

Effect of Hydrophilic Gums on Frozen Dough. I. Dough Quality

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ABSTRACT

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Disadvantages of frozen doughs are their variable performance and loss of stability over long-term frozen storage. Changes in rheological properties of frozen doughs have been reported to be due to the physical damage of the gluten network caused by ice crystallization and recrystallization. The objective of this study was to determine the effect of hydrophilic gums on ice crystallization and recrystallization for improvement of the shelf-life stability of frozen dough. The present research involved use of the Hard Red Spring wheat cultivar Grandin and hydrophilic gums such as carboxymethyl cellulose (CMC), gum arabic, kappa carrageenan (κ -carrageenan), and locust bean gum at three different levels each on doughs stored frozen for up to 16 weeks. The dough characteristics were analyzed after day 0, day 1, and after 4, 8, 12, and 16 weeks of frozen storage using data from differential scanning calorimetry (DSC), water activity, extensigraph, and proof time. The ΔH value of freezable water endothermic transitions obtained using DSC increased with storage time for all treatments. However, addition of

different levels of the four gums lowered the ΔH value, indicating a decrease in freezable water. Doughs with locust bean gum gave a higher peak force, measured using the Kieffer dough extensibility rig of the texture analyzer, and lower proof time, indicating better retention of baking quality. Maximum resistance to extension increased upon addition of 1 and 3% CMC; 1 and 3% κ -carrageenan; and 1, 2, and 3% locust bean gum as compared with the control. The various periods of storage or gum treatments did not affect the water activity of the thawed frozen doughs. Doughs with locust bean gum gave significantly lower proof time compared with the other treatments and the control. CMC gave the second lowest values, followed by gum arabic treatment. Addition of κ -carrageenan increased the proof time compared with the control. In summary, locust bean gum, gum arabic, and CMC improved the dough characteristics to varying degrees. κ -Carrageenan was the only gum that showed a detrimental effect on frozen dough.

The current trend in the baking industry is to use frozen dough to manufacture quality products because it can be quickly transformed into fresh baked product. However, the use of frozen dough has certain disadvantages such as its variable performance and loss of stability over long-term frozen storage (Inoue and Bushuk 1991; Berglund 1988). The loss of stability is indicated by increase in proof time, decrease in loaf volume, poor bread characteristics, and loss of shelf life. During freezing, frozen storage, and thawing, frozen dough encounters processing stresses that lead to loss of dough strength, yeast stability, and, consequently, deterioration in the product quality. In foods containing an appreciable amount of water, some ice crystal formation will definitely occur, producing changes in distribution of solutes and, perhaps, also in structure of biochemical components.

Research has shown that ice crystallization and recrystallization causes physical damage to the gluten network, leading to changes in the rheological properties of the frozen dough. Water available for freezing forms ice crystals that injure yeast cells (Mazur 1961). The ice crystals formed during freezing puncture the outer membrane of the yeast cell, leaching out its cytoplasmic contents, whereas, in dormant yeast cells, the thicker cell membranes resist this physical damage. Activated yeast cells undergo autolysis due to metabolic products such as ethanol, acetic acid, lactic acid, and small quantities of esters formed during fermentation. Cell death occurs during freezing because these materials concentrate in unfrozen medium and rupture the cell. Therefore the yeast activity has to be minimized during the preparation of frozen dough (Bruinsma and Giesenschlag 1984).

Kobbs (1997) has suggested that there could be a possibility of reducing the freeze/thaw damage by incorporating gums in frozen dough. Gums trap free water and control moisture migration. Furthermore, Ward and Andon (1993) mentioned that gums such as carboxymethyl cellulose, carrageenan, gum arabic, and locust bean gum may be used to alleviate the problems associated with frozen dough. Schwarzlaff et al (1996) observed positive effects

on the shelf life of bread by partially replacing flour with locust bean gum and guar gum. Finding gums that give anti-freeze properties and depress freezing temperature may help to alleviate the problem.

Therefore, in this study, it was hypothesized that the hydrophilic gums will help in holding or binding water in the frozen dough and in minimizing water migration in the dough during frozen storage and freeze-thaw cycles. The binding or immobilization of water should reduce ice crystal formation and subsequent damage to the gluten network, loss of frozen dough strength, and damage of yeast cells, resulting in shorter proof times, higher loaf volumes, and better quality of final baked product. The major objective of our research was to determine the effect of incorporating gums on ice crystallization and recrystallization in frozen dough.

MATERIALS AND METHODS

Materials

The Hard Red Spring wheat cultivar Grandin was used in this study. It was tempered to 15.5% moisture content for 24 hr and milled on a Miag pilot mill to obtain a 70% extraction. The gums used were CMC from Hercules (Wilmington, DE), gum arabic A-23 from Hi-Tek Polymers (Clifton, NJ), κ -carrageenan (Carravis 88, Carrageenan, Santa Ana, CA), and locust bean gum (Dycol 2600, National Starch and Chemical Co., Bridgewater, NJ). Compressed yeast was procured from Fleischmann's Yeast (Fenton, MO) and used within one week of receipt.

Flour Quality

Approved Methods (AACC 2000) were used to determine moisture (44–15A), protein (46–16), ash (08–01), wet gluten and gluten index (38–12), farinograph (54–28A), extensigraph (54–10), alveograph (55–21), mixograph (54–40A), and falling number (56–81B) of the flour (data not shown). A Rapid Visco Analyser (RVA) (Newport Scientific Ltd., Warriewood, Australia) and the procedure described by Deffenbaugh and Walker (1989) were used to analyze starch pasting properties.

Levels of Gums

Levels of gums used in this study were chosen based on the farinograph results and the baking performance. To find the optimum levels of each gum, farinograph curves were obtained

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with levels of each gum at 0–15%. The parameters calculated from the farinogram were absorption (%), peak or dough development time (min), stability (min), and mixing tolerance index (BU). The optimum levels were 1, 2, and 3% of gum arabic, CMC, κ -carrageenan, and locust bean gum. Farinograph characteristics are summarized in Table I. Also, specific loaf volume was measured, and external and internal appearances were evaluated from the bread loaves prepared with each level of the four gums. The optimum levels were 1, 2, and 3% of the four gums.

Dough Formulation and Preparation of Frozen Doughs

A straight no-time dough formulation procedure of Inoue and Bushuk (1991) with 5% yeast, 2.5% sugar, 1.5% shortening, 1% salt, 100 ppm of ascorbic acid, and optimum amount of water based on farinograph absorption was used for the preparation of frozen dough. The ingredients, including gums, were weighed on a flour weight basis. Dough (1 kg from each batch) was mixed at a time in a Hobart mixer for 1 min at low speed, 1 min at medium speed, and the rest at high speed until optimum dough development was obtained. The gums were added to the other ingredients in the mixer and mixed at low speed for 15 sec before adding water to avoid lumping. The dough was divided into 160-g pieces, rounded, and rested in a fermentation cabinet at 28°C. The procedure was modified. 1) Fermentation time or the resting time for dough relaxation was reduced from 20 min to 10 min to minimize yeast activity because the metabolized cells in the activated yeast after dough mixing and fermentation lead to greater freeze-damage (Bruinsma and Giesenschlag 1984). 2) Relative humidity in the proofing chamber was maintained at 70–75% rh instead of 85–90% rh. The doughs were molded on a sheet-molder and immediately frozen in a quiescent freezer (–72°C) at a rate of 1.14°C/min until the core temperature reached 0°C. Furthermore, the freezing rate was reduced to 0.68°C/min until the core of the dough reached a temperature of –16°C. The dough was then double-bagged in polyethylene bags, vacuum-sealed, and stored at –23°C (Brummer 1995).

The study was based on 16 dough treatments: three levels each of gum arabic, CMC, κ -carrageenan, and locust bean gum. A respective control treatment without gum additives was prepared with each of the four gum treatments, giving a total of four control treatments. These 16 treatments were done in triplicate and used for the analysis of dough characteristics through the DSC, extensigraph, proof time, water activity, and extensibility studies.

Each dough sample was analyzed after six storage times: at day 0 (unfrozen) and after 1 day, and 4, 8, 12, and 16 weeks of frozen storage. Each of the dough analyses was performed in duplicate (two samples) after thawing the doughs for 16 hr at 4°C.

Proof Time

The proof height of the unfrozen control dough without the gum additive for two samples and three replicates was measured after 45 min of proofing. The average height of these six dough pieces was used as the standard height of reference for the analogous frozen dough samples. The proof time required for the doughs to reach the standard proofing height of reference was recorded.

Water Activity

The water activity of each frozen dough was measured at 4°C using a water activity meter (model cx2, Aqualab, Decagon Devices, Pullman, WA) according to manufacturer instructions. The sample was prepared by placing a piece of thawed dough to fill not more than half of the sample cup. Then water activity values were obtained directly from the water activity meter by placing the sample cup into the water activity chamber.

Differential Scanning Calorimetry

The freezing point depression of all the samples of frozen dough, with and without gums, was determined after 1 day, and after 4, 8, 12, and 16 weeks of frozen storage. A DSC 220C with a SSC/5200 module, auto cooling unit, SSC/5200H station, and a Person Color point (model CH-4104, Seiko, Japan) was used. The DSC was calibrated with indium and tin.

A method suggested by application technicians at Seiko Japan was used to determine the freezing point of the dough as follows: 4–9 mg of the thawed dough samples were cut from the prepared dough with a razor blade and sealed in large volume, stainless steel, o-ring pans (Perkin-Elmer, Norwalk, CT). Samples were placed in the DSC and cooled from 30 to –30°C at a rate of 10°C/min, then held at –30°C for 5 min. An empty stainless steel pan was used as the reference. Temperature of maximum differential flow was determined. All analyses were performed in duplicate.

The amount of freezable water in the doughs was measured according to the method of Davies and Webb (1969). The samples were further cooled to –50°C and then heated to a temperature of

TABLE I
Farinograph and Baking Characteristics of Flour Supplemented with Various Levels^a of Gum Arabic, Carboxymethyl Cellulose (CMC), κ -Carrageenan, and Locust Bean Gum^b

Sample	Water Absorption ^c (%)	DDT ^d (min)	Stability (min)	MTI ^e (BU)	Time to Break Down (min)	Specific Loaf Volume (cm ³ /g)
Flour only	67.1	14.0	12.6	29	18.1	0.21
Gum arabic						
1%	69.3	12.6	19.7	10	20.0	0.15
2%	70.8	11.4	19.6	20	19.7	0.15
3%	73.5	10.8	14.6	11	19.8	0.13
CMC						
1%	72.4	15.0	8.9	20	20.0	0.16
2%	73.5	14.9	8.8	35	20.0	0.14
3%	83.2	13.3	10.0	25	16.7	0.13
κ -Carrageenan						
1%	70.6	11.7	15.0	15	20.0	0.17
2%	72.2	11.7	14.3	30	17.0	0.17
3%	73.4	12.2	13.1	25	18.5	0.17
Locust bean						
1%	71.4	13.8	13.7	9	20.0	0.15
2%	73.3	12.0	14.7	15	20.0	0.13
3%	74.5	11.5	14.5	11	20.0	0.13

^a Levels of gums based on flour weight basis.

^b Mean values of three replicates.

^c Corrected to 14.0%.

^d Dough development time.

^e Mixing tolerance index.

100°C at a rate of 10°C/min. The ΔH of the freezable water endothermic transition was recorded.

Extensigraph of Frozen Doughs

Extensigraph properties of frozen doughs were measured according to Inoue and Bushuk (1991). The frozen dough pieces were thawed at 4°C for 16 hr and proofed at 30–32°C, 85–90% rh in a proofing chamber before conducting the extensigraph analyses.

Textural Analysis

The maximum resistance and extensibility of the thawed doughs were determined by modifying the method of Smewing and Court (1995) using the Kieffer dough extensibility rig of the texture analyzer (TA.XT2).

Statistical Design and Analysis of Data

A randomized complete block design (RCBD) with a factorial arrangement of dough treatment and storage time was used for the statistical analysis for all data. Differences in dough and bread characteristics due to addition of gums were tested for significance using analysis of variance techniques. Analysis of variance was performed using the general linear model (GLM) procedure of the Statistical Analysis System computer software package, and the least significant differences were calculated (SAS Institute, Cary, NC). A level of significance of $P \leq 0.05$ was used throughout the analysis. The design was based on 16 gum treatments, six storage treatments, three replicates, and two samples.

RESULTS AND DISCUSSION

Levels of Gums Chosen

As shown in Table I, levels of gums at 1, 2, and 3% gave the optimum farinograph properties for frozen dough such as low farinograph absorption, low dough development time (DDT), and high stability. Flour samples with 4–15% level of each gum (results are not shown) gave farinograms similar to a weak flour with poor stability and very low mixing tolerance. Usually, a high farinograph

absorption is desirable for breadmaking purposes. However, in the case of frozen dough, lower farinograph absorption is desirable to minimize free water and its migration in the dough. DDT is the time in minutes required for the flour water dough to reach the 500 BU line. Although a relatively high value is desirable for breadmaking, in frozen dough, a lower DDT is desirable because that allows for less fermentation time for the yeast. Kline and Sugihara (1968), and Merritt (1960) found that fermentation before freezing in prepared doughs leads to loss of freeze tolerance in the yeast. Flour samples with gum levels >3% had very high water absorption as well as DDT.

Levels 1, 2, and 3% gave the maximum specific loaf volume. Levels >3% imparted an off flavor from gums to the bread loaf. This observation was not part of the experiment. The texture and specific loaf volume of these bread loaves were not acceptable. Levels <1% did not show an increase in specific loaf volume compared with the control bread loaf. Loaves with 1, 2, and 3% of each of the four gums showed good break and shred, good symmetry, uniform grain with thin cell walls, and a soft texture. Therefore, all gums were chosen at the 1, 2, and 3% levels.

Physical and Chemical Analysis of Flour

The flour was analyzed for moisture, protein, ash, wet gluten, gluten index, falling number, pasting properties, extensigraph, mixograph, and alveograph. The values indicated a breadmaking cultivar of good quality. A 70% extraction flour was obtained for this research, with a protein content of 14.1% and ash content of 0.46%. The wheat obtained for this research was considered a sound wheat with a falling number of 418 sec

A farinograph water absorption of 67.1%, and a dough development time of 14 min indicated strong quality gluten. Flour derived from wheat cultivar Grandin showed a normal farinograph profile as reported by Lu and Grant (1999), which indicates good quality for baking. Similarly, the resistance to extension value obtained through extensigraph agreed with the farinograph results, all indicating a good quality protein. The gluten index obtained for Grandin by Lu and Grant (1999) was 10% lower than our results.

TABLE II
Effects of Storage of Frozen Doughs on Various Parameters of Differential Scanning Calorimetry^{a,b}

Storage	Freezing Endotherm					
	T_o (°C)	Heat Flow at Onset (mW)	T_c (°C)	Heat Flow at Peak (mW)	Heat Flow at Completion (mW)	Enthalpy (ΔH) (mJ/mg)
0 day	-13.3a	2.3c	-14.4a	14.7e	2.5c	-39.2f
1 day	-13.0ab	3.3b	-13.8bc	17.4d	3.2b	-48.4e
4 wks	-13.2ab	3.4b	-14.0ab	17.9d	3.2b	-57.2d
8 wks	-12.7bc	3.4b	-13.1d	19.8c	3.1bc	-65.5c
12 wks	-12.8bc	4.0a	-13.3cd	21.5b	3.5b	-72.4b
16 wks	-12.5c	4.3a	-13.0d	23.0a	4.1a	-92.2a

^a Mean values of 16 gum treatments, three replicates, and two samples.

^b Within each column, means followed by the same letter are not significantly different ($P = 0.05$). Any mean may be compared with any other mean within a column.

TABLE III
Effects of Storage of Frozen Doughs on Various Parameters of Differential Scanning Calorimetry^{a,b}

Storage	Melting Endotherm					
	T_o (°C)	Heat Flow at Onset (mW)	Heat Flow at Peak (mW)	T_c (°C)	Heat Flow at Completion (mW)	Enthalpy (ΔH) (mJ/mg)
0 day	-17.8c	-2.3c	-9.7e	8.3d	-2.8e	47.6f
1 day	-18.7b	-2.5c	-11.5d	8.5cd	-3.3de	57.6e
4 weeks	-19.1b	-2.6c	-12.3d	8.9b-d	-3.6cd	68.4d
8 weeks	-20.5a	-3.0b	-13.4c	9.1bc	-4.0bc	76.0c
12 weeks	-20.2a	-3.0b	-14.6b	9.4ab	-4.1b	85.3b
16 weeks	-18.6bc	-3.8a	-16.0a	9.9a	-4.9a	107.4a

^a Each value is a mean value of 16 gum treatments, three replicates, and two samples.

^b Within each column, means followed by the same letter are not significantly different ($P = 0.05$). Any mean may be compared with any other mean within a column.

A high gluten index indicates a stronger gluten, which seems to be better for frozen dough manufacture (Inoue and Bushuk 1991, 1992).

Differential Scanning Calorimetry

The freezing endotherm of each dough treatment was obtained using DSC. The onset temperature (T_o) increased gradually from -13.3 to -12.5°C (lower negative number is a higher value) with frozen storage time from day 0 to 16 weeks of frozen storage (Tables II and III). However, the increase was not significant between day 0 (unfrozen) (-13.3°C), day 1 (-13.0°C), and 4 weeks (-13.2°C). Similarly, there were no significant differences from day 1 (-13.0°C) to 12 weeks (-13.0°C), and from 8 weeks (-12.7°C) to 16 weeks (-12.5°C) of frozen storage. The heat flow at onset of freezing endotherm increased due to an increase in frozen storage time with no significant difference between day 1 (3.3 mW) and 8 weeks (3.4 mW) of frozen storage. T_o and heat flow values obtained at day 0 (-13.3°C , 2.3 mW), 12 weeks (-12.8°C , 4.0 mW), and 16 weeks (-12.5°C , 4.3 mW) of frozen storage were significantly different. After 12 weeks of frozen storage, the

freezing endotherm onset temperature and the heat flow increased. The higher freezing temperatures could possibly lead to deterioration in the quality of frozen dough because higher freezing temperatures still allow the various physical, enzymatic, and biochemical reactions to occur. However, addition of all levels of gums, except 1% κ -carrageenan, decreased the heat flow, indicating a decrease in T_o (higher negative number is a lower value) (Tables IV and V).

Freezing endotherm peak temperature (T_p) also gives an indication of the storability of frozen dough. The physical, enzymatic, and biochemical reactions that deteriorate the quality of frozen dough are minimized in doughs with lower freezing temperatures because doughs can be stored at lower temperatures. Lower T_p is more desirable. As shown in Tables II and III, the increase in T_p (from -14.4 to -13.0°C) and an increase in heat flow at peak (from 14.7 to 23.0 mW) with an increase in frozen storage time clearly demonstrates the detrimental effect of frozen storage time on the quality of frozen dough.

Tables IV and V show the main effects of gum treatment on heat flow at onset, peak, and completion temperatures of freezing

TABLE IV
Effects of Gum Treatment of Frozen Doughs on Various Parameters of Differential Scanning Calorimetry^{a,b}

Treatment	Freezing Endotherm			
	Heat Flow at Onset (mW)	Heat Flow at Peak (mW)	Heat Flow at Completion (mW)	Enthalpy (ΔH) (mJ/mg)
Gum arabic control	4.1a-c	21.3a	3.8a	-68.7a
1%	3.0de	18.4d-g	2.9b-d	-61.1gh
2%	3.2c-e	19.5a-e	3.3a-c	-60.4hi
3%	3.1de	19.2b-f	3.2a-c	-59.7ij
CMC ^c control	3.7b-d	20.9a-c	3.4a-c	-68.9a
1%	3.4b-e	18.4d-g	3.2a-c	-63.3de
2%	3.4b-e	19.0d-f	3.3a-c	-62.6ef
3%	3.4b-e	19.2b-f	3.8a	-61.7fg
κ -Carrageenan control	4.1ab	20.9a-c	3.9a	-68.8a
1%	4.1a-c	19.8a-d	3.3a-c	-65.5b
2%	2.5e	17.7fg	2.4d	-64.8bc
3%	3.2c-e	17.8fg	3.6ab	-63.9cd
Locust bean control	4.8a	21.1ab	3.8a	-68.7a
1%	3.1de	16.8g	2.8cd	-55.1k
2%	3.1de	17.0g	2.9b-d	-54.4k
3%	3.0de	17.6fg	2.7cd	-52.4l

^a Each value is a mean value of six storage treatments, three replicates, and two samples.

^b Within each column, means followed by the same letter are not significantly different ($P = 0.05$). Any mean may be compared with any other mean within a column.

^c Carboxymethyl cellulose.

TABLE V
Effects of Gum Treatment of Frozen Doughs on Various Parameters of Differential Scanning Calorimetry^{a,b}

Treatment	Melting Endotherm			
	Heat Flow at Onset (mW)	Heat Flow at Peak (mW)	Heat Flow at Completion (mW)	Enthalpy (ΔH) (mJ/mg)
Gum arabic control	-3.3a	-14.5ab	-4.4ab	79.3a
1%	-2.4de	-12.5d-f	-3.6cd-f	72.3cd
2%	-3.1ab	-13.4b-d	-4.1a-d	71.7cd
3%	-2.7b-e	-12.8c-f	-3.4d-f	71.1d
CMC ^c control	3.1a-c	14.3a-c	4.2a-c	81.6a
1%	-3.0a-c	-13.4b-d	-3.9b-e	74.3bc
2%	-2.7b-e	-13.0bc-e	-3.8b-e	73.7b-d
3%	-3.0a-d	-12.1d-f	-3.6b-ef	72.5cd
κ -Carrageenan control	-3.5a	-15.0a	-4.7a	81.4a
1%	-3.1a-c	-11.4f	-4.0b-e	74.5bc
2%	-2.2e	-11.9d-f	-3.3ef	75.8b
3%	-2.9a-d	-12.6d-f	-3.8b-e	76.0b
Locust bean control	-3.3a	-14.3a-c	-4.3ab	80.6a
1%	-2.7b-e	-11.7ef	-3.3ef	67.4e
2%	-2.6c-e	-11.7ef	-3.4d-f	64.6ef
3%	-2.4de	-11.9d-f	-3.0f	62.7f

^a Each value is a mean value of six storage treatments, three replicates, and two samples.

^b Within each column, means followed by the same letter are not significantly different ($P = 0.05$). Any mean may be compared with any other mean within a column.

^c Carboxymethyl cellulose.

endotherm. T_o , T_p , and T_c are not listed because the main effects of gum treatments on these parameters were not significant. However, a significant decrease in heat flow at onset, peak, and completion temperatures upon addition of gum arabic, CMC, κ -carrageenan, and locust bean gum is indicative of the decrease in freezing temperatures. This may have occurred due to increased binding of water to the gums.

Addition of different levels of each gum gave similar heat flow and similar temperatures at onset, peak, and completion of the freezing endotherm (Figs. 1 and 2). However, the important observation was that these values significantly varied from the control doughs, although the values obtained from different levels of each gum did not differ significantly amongst themselves. The gum additives decreased the freezing temperatures and the heat flow in general, suggesting a possible improvement in the frozen dough quality.

Figure 3 shows an interaction between each gum treatment and storage period with reference to the enthalpy of freezing peak. Enthalpy, or the ΔH value calculated as the area under the peak of the freezing endotherm in mJ/mg, is an indicator of freezable water present in the dough. Lu and Grant (1999) reported that as frozen storage time increased, freezable water increased until week 8 of frozen storage, then began to decrease slowly until week 16 for the cultivars Grandin, Prospect, and Glenlea. The reason attributed to this phenomenon was that the wheat protein released its bound water until week 8 of storage and therefore freezable water increased. However, after 8 weeks there was no release of additional water molecules, and the water bodies formed larger and larger pools. In Glupro, freezable water increased continuously with frozen storage time due to its higher protein content and more water associated with it. In contrast, in the present research with Grandin flour, the ΔH value or the freezable water increased significantly with an increase in storage period from day 0 (-39.2 mJ/mg) to 16 weeks (-92.2 mJ/mg) of frozen storage for all the treatments (Tables II and III). This was due to an increase in freezable water, which may be attributed to the separation of water from the other components of the dough. Although the protein content of Grandin flour was 14.1%, the nonpolar and polar amino acid groups of the protein initially might be holding water molecules, therefore the freezable water was low. These results are in agreement with the explanation given by Lu and Grant (1999). They reported that an increase in frozen storage time leads

to an increase in freezable water because the protein liberates bound water forming pools of water, which consequently increases the ΔH values in the DSC.

There was a significant decrease in the freezable water on addition of the different levels of gums as shown in Fig. 3 and Tables IV and V. Locust bean gum showed very low values ranging from -55.1 to -52.4 mJ/mg compared with the other treatments ranging from -59.7 to -65.5 mJ/mg and the control ranging from -68.7 to -68.9 mJ/mg, which meant that free water content was lower in these doughs. Lower freezable water reduces ice crystals in the dough, consequently improving the frozen dough quality. Although the ΔH values of the gum treatments were significantly lower than the frozen control, there were no significant differences in ΔH values between the different levels of gum arabic, CMC and κ -carrageenan. The addition of 3% locust bean gum gave significantly lower ΔH values compared with the 1 and 2% levels. Locust bean gum had the lowest ΔH values followed by gum arabic and CMC. κ -Carrageenan had higher values than the other gums but significantly lower values than the control treatment.

As shown on Fig. 3, unfrozen control doughs on day 0 had ΔH values ranging from -43.5 to -44.2 mJ/mg, whereas frozen control doughs after 16 weeks of frozen storage had -107.0 to -107.9 mJ/mg, which was significantly higher than the ΔH values of doughs after 16 weeks of frozen storage with 3% gum arabic (-83.2 mJ/mg), 3% CMC (-87.4 mJ/mg), 3% locust bean gum (-79.3 mJ/mg), and 3% κ -carrageenan (-92.2 mJ/mg). The 3% κ -carrageenan had a significantly higher ΔH value compared with the 3% level of other gums after 16 weeks of frozen storage.

The temperature profile of the DSC was further expanded to observe the melting curves associated with each frozen dough treatment. Although the temperature was increased to 100°C and a peak was obtained, the phenomenon of gelatinization was not observed. Most likely, the dough subjected to -50°C lost its gelatinization property. The concentrative process in freezing influences the starch to produce stable cross-links, and rehydration of starch on thawing is less effective (Reid 1993). The data for onset, peak, and completion of the melting endotherms and their respective heat flow values are reported in Tables II to V. A definite trend was observed in these values. As temperature increased, T_o of the melting peak ranged from -17 to -20°C . The heat flow at onset, peak, and completion of melting endotherm

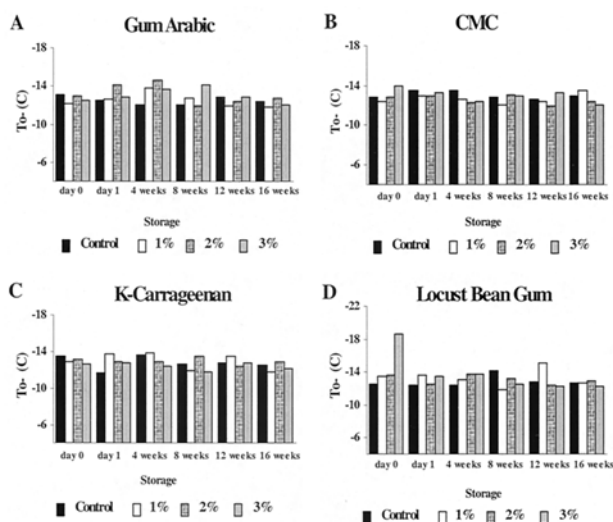


Fig. 1. Interaction of gum treatment and storage on freezing endotherm onset temperature (T_o , $^\circ\text{C}$). Bars represent mean value of three replicates and two samples ($P = 0.05$). A, gum arabic; B, carboxymethyl cellulose (CMC); C, κ -carrageenan; D, locust bean gum. Any mean may be compared with any other mean for all treatments.

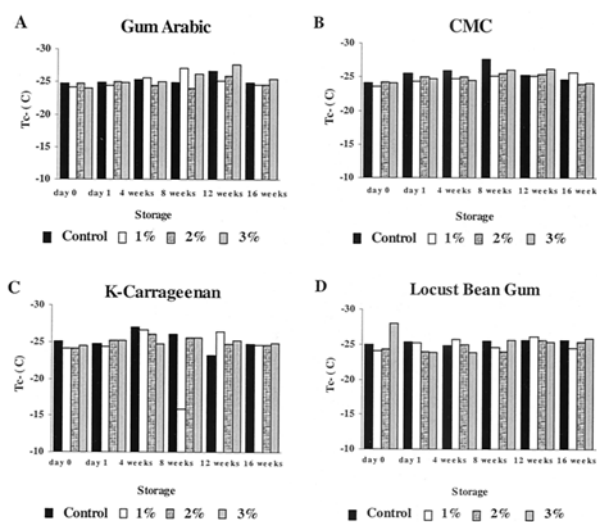


Fig. 2. Interaction of gum treatment and storage on freezing endotherm completion temperature (T_c , $^\circ\text{C}$). Bars represent mean value of three replicates and two samples ($P = 0.05$). A, gum arabic; B, carboxymethyl cellulose (CMC); C, κ -carrageenan; D, locust bean gum. Any mean may be compared with any other mean for all treatments.

decreased with an increase in frozen storage time. The enthalpy (ΔH) of melting peak increased from 47.6 to 107.4 mJ/mg with an increase in frozen storage time as shown in Tables II and III and Fig. 4. The higher enthalpy is caused by localized microscopic water content due to starch damage and freezing as explained by Lu and Grant (1999). They also reported that the gelatinization thermograms of starches isolated from frozen doughs indicated an increase in enthalpy after 16 weeks of frozen storage time due to the retrogradation of starch granules. However, we found that the addition of gum additives decreased the enthalpy especially after 16 weeks of frozen storage. Locust bean gum showed very low values compared with the other treatments and control, which meant that the retrogradation of starch granules was minimized in these doughs.

The quality of frozen dough is affected by the freezable water present in the dough that can form ice crystals. Gums, especially locust bean gum, reduced the freezable water as indicated by the enthalpy values. The property of locust bean gum to bind freezable water and reduce ice crystal formation was further evident from the higher resistance to extension values, lower proof times, and higher loaf volumes that are all dependent on the gluten quality of the frozen dough. Onset, peak, and completion temperatures were lowered by the addition of gums, which suggests that frozen dough quality was improved because the doughs can be stored at a lower temperature.

Water Activity

The mean values of water activity of thawed doughs with respect to gum treatment and storage treatment ranged from 0.9743 to 0.9768 and from 0.9750 to 0.9764 respectively. There were no significant differences between the mean values due to gum treatments and storage time. The results were similar to those obtained by Berglund (1988). Because the equipment could determine the water activity only in the thawed state, it may be concluded that the water activity was not affected by the gum treatments in thawed state. However, it would be interesting to find the water activity of frozen dough under frozen conditions that can determine the various biochemical changes dependent on water activity occurring in the frozen dough system.

It is a known fact that water activity is less important under freezing temperatures. The chemical and physiological changes could be more dependent on the temperature rather than water

activity. For this reason, water activity is not a very good indicator of frozen dough quality. Also, water activity is affected by the addition of short chain molecules such as sugars and not by the addition of long chain molecules such as hydrophilic gums.

Proof Time

Increased duration of frozen storage caused increased proof time for all the doughs from day 0 unfrozen to 16 weeks of frozen storage (Table VI). These results agree with extensigraph maximum resistance to extension values, which decreased with frozen storage time. Also, the extensibility of the frozen dough increased, resulting in poor gas retention, while the area under the curve decreased with frozen storage time.

The proof time ranged from 46 min (shortest) for unfrozen doughs to 258 min (longest) for 16 weeks frozen doughs. These results are similar to the results obtained by Berglund (1988). Brackelsberg (1996) reported no significant change in proof time up to 16 weeks of frozen storage, contrary to the results of this research. Brackelsberg (1996) used a Miller's choice commercial flour with a protein content of 16.84%, a very high protein content compared with 14.1% used in this research.

Analysis of variance indicated significance for main effects of storage and treatments as well as interaction between gum treatment and storage. However, because the significance of the interaction was due to differences in magnitude of the means between storage times, the main effects of gum treatment on proof time will be discussed. It was observed that the doughs with locust bean gum, CMC, and gum arabic gave significantly lower proof time compared with the control and doughs treated with κ -carrageenan (Table VII).

Doughs with 2% CMC gave the lowest values followed by 3% locust bean gum, 3% CMC, 2% gum arabic, 2% locust bean gum, and 3% gum arabic. Addition of κ -carrageenan increased the proof time compared with the control.

Interaction of gum treatment and frozen storage showed that unfrozen control doughs on day 0 proofed in 45–46 min, whereas frozen control doughs after 16 weeks of frozen storage proofed in 265–272 min, which was significantly higher than the proof time of doughs frozen for 16 weeks with 2% gum arabic (241 min), 2% CMC (226 min), and 3% locust bean gum (233 min), and significantly lower than 1% κ -carrageenan (295 min) (these interaction results are not shown).

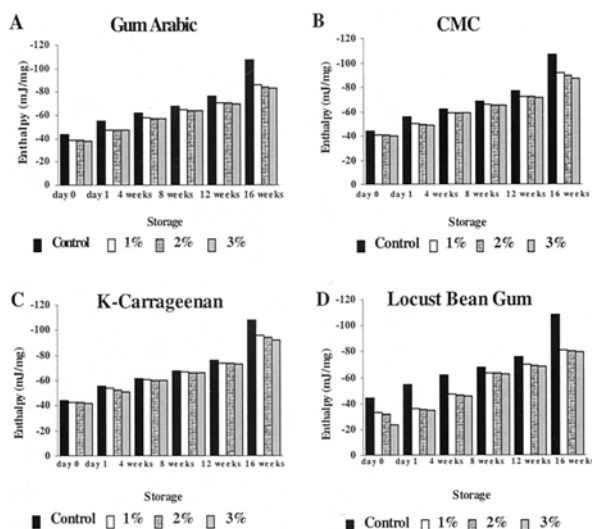


Fig. 3. Interaction of gum treatment and storage on enthalpy (ΔH) of freezing peak (mJ/mg). Bars represent mean value of three replicates and two samples ($P = 0.05$). A, gum arabic; B, carboxymethyl cellulose (CMC); C, κ -carrageenan; D, locust bean gum. Any mean may be compared with any other mean for all treatments.

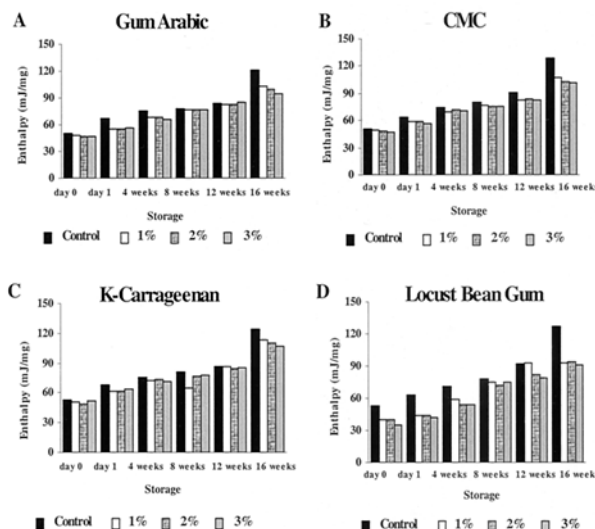


Fig. 4. Interaction of gum treatment and storage on enthalpy (ΔH) of melting peak (mJ/mg). Bars represent mean value of three replicates and two samples ($P = 0.05$). A, gum arabic; B, carboxymethyl cellulose (CMC); C, κ -carrageenan; D, locust bean gum. Any mean may be compared with any other mean for all treatments.

Extensigraph Measurements

Extensigrams were obtained for the frozen doughs with different levels of all four gums subjected to various frozen storage periods to understand the mechanism of dough weakening. Extensibility indicates the ability of the dough to extend during fermentation and gas production of the yeast. A very high extensibility results in weak and slack dough, which collapses during the proofing stage or while baking in the oven. Maximum resistance to extension of the dough indicates the ability of the dough to retain gas sufficiently and give a springy bread. A very low resistance to extension results in poor gas retention and, consequently, a lower loaf volume. A very high resistance to extension also results in a lower loaf volume because the tough dough is not capable of proofing to an optimum height with the gas produced by the yeast.

Table VI shows maximum resistance to extension and extensibility values of frozen doughs obtained after 45 min of proofing and again after 135 min of proofing. Extensibility values showed no trend with frozen storage time as reported by McCleary-Bayley (1992), and Inoue and Bushuk (1991). However, McCleary-Bayley (1992) also reported no trend in maximum resistance to extension, which is contrary to the results obtained in the present research. The maximum resistance measured after 45 min of proofing decreased significantly with storage time, similar to the observations of Inoue and Bushuk (1991). The values ranged from 820 BU (highest) at day 0 and 430 BU (lowest) after 16 weeks of frozen storage. The maximum resistance measured after 135 min of proofing showed a similar decrease with storage time. The values ranged from 604 BU (highest) at day 0 and 219 BU (lowest) after 16 weeks of frozen storage.

Higher maximum resistance to extension value indicates a strong wheat flour and correlates with good breadmaking characteristics (Inoue and Bushuk 1992). The main effects of gum treatments shown in Table VII indicate an increase in maximum resistance to extension for addition of 1 and 3% CMC, 1 and 3% κ -carrageenan, and 1, 2, and 3% locust bean gum compared with the respective control treatments. However, addition of 3% gum arabic gave values similar to the control, and addition of 2% CMC, 2% κ -carrageenan, and 1 and 2% gum arabic gave values lower than the control treatment. These results were unexpected.

Interaction of gum treatment and frozen storage showed that unfrozen control doughs on day 0 gave maximum resistance to extension of 688–965 BU measured after 45 min, whereas frozen control doughs after 16 weeks of frozen storage gave 353–498 BU, which was significantly lower than doughs after 16 weeks of frozen storage with 3% gum arabic (603 BU), 3% CMC (593 BU), and 2% locust bean gum (588 BU) (these interaction results are not shown).

Extensibility and Maximum Resistance to Extension of Dough from Texture Analyzer

Kieffer dough extensibility rig of the texture analyzer was used to measure the extensibility and maximum resistance to extension of each dough sample. The advantage of Kieffer dough extensibility rig is that it uses a micro-extension method involving a very small sample size. It correlates highly with the macro methods such as the extensigraph as indicated by the baking performance (Kieffer et al 1998; Kieffer and Stein 1999; Suchy et al 2000).

The peak force reached while stretching or extending the dough by means of a hook is considered to be the maximum resistance to

TABLE VI
Effects of Storage of Frozen Doughs on Proof Time and Extensigraph^{a,b}

Storage	Proof Time (min)	Maximum Resistance to Extension After 45 min (BU)	Extension After 45 min (cm)	Maximum Resistance to Extension After 135 min (BU)	Extension After 135 min (cm)
0 day	46f	820a	15.3b	604a	18.1b
1 day	82e	723b	15.7ab	508b	18.5ab
4 weeks	126d	664c	17.1a	449c	19.9a
8 weeks	151c	594d	16.5ab	378d	19.3ab
12 weeks	223b	519e	15.7ab	304e	18.6ab
16 weeks	258a	430f	16.4ab	219f	19.5ab

^a Each value is a mean value of 16 gum treatments, three replicates, and two samples.

^b Within each column, means followed by the same letter are not significantly different ($P = 0.05$). Any mean may be compared with any other mean within a column.

TABLE VII
Effects of Gum Treatment of Frozen Doughs on Proof Time and Extensigraph^{a,b}

Treatment	Proof Time (min)	Maximum Resistance to Extension After 45 min (BU)	Extension After 45 min (cm)	Maximum Resistance to Extension After 135 min (BU)	Extension After 135 min (cm)
Gum arabic control	157d	753a	17.7a–c	537a	20.5a–c
1%	148f	576i	15.0d–f	361h	18.0c–e
2%	132j	581h	11.4h	366g	14.2g
3%	141h	753a	13.6f–h	538a	16.4e–g
CMC ^c control	154e	614f	18.9a–c	398e	22.5a
1%	143g	625d	19.8ab	410d	22.5a
2%	123l	481n	17.9a–c	275m	20.7ab
3%	132j	748b	14.5e–g	532b	17.3d–f
κ -Carrageenan control	154e	533l	12.1gh	318k	14.9fg
1%	159c	618e	16.5c–e	400e	19.2b–d
2%	167b	513m	19.0ab	299l	21.8a
3%	180a	739c	17.3b–d	524c	20.1a–c
Locust bean control	160c	561k	13.4f–h	346j	16.2e–g
1%	144g	567j	13.3f–h	352i	16.1e–g
2%	138i	739c	17.6a–c	524c	20.4a–c
3%	128k	599g	19.9a	384f	22.6a

^a Each value is a mean value of six storage treatments, three replicates, and two samples.

^b Within each column, means followed by the same letter are not significantly different ($P = 0.05$). Any mean may be compared with any other mean within a column.

^c Carboxymethyl cellulose.

extension of the dough. The distance traveled by the hook to reach the peak force value is the extensibility. Because the interaction between the treatments and storage with reference to extensibility and maximum resistance to extension were not significant, the main effects will be discussed.

Table VIII shows the effect of frozen storage on texture of the dough. The maximum resistance to extension values decreased with frozen storage time from day 0 to 16 weeks of frozen storage. The extensibility of the frozen dough increased with frozen storage time while the area under the curve decreased. Decreases in maximum resistance, area under the curve, and increase in extensibility clearly indicate deterioration in the quality of gluten as explained by Inoue and Bushuk (1992). These results agree with the proof time results. An increase in extensibility resulted in poor gas retention of the dough; consequently, the proof time increased with an increase in frozen storage time.

Interaction of gum treatment and frozen storage showed that unfrozen control doughs on day 0 gave a peak force value of 59.6–60.3 g, whereas frozen control doughs after 16 weeks of frozen storage gave a peak force of 17.4–25.2 g, which was significantly lower than the proof time of doughs after 16 weeks of frozen storage with 3% gum arabic (36.2 g), 1% CMC (42.6 g), and 3% locust bean gum (38.5 g) (these interaction results are not shown).

Table IX shows the effect of gum treatments. The differences in peak force values due to the addition of CMC, gum arabic, and κ -

carrageenan were not significant. However, doughs with locust bean gum gave a higher peak force compared with the control, with a maximum value at 3% level of locust bean gum. Higher peak force indicated that the quality of gluten in dough treated with locust bean gum has been retained to a greater degree than the control and other treatment doughs. Higher resistance to extension with the addition of locust bean gum resulted in better gas retention and lower proof time. As reported earlier, locust bean gum proofed to an optimum height in a relatively short period of time.

SUMMARY AND CONCLUSIONS

The addition of gums improved the quality of frozen dough by binding freezable water and reducing ice crystallization and recrystallization as indicated by the ΔH values of the freezable water endothermic transition. As frozen storage time increased, the ΔH of the freezable water endothermic transition increased significantly for all treatments. However, addition of different levels of the four gums lowered the ΔH when compared with the control doughs. The freezing endotherm onset temperature and heat flow increased after 12 weeks of frozen storage, compared with the day 0 (unfrozen) dough. However, the addition of all the levels of gums, except 1% κ -carrageenan, decreased the heat flow, indicating a decrease in onset temperature (T_o). A decrease in T_o improves the keeping quality of the frozen dough.

Doughs with locust bean gum gave a higher peak force, which was measured using the Kieffer dough extensibility rig of the texture analyzer, indicating a better retention of baking quality. The various periods of storage and gum treatments did not affect the water activity of the thawed frozen doughs. Doughs with locust bean gum added, which showed better gluten quality through dough extensibility analysis, had significantly lower proof times compared with the other treatments and the control. Doughs with CMC added had the second lowest values, followed by the doughs with gum arabic added. κ -Carrageenan was an undesirable gum because the proof time of the doughs increased due to the addition of this gum when compared with the control. The increase in resistance to extension values, due to the addition of different levels of gum additives, suggested the ability of gums to improve the quality of frozen dough by reducing freeze-thaw damage.

Overall, frozen dough quality was improved with the addition of locust bean gum, gum arabic, and CMC as indicated by their lower freezable water and higher maximum resistance to extension. Consequently, these gums gave lower proof times. Locust bean gum gave the best results, followed by gum arabic and CMC. κ -Carrageenan showed detrimental effects on the frozen dough quality throughout the study. Locust bean gum was the best hydrophilic gum for improving frozen dough quality, whereas κ -carrageenan was the least desirable gum for frozen dough.

ACKNOWLEDGMENTS

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TABLE VIII
Textural Data for Effects of Storage of Frozen Doughs from Kieffer Dough and Gluten Extensibility Rig^{a,b}

Storage	Maximum Resistance to Extension (force, g)	Extension (distance at peak, mm)	Area Under the Curve (g-mm)
0 day	69.0a	-36.9c	1,289a
1 day	59.2b	-39.5bc	1,265b
4 weeks	52.7c	-40.8ab	1,174c
8 weeks	47.5d	-42.1ab	1,079d
12 weeks	42.4e	-43.3a	1,022d
16 weeks	32.2f	-41.8ab	806e

^a Each value is a mean value of 16 gum treatments, three replicates, and two samples.

^b Within each column, means followed by the same letter are not significantly different ($P = 0.05$). Any mean may be compared with any other mean within a column.

TABLE IX
Textural Data for Effects of Gum Treatment of Frozen Doughs from Kieffer Dough and Gluten Extensibility Rig^{a,b}

Treatment	Maximum Resistance to Extension (force, g)	Area Under the Curve (g-mm)
Gum arabic control	44.3d	1,211ab
1%	50.0cd	1,081b-e
2%	50.5cd	1,182a-c
3%	51.0cd	1,086b-e
CMC ^c control	44.8d	1,047c-e
1%	50.2cd	1,098b-e
2%	48.9d	1,144b-d
3%	47.9d	1,028de
κ -Carrageenan control	45.3d	980e
1%	47.1d	1,032de
2%	47.5d	1,051c-e
3%	48.1d	1,034de
Locust bean control	44.4d	1,011de
1%	56.3bc	1,205ab
2%	59.0b	1,316a
3%	72.6a	1,188a-c

^a Each value is a mean value of six storage treatments, three replicates, and two samples.

^b Within each column, means followed by the same letter are not significantly different ($P = 0.05$). Any mean may be compared with any other mean within a column.

^c Carboxymethyl cellulose.

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