In addition to a greater quantity of protein, this cultivar has a gluten index and farinograph profile that indicated it had good quality protein as well. Prospect, which was chosen for its weak gluten characteristics showed that, although it had a respectable amount of protein (12.8 and 35.8% protein and wet gluten, respectively), the quality of that protein was inferior to the protein of the other three cultivars. This was evident by its low gluten index value and weak farinograph profile. Of the four cultivars, Grandin had a normal farinograph profile, indicating good quality for conventional breadmaking. Highest and lowest starch

TABLE V
Correlation Coefficients Between Starch Properties of Flour Starch Isolates and Rheological Properties of Wheat Cultivars^a

	Farinograph		Extensigraph	
	Absorption	Dough Stability	Development Time	Max. Resistance
Damaged starch	-0.386	0.281	0.942** ^b	0.772**
Water-binding capacity	-0.119	0.703*	0.883**	0.941**
Intrinsic viscosity	-0.475	0.257	0.903**	0.682*
Total starch	-0.908**	-0.374	0.561	0.133
Amylose content	0.637*	0.088	-0.776**	-0.461
Onset temperature	0.666*	0.466	-0.028	0.363
Peak temperature	0.771**	0.559	-0.055	0.361
Enthalpy	0.082	-0.055	-0.360	-0.216

^a Triplicate analysis of four starch samples, $n = 12$.

^b *,** = Significant at $P < 0.05$ and 0.01, respectively.

TABLE VI
Differential Scanning Calorimetry (DSC) Starch Gelatinization Properties of Fresh and Frozen Dough Starch Isolates at 0 and 16 Weeks of Frozen Storage^a

	Glupro		Grandin		Glenlea		Prospect	
	0 weeks	16 weeks	0 weeks	16 weeks	0 weeks	16 weeks	0 weeks	16 weeks
Onset temperature ($^{\circ}\text{C}$)	56.1	56.3	56.0	56.9** ^b	54.9	55.0	54.2	54.8*
Peak temperature ($^{\circ}\text{C}$)	61.1	61.1	60.9	61.5*	59.9	60.3	59.3	59.6
Enthalpy (J/g)	10.9	12.0**	11.0	11.5*	10.2	11.6**	11.0	11.9*

^a Mean of triplicate analysis for weeks 0 and 16 of frozen storage.

^b *,** = Significantly different at $P < 0.05$ and 0.01, respectively.

content (72.9 and 68.5%) was obtained for Glenlea and Glupro, respectively. Starch content of wheat appears to be inversely related to protein content (Hopkins and Graham 1935). This phenomenon was evident with all four wheat flours, which showed significant differences between the two higher and two lower protein cultivars. Starch damage was similar for Glupro, Grandin, and Prospect but significantly higher (1%) for Glenlea. Environmental as well as soil and nutrient conditions can have a profound effect on wheat kernel hardness. This, in turn, may affect the grinding process during milling, producing a higher amount of starch damage. Because Glenlea is a Canadian wheat and the other three cultivars were grown at one location in North Dakota, environment may be the most likely factor for the difference.

Physicochemical Properties of Starch

The chemical and physical properties of starch isolated from the four flour samples are shown in Table II. Starch derived from a flour with high starch damage generally will have a high water-binding capacity as well. This may be related to the gluten strength of the flour. Glenlea had the highest damaged starch and water-binding capacity values of the four cultivars examined. The fact that Glenlea was the cultivar exhibiting overly strong gluten characteristics may explain these differences. Differences in gluten strength may also explain the low starch damage and water-binding capacity obtained for the weak gluten cultivar, Prospect. The intrinsic viscosity of Glenlea starch was significantly higher than that of the other three starches. Although not statistically significant, Glupro starch had the next highest value. Highly significant correlations ($P < 0.01$) existed between damaged starch, water-binding capacity, and intrinsic viscosity for the starches isolated from the four cultivars of wheat (Table III). Because intrinsic viscosity has been referred to as an index of starch molecular dimensions (Leach 1963), water-binding capacity and the amount of mechanical damage a starch sustains during the milling process could be related to its molecular structure and composition.

A statistically significant difference in amylose content (Table II) was obtained between Glenlea and the other three starches. The greatest difference existed between Glenlea and Glupro. Table III also showed a significant correlation between intrinsic viscosity and amylose content of the four starches. Higher amounts of amylopectin in the starch, as shown for Glenlea, was correlated with higher intrinsic viscosity and higher starch damage. Amylose content was also highly correlated with total starch, which would be an expected result. Differences in amylose content have been

associated with grain development and maturity (Bice et al 1945, Abou-Guendia and D'Appolonia 1973) and with environment (Medcalf and Gilles 1965). Therefore, the correlations found between amylose content, starch damage, and intrinsic viscosity could all be environmental or cultivar effects.

The DSC thermal properties of the starches isolated from the four flours (Table II), showed small differences in transition temperatures and enthalpies of gelatinization. Glupro and Grandin had significantly different T_o and T_p transition temperatures than Glenlea and Prospect. These observations coincide with the lower and higher starch contents of the two sets of cultivars and also with the higher and lower protein contents of the two sets (Table I), respectively. A significant negative correlation (Table IV) was obtained between total starch and T_o and T_p transition temperatures. No statistically significant differences were found for ΔH for all starches, but the lower ΔH values obtained for Glenlea and Glupro agree with the higher damaged starch values. Gelatinization enthalpy is directly proportional to the level of starch damage, the more starch damage, the lower the ΔH (Eliasson and Larsson 1993).

Table V showed that damaged starch, water-binding capacity, and intrinsic viscosity were highly associated with the rheological strength of the flour. The two flours, Glenlea and Glupro, exhibiting overly strong and very strong gluten characteristics, respectively, had higher starch damage, water-binding capacity, and intrinsic viscosity values than the other two flours. Table V also showed a significant correlation between starch content and farinograph absorption for the Glupro and Grandin flours. The positive correlations existing between T_o and T_p and farinograph absorption (Table V) indicated that farinograph absorption may be related to starch gelatinization properties.

Thermal Properties of Starch Isolated from Frozen Dough

Starch isolated from thawed frozen dough after four-week intervals of frozen storage was compared with starch isolated from the flour (Table II) for each cultivar. Data for the control starch (zero weeks) and the starch isolated after 16 weeks of frozen storage are summarized in Table VI. Only the gelatinization thermograms for each of the starches were examined. In general, frozen storage time significantly increased the T_o , T_p , and ΔH of the Grandin frozen dough starch. Prospect showed a significant increase in T_o and ΔH , and Glupro and Glenlea showed only significant increases in ΔH with increased frozen storage time. The increase in ΔH of the starches after 16 weeks of frozen storage, although small, may reflect the possibility of some retrogradation taking place within the starch granules during frozen storage or perhaps

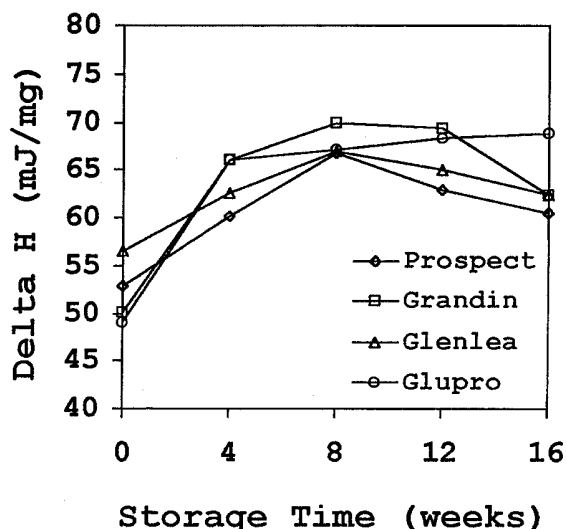


Fig. 1. Change in freezable water in frozen doughs over 16 weeks of frozen storage measured as change in ΔH using differential scanning calorimetry.

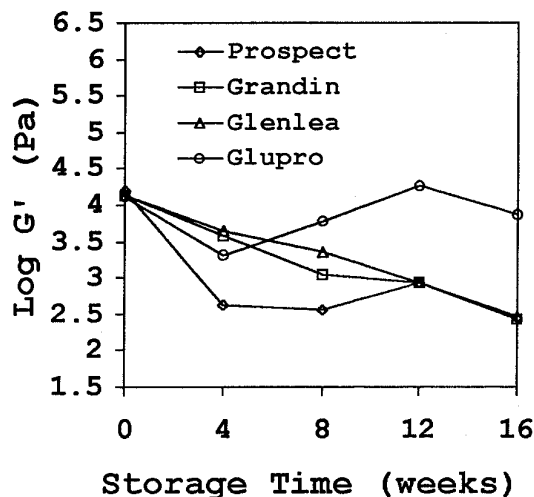


Fig. 2. Change in storage modulus (G') in frozen doughs over 16 weeks of frozen storage.

during the thawing of the doughs before starch isolation. Another possibility may be related to the differences in starch damage of the four cultivars. Differences in localized microscopic water content due to starch damage and freezing may result in higher enthalpies.

Freezable Water in Frozen Doughs

Water is essential for the transformation of flour to dough. Water is also necessary to establish a viscoelastic structure in dough and may be directly involved in the structure by providing a medium for interactions among flour constituents. The results shown in Fig. 1 indicate that the initial freezing and subsequent frozen storage of the doughs changed the amount of freezable water in the doughs. The amount of freezable water increased as frozen storage time increased until week 8, then began to decrease slowly until week 16 for all cultivars, except Glupro. Glupro showed a consistent increase in freezable water during frozen dough storage. Due to the high protein content (16.6%) of Glupro, more water could possibly be associated with both nonpolar and polar amino acid groups of the flour protein, which would account for less initial free water in the Glupro dough (Fig. 1). This bound water in the Glupro dough was continuously liberated from the gluten structure and gathered into a pool as frozen storage continued. The migration of water in the Glupro dough continued after the rate of separation had declined in the other three cultivars. The results of this study provide quantitative evidence supporting the observations of Berglund et al (1991). Water migration in frozen doughs would affect gluten structure. Gluten proteins contain a large proportion of amino acids with nonpolar chains. According to Fennema (1972), these nonpolar amino acid groups have a structure-forming action on the adjacent water. The interaction between water and nonpolar groups of protein, mainly hydrophobic interaction, has an important bearing on the native

conformation of gluten proteins. In addition to the nonpolar amino acid groups, gluten also contains ionic and other groups capable of participating in hydrogen bonding. Water may also be involved in the gluten structure by forming cross-links among the polar groups. Dislocation of water, which occurs during the freezing process and continues during frozen storage, would offer an opportunity for additional intermolecular and intramolecular protein bonding, including hydrophobic and hydrogen bonding. This interaction may change the gluten structure irreversibly. Using LT-SEM, Berglund et al (1991) showed that gluten strands became thinner and the gluten matrix appeared less continuous and more ruptured after 24 weeks of frozen dough storage. According to Kulp (1995), dehydration undoubtedly caused disruption of certain bonds in dough systems, which could affect the functionality of doughs.

Rheological Properties of Frozen Doughs

The extensigraph is used and regarded as a suitable instrument for frozen dough evaluation (Kulp 1995). For our study, the rheological properties of the frozen doughs were determined using an extensigraph and a parallel plate dynamic rheometer. Changes in extensigram maximum resistance and extensibility of frozen dough during frozen storage from zero to 16 weeks are shown in Table VII. Maximum resistance decreased significantly for thawed doughs made from all four cultivars as frozen storage time increased. Extensibility of the thawed doughs significantly increased over time for Glenlea and, for the most part, Glupro. No consistent trends could be established for Grandin and Prospect. Our results agreed with the findings of Inoue and Bushuk (1991), who found that maximum resistance decreased and extensibility increased significantly for frozen dough stored for one week. A Canadian

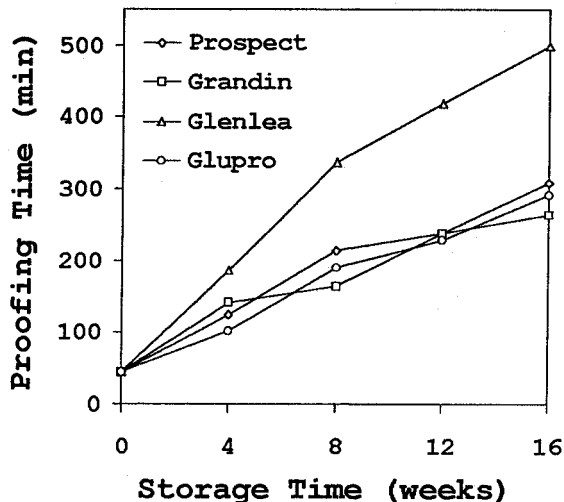


Fig. 3. Change in proofing time of frozen doughs over 16 weeks of frozen storage.

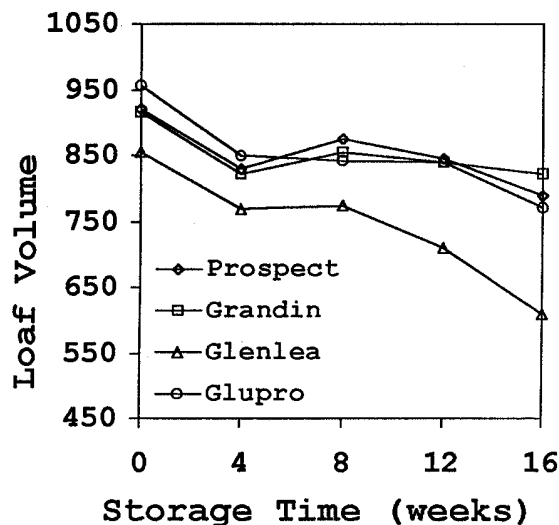


Fig. 4. Change in loaf volume (cm³) of frozen doughs over 16 weeks of frozen storage.

TABLE VII
Maximum Resistance and Extensibility of Frozen Doughs After Proofing Using an Extensigraph

Storage Time (weeks)	Glupro		Grandin		Glenlea		Prospect	
	Resistance (BU)	Extensibility (cm)	Resistance (BU)	Extensibility (cm)	Resistance (BU)	Extensibility (cm)	Resistance (BU)	Extensibility (cm)
0	736a ^a	9.8c	480a	10.1b	797a	9.7c	382a	9.7a
4	711a	12.1a	398b	9.6c	666b	10.7b	337b	7.9b
8	620b	12.5a	385b	9.1c	633b	11.2b	306b	8.0b
12	533c	11.4b	337c	11.5a	547c	11.9a	237c	5.9c
16	538c	12.6a	316c	10.3b	535c	12.2a	236c	9.9a

^a Values followed by the same letter in the same column are not significantly different ($P < 0.05$).

western red spring wheat cultivar was used in their study. The differences observed in our study may be, in part, due to the differences in gluten strength of the four cultivars examined. In contrast, Varriano-Marston et al (1980) found the opposite results (increased maximum resistance and decreased extensibility) for dough stored one month at -18°C . No mention was made in reference to the class or cultivar of wheat or the gluten characteristics of the flour used to prepare the frozen doughs. Assuming a hard red winter wheat was used, the difference in gluten strength may well account for the differences in their results compared with ours.

Frozen dough rheology was also measured using a parallel plate dynamic rheometer. Figure 2 shows that G' decreased for all cultivars except Glupro for the entire 16 weeks of frozen storage. The G' reflects the property of elasticity in a dough system (Abdelrahman and Spies 1986). A decrease in G' represents a decline in dough elasticity and a weakening of the gluten structure. This was particularly evident for Prospect. Similar observations were reported by Autio and Sinda (1992). They indicated that the decrease in G' due to freezing and thawing could be attributed to a loss of polymer cross-bonding. They also stated that the release of reducing compounds from the yeast was not responsible for dough weakening. However, their rheological testing was based only on a thawed frozen dough that had not been proofed. Of the four cultivars we examined, only Glupro exhibited good stability of G' during frozen dough storage. This indicated that protein quality, as well as quantity, plays an important role in frozen dough performance.

Effect of Frozen Dough Storage on Baking Quality

Pertinent baking properties of frozen doughs made from the four wheat cultivars are shown in Figs. 3 and 4. Significant increases in proofing time and decreases in loaf volume were obtained for all of the thawed frozen doughs as frozen storage time increased. These results were consistent with other reports (Wolt and D'Appolonia 1984, Dubois and Blockcolsky 1986, Hino et al 1987, Holmes and Hosenev 1987, Neyreneuf and Van Der Plaet 1991, Inoue and Bushuk 1992). The frozen retarded dough of Glenlea that had overly strong gluten characteristics but relatively low protein content (12.1%) exhibited the greatest increase in proofing time and decrease in loaf volume when compared with the other three cultivars. Because the dough strength of Glenlea (resistance to extension) (Table VII) was higher than that of Grandin and Prospect as frozen storage increased, damage to yeast during freezing and frozen storage should be considered. If significant yeast damage occurred during the freezing process and during long frozen dough storage, limited amounts of yeast would be available in the dough to produce CO_2 . Other possibilities, reported by Varriano-Marston et al (1980), include the release of certain chemical compounds from dead yeast cells, particularly reducing compounds that may affect the dough structure in a deleterious manner, causing thinning of the gluten strands. The gluten network of Glenlea may be too strong for the limited CO_2 to expand or leakage of CO_2 may have occurred due to disrupted or altered gluten structure. In either case, a prolonged proofing time was required to reach the predetermined proof height, which undoubtedly contributed to its lower loaf volume. If the overly strong gluten structure of Glenlea restricted the limited CO_2 from expanding, then Prospect, which exhibited weak gluten characteristics, should have shown good baking performance. However, this was not the case. In addition to the effect of reduced yeast activity, damage caused by the freezing process and frozen storage on the weak gluten structure of Prospect was very significant. It is speculated that Prospect may be less freeze-tolerant because of its weaker gluten properties and may be more susceptible to ice crystallization-induced damage resulting in its prolonged proof time and lower loaf volume. Of the four cultivars, Grandin had the shortest proof time and greatest loaf volume after 16 weeks of frozen storage.

Damaged starch, intrinsic viscosity, and water-binding capacity of the four flour starch isolates were positively associated with gluten strength of the wheat cultivars from which they were derived. These results indicated that a relationship may exist between certain starch properties and dough rheological properties. Although environmental influences may play a part in these observations, this is an area that needs additional research.

Water migrates in frozen dough (Berglund 1991). Water separates from the protein and starch components in the dough and accumulates into a pool that subsequently crystallizes. During prolonged frozen storage, the amount of freezable water in the frozen doughs increased significantly, but the rate of increase varied among the four cultivars. Protein content as well as protein quality, in terms of gluten strength, appeared to influence the amount of freezable water in the dough. The amount of freezable water in the high protein cultivar dough (Glupro) increased 41.6%, whereas, for Prospect, the increase was 24.0% after 16 weeks of frozen storage.

Extensigraph maximum resistance for thawed, proofed frozen doughs decreased with prolonged frozen storage. Proofing may be an important period in the loss of gluten strength for frozen doughs. Although strong gluten wheats are recommended for frozen dough production, wheat cultivars exhibiting overly strong gluten characteristics may not provide desirable frozen dough baking performance.

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