

# Role of Flour Fractions in Breadmaking Quality of Frozen Dough

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## ABSTRACT

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The primary objective of the research was to fractionate two flours into four major flour components (starch, water solubles, gliadin, and glutenin) and determine the contributions of these fractions to frozen dough quality. Two hard red spring wheat flours of diverse mixing properties, Glupro (strong) and Prospect (weak), were used. When each fraction of Prospect was replaced by the corresponding Glupro fraction, the baking quality of the Prospect reconstituted frozen doughs was improved. Replacement of Glupro fractions with equivalent Prospect fractions resulted in a decline in baking quality of the reconstituted frozen doughs. The functional properties of the four fractions appeared to depend on interactions between fraction and flour components. This was observed when two fractions from one cultivar were simultaneously exchanged with the corres-

ponding two fractions of the other cultivar. This experiment resulted in better baking quality than that of the original reconstituted flours. Within the strong and weak flours, the effect of each fraction on frozen dough was significantly different. Of the four fractions, glutenin played a predominant role in baking quality of the frozen doughs. The gliadin and starch fractions contributed significantly to frozen dough quality but not as much as the glutenin fraction. The contribution of the water-soluble fractions to frozen dough quality was minimal. Results of this study corroborate published reports that stronger flours perform better in frozen bread doughs. Intercultivar differences in flour strength required for frozen doughs appear to be in the glutenin protein fraction.

Quality of frozen doughs for breadmaking deteriorates with freeze-thaw cycling and during long-term frozen storage. Breadmaking quality is inferior to that of fresh dough in terms of extremely long proof time, lower loaf volume, open and harsh grain, and gummy texture (Bruinsma and Giesenschlag 1984, Wolt and D'Appolonia 1984a, Inoue and Bushuk 1991). The quality of a frozen dough depends on the strength of the flour. Wolt and D'Appolonia (1984a) studied the effects of flour type on frozen dough quality and indicated that flour type and flour protein quality were important variables in the proof-time stability of frozen dough. They suggested that protein content was not a reliable indicator of a flour's performance in frozen dough, and that starch characteristics of bread crumb changed with frozen dough storage.

Inoue and Bushuk (1992) also reported that protein quality appeared to be more important than protein content for flour that was to be used for frozen dough bread production.

Fractionation and reconstitution of wheat flour components is regarded as the most direct method for investigating the basis of baking quality in wheat flour and bridging the gap between functional baking and basic biochemical examinations of wheat flour components (MacRitchie 1985). Using this technique to investigate flour fraction functionality in frozen doughs may help to understand and eventually solve the problem of quality deterioration in frozen doughs. The objective of this study was to determine the functional properties of flour fractions isolated from strong and weak hard red spring (HRS) wheat cultivars (based on rheological properties) and to identify the flour components that are primarily responsible for the quality differences in frozen doughs.

## MATERIALS AND METHODS

### Materials

Two HRS wheat cultivars, Glupro and Prospect, were used for fractionation and reconstitution of flour components. The two cul-

tivars, grown in North Dakota during the 1995 crop year, were selected based on protein content and dough rheological characteristics. 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.

### Flour Quality Tests

Flour moisture, protein, ash, wet gluten, and gluten index were determined using Approved Methods 44-15A, 46-13, 08-01, and 38-12, respectively (AACC 1995). Farinograph and extensigraph tests were conducted according to Approved Methods 54-21 and 54-10, respectively.

### Design of Reconstitution Experiment

For the initial part of the reconstitution study, four fractions—starch, water solubles, gliadin, and glutenin—were isolated from each cultivar and reconstituted into “new” flours. Each new flour contained three fractions of the original cultivar and one fraction substituted for the corresponding fraction of the other cultivar. Control reconstituted flours contained all four fractions from the same flour.

The second part of the reconstitution study dealt with a fraction interaction determination. For this part of the study, the same two flours were fractionated into two fractions, gluten and starch. The starch fraction contained the water solubles and insolubles. Control reconstituted flours contained both fractions from the same flour.

### Fractionation of Flours

Flours were fractionated into three basic components: starch, water solubles, and gluten (Chakraborty and Khan 1988). The gluten was further fractionated into gliadin and glutenin protein components using the method of MacRitchie (1978). Flour (300 g) was first mixed into a dough according to its farinograph water absorption. The starch was isolated by hand-kneading the dough in small aliquots of a total amount (1,400 mL) of distilled water. Water and dough temperature were maintained at 15°C during the isolation process.

The wet gluten was divided into three equal parts and freeze-dried immediately. The starch slurry was centrifuged at 3,000 × g for 10 min, and the supernatant (water-soluble fraction) was decanted, shell-frozen, and freeze-dried. The starch, which also contained the water-insoluble materials, was spread in glass cake pans (9 × 13 in.) and allowed to air-dry at room temperature (25°C) for 72 hr. The dried gluten and starch fractions were initially ground using a mortar and pestle, then further ground using an Ultra Centrifugal ZM1 mill (Brinkman Instrument Co., Westbury, NY) to pass a

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1.0-mm screen. Separate fractions were stored at 4°C in air-tight containers until needed. Each dried and ground gluten fraction was divided into six equal parts ( $\approx 6.0$  g), and each part was extracted with 0.0015M HCl (30  $\times$  dry wt of gluten) in a 250-mL centrifuge bottle. A high-speed Ultra-turrax T25 mixer (Janke and Kunkel GMBH & Co., Hamburg, Germany) was used to homogenize the sample for 2 min, followed by immediate neutralization with 0.1M NaOH. The final pH was brought to 5.8, which is similar to the pH of bread dough immediately after mixing (MacRitchie 1985). Using this procedure avoided prolonged exposure of the protein to acid conditions. The small amount of NaCl produced presented no problem in the baking experiments because salt is a baking ingredient (MacRitchie 1985).

Once extracted and centrifuged at 5,000  $\times$  g for 10 min, the supernatant (gliadin) and the residue (glutenin) were separated and freeze-dried. The dried gliadin and glutenin were initially ground using a mortar and pestle, then further ground using the Ultra Centrifugal ZM1 mill to pass a U.S. 70 sieve and stored in sealed containers at 4°C.

### Preparation of Original Flour Control Doughs

A straight no-time dough formulation was used for all doughs, unfrozen and frozen, according to the method described by McCleary-Bayley (1992). The formulation consisted of flour (100%), compressed yeast (5.0%), shortening (4.0%), sugar (4.0%), salt (1.5%), ascorbic acid (100 ppm), potassium bromate (50 ppm), and water (farinograph absorption – 4%). Dough containing 300 g of flour was mixed to optimum development as determined by the farinograph data and visual inspection of the dough sheet using the short-time procedure of Inoue and Bushuk (1991). The yeast and sugar and salt were separately predissolved in water and calculated as part of the total water. After mixing, the dough was immediately divided into three 160-g pieces, rounded by hand, placed in stainless steel bowls, and put in a proof cabinet maintained at 25°C and 85% rh for 10 min. Following the 10-min rest period, the doughs were molded on a laboratory-scale molder into a cylinder shape and placed into greased baking pans.

### Preparation of Reconstituted Flour Control Doughs

Frozen and unfrozen reconstituted flour control doughs and test doughs made from the reconstituted new flours were made using the same formulation and mixing procedures as used for the original flour control doughs, but with the following modifications. Temperature was kept <20°C by using ice water in the formulation to minimize yeast activity. Immediately after the 10-min rest period, the panned dough pieces were placed into 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 doughs were removed from the freezer, depanned, double-bagged in polyethylene bags, and stored in a walk-in freezer maintained at –23°C for eight weeks of frozen storage. Sixteen hours before testing, six dough pieces (three for each cultivar) were removed from the freezer and thawed in a retarder at 4°C according to Inoue and Bushuk (1991).

### Baking Test

The unfrozen doughs, as well as the thawed reconstituted flour doughs, were placed into a fermentation cabinet at 30°C and 85% rh and proofed to a predetermined height. The heights for the reconstituted doughs (79.1 and 75.9 mm for Glupro and Prospect, respectively) were determined on the unfrozen control doughs for both flours using a 45-min fermentation time (Inoue and Bushuk 1991). Proof times were recorded.

After proofing, the loaves were baked in an oven at 218°C (425°F) for 25 min and cooled for 30 min before being weighed. The loaf volume was determined according to the method of Inoue and Bushuk (1991).

### Statistical Analyses

All analyses in this study were performed in triplicate. The data were analyzed using analysis of variance and Duncan's new multiple range test using the Statistical Package for the Social Science (SPSS) system. Values with  $P > 0.05$  and 0.01 were considered significant and highly significant, respectively.

## RESULTS AND DISCUSSION

### Flour Characteristics

The physical and chemical properties of Glupro and Prospect flours are summarized in Table I. Glupro had higher protein, wet gluten, and gluten index values than Prospect. A high gluten index indicates strong gluten. Further evidence of the markedly different gluten characteristics of the two cultivars is shown in Table II. Higher farinograph and extensigraph values were obtained from Glupro for all parameters tested. The rheological property values obtained for Prospect are typical of a weak gluten flour.

### Original and Reconstituted Flour Control Doughs

Table III shows the baking properties of the control doughs. A comparison was made between the unfrozen original flour control dough and the unfrozen and frozen reconstituted flour control doughs. The purpose of this comparison was to act as a check on the fractionation procedure. Results indicate that there were significant differences in proofing time and loaf volume among the control doughs. These differences may be attributed to freeze damage

TABLE I  
Chemical Composition and Gluten Content of Flours

Evaluation (%) <sup>a</sup>	Glupro	Prospect
Moisture	12.5	13.0
Ash	0.46	0.41
Protein	16.6	12.8
Wet gluten	45.4	35.8
Gluten index	87.3	57.1

<sup>a</sup> Expressed on 14% mb.

TABLE II  
Rheological Properties of Flours

Evaluation	Glupro	Prospect
Farinograph		
Absorption (%)	64.1	61.0
Peak time (min)	11.5	5.5
Stability (min)	48.5	8.0
Extensigraph		
Resistance (BU)	816	169
Extensibility (cm)	23.4	21.6

TABLE III  
Baking Characteristics of Original, Unfrozen Reconstituted, and Frozen Reconstituted Flour Dough Controls Using Gliadin, Glutenin, Starch, and Water-Soluble Fractions

Flours <sup>a</sup>	Proofing Time (min)	Loaf Volume (cm <sup>3</sup> )
Original		
Control (unfrozen)		
Glupro	45.0d <sup>b</sup>	966.0a
Prospect	45.0d	913.0a
Reconstituted		
Control (unfrozen)		
Glupro (GGGG)	55.0cd	838.0b
Prospect (PPPP)	65.0c	637.0d
Control (frozen)		
Glupro (GGGG)	208.0b	706.0c
Prospect (PPPP)	380.0a	450.0e

<sup>a</sup> GGGG = Gliadin, glutenin, starch, and water-solubles from Glupro; PPPP = Gliadin, glutenin, starch, and water-solubles from Prospect.

<sup>b</sup> Values followed by the same letter in the same column are not significantly different ( $P < 0.05$ ).

imparted to the dough during freezing and frozen storage which results in diminished quality of the bread produced or changes in dough components due to fractionation and reconstitution. A comparison of loaf volume data between the frozen and unfrozen reconstituted control doughs (-132 and -187 cm<sup>3</sup> for Glupro and Prospect, respectively) suggested freeze damage on baking quality because all fractions were identical. The only difference in the doughs was that one set was frozen and the other was not. The difference in data between the unfrozen original flour control and the unfrozen reconstituted flour control doughs (-128 and -276 cm<sup>3</sup> for Glupro and Prospect, respectively) indicate some loss of material during the separation process or possible changes in functionality of the fractionated components. Recovery of the four solids in the fractionation was 94 and 92% for Glupro and Prospect, respectively. The results shown in Table III suggest that Glupro dough is more freeze-tolerant than Prospect dough. Freeze tolerance can be attributed to gluten strength. It has been suggested (Varriano-Marston et al 1980, Wolt and D'Appolonia 1984b, Autio and Sinda 1992) that damage to the gluten network of a dough may be caused by disruption of certain gluten bonds as a result of the mechanical action of ice crystallization. Because Glupro has a strong gluten matrix, demonstrated by its rheological data (Table II), it may be able to tolerate freeze damage better than Prospect, which has demonstrated weak gluten characteristics.

### Frozen Reconstituted Doughs

Table IV shows the baking properties of the frozen reconstituted doughs and compares these results with those obtained for the frozen reconstituted control doughs (Table III). Each new flour was made by interchanging fractions from Glupro and Prospect. The dough was frozen for eight weeks and then baked.

*Effect of starch fraction.* For the first experiment, the starch fraction included the prime starch and the water-insoluble materials associated with the tailings such as the water-insoluble pentosans, cell-wall materials, minute bran particles, and some damaged starch granules (MacRitchie 1985).

Table IV showed that when the starch fraction of Prospect was substituted for that of Glupro, there was an increase in loaf volume (+58 cm<sup>3</sup>) and a decrease in proofing time (-48 min) when compared with the frozen reconstituted control doughs. Substituting the starch fraction of Glupro for that of Prospect, however, decreased loaf volume (-100 cm<sup>3</sup>) and increased proofing time (+102 min). These results clearly show that the exchange of the starch fractions from the two cultivars resulted in changes in the final baking performance of the frozen reconstituted doughs. The differences observed in the baking performance of these doughs could be attributed to the characteristics of the starch fraction of

each cultivar and its behavior during the process of freezing and frozen dough storage. These same differences may or may not be observed in the baking quality of unfrozen doughs made from the same cultivars. This was not tested, but the starches isolated from Glupro and Prospect do differ in their physicochemical properties (Lu and Grant 1999). These differences may contribute to the way water interacts with the starch of each cultivar during the freezing process and the rate of water migration in the frozen dough during frozen storage (Kulp 1985).

*Effect of water-soluble fraction.* Water-soluble materials play significant roles in fresh dough rheology which is partially attributed to their interaction with gluten. Jelaca and Hlynka (1972) reported that the rate of stretching of gluten was reduced by the addition of water-soluble pentosans. They concluded that gluten was strengthened by the addition of water-soluble pentosans and that the strengthening effect was greater for the addition of water-soluble pentosans than for the addition of water-insoluble pentosans.

When the water-soluble fractions were exchanged between Glupro and Prospect (Table IV), the Glupro water-soluble fraction (PPPG = gliadin, glutenin, and starch from Prospect; water-solubles from Glupro) had a positive effect on the baking quality of the frozen reconstituted doughs. Loaf volume increased (+122 cm<sup>3</sup>) and proofing time decreased (-34 min). Conversely, the water-

**TABLE V**  
Baking Characteristics of Original, Unfrozen Reconstituted, and Frozen Reconstituted Flour Dough Controls Made with Glupro and Prospect Gluten and Starch Fractions

Flours <sup>a</sup>	Proofing Time (min)	Loaf Volume (cm <sup>3</sup> )
Original		
Control (unfrozen)		
Glupro	45.0d <sup>b</sup>	966.0a
Prospect	45.0d	913.0b
Reconstituted		
Control (unfrozen)		
Glupro (GG)	50.0d	882.0b
Prospect (PP)	58.0d	872.0bc
Reconstituted		
Control (frozen)		
Glupro (GG)	251.0b	683.0d
Prospect (PP)	251.0b	656.0d
Reconstituted (frozen)		
GP	165.0c	791.0c
PG	340.0a	500.0e

<sup>a</sup> GG = Glupro gluten, Glupro starch; PP = Prospect gluten, Prospect starch; GP = Glupro gluten, Prospect starch; PG = Prospect gluten, Glupro starch.

<sup>b</sup> Values followed by the same letter in the same column are not significantly different ( $P < 0.05$ ).

**TABLE IV**  
Baking Parameters of Frozen Reconstituted Flour Doughs Compared with Frozen Reconstituted Control Doughs

Reconstituted Flour Source				Loaf Volume (cm <sup>3</sup> )	Loaf Volume Change <sup>b</sup> (cm <sup>3</sup> )	Proofing Time (min)	Proofing Time Change <sup>b</sup> (min)	Oven Spring (mm)
Gliadin	Glutenin	Starch	W-S <sup>a</sup>					
P	P	P	P	450	...	380	...	...
P	P	P	G	572c <sup>c</sup>	+122	346a	-34	4.0c
P	P	G	P	508e	+58	332ab	-48	1.8d
P	G	P	P	668a	+218	296c	-84	13.6ab
G	P	P	P	590c	+140	346a	-34	3.0c
G	G	G	G	706	...	208	...	...
G	G	G	P	523bc	-183	365a	+157	16.0a
G	G	P	G	606bc	-100	310bc	+102	11.1b
G	P	G	G	561cd	-145	205d	-3	-1.0d
P	G	G	G	641ab	-65	226d	+18	14.3ab

<sup>a</sup> Water-solubles.

<sup>b</sup> Difference vs. frozen reconstituted flour controls (GGGG or PPPP) shown in Table III.

<sup>c</sup> Values followed by the same letter in the same column are not significantly different ( $P < 0.05$ ).

soluble fraction of Prospect had a negative effect on baking performance of the Glupro doughs when used in place of Glupro water-solubles. Loaf volume decreased ( $-183 \text{ cm}^3$ ) and proofing time increased ( $+157 \text{ min}$ ).

*Effect of glutenin fraction.* Glutenin represents a heterogeneous mixture of polypeptides linked together by intermolecular disulfide bonds. The polymeric nature of glutenin is a major factor influencing its functional properties.

When the entire glutenin fractions of Glupro and Prospect were exchanged (Table IV), the Glupro glutenin had a positive effect on Prospect frozen dough quality. Loaf volume increased ( $+281 \text{ cm}^3$ ) and proofing time decreased ( $-84 \text{ min}$ ). Conversely, when Prospect glutenin was exchanged for Glupro glutenin, a negative effect loaf volume was obtained ( $-145 \text{ cm}^3$ ), but no effect on proofing time ( $-3 \text{ min}$ ) was observed. The results of glutenin reconstitution indicated that the glutenin plays an important role in frozen dough quality and corroborates earlier findings of Inoue and Bushuk (1991, 1992) that strong gluten flours perform better than weak gluten flours in terms of frozen dough quality.

The gluten protein that controls loaf expansion appears to be glutenin. Khan and Bushuk (1979) stated that flour containing better quality gluten will expand to a greater degree and will produce bread of larger loaf volume. It is clearly evident when observing the oven spring data of the frozen reconstituted flour doughs (Table IV) that the gluten quality of Glupro surpasses that of Prospect. All loaves containing primarily Glupro flour fractions showed consistently higher oven spring than loaves containing primarily Prospect flour fractions. This observation was dramatically demonstrated when Glupro glutenin replaced Prospect glutenin (PGPP = gliadin from Prospect; glutenin from Glupro; starch and water-solubles from Prospect) (Table IV). This data indicates that the glutenin fraction plays the predominant role in improving frozen bread quality.

*Effect of gliadin fraction.* The gliadin protein fraction in this study refers to the acid-soluble materials of the extraction (MacRitchie 1985). When gliadin fractions of Glupro and Prospect were interchanged, that derived from Glupro showed a positive effect on frozen dough quality of Prospect (Table IV). Loaf volume increased ( $+140 \text{ cm}^3$ ) and proofing time decreased ( $-34 \text{ min}$ ). Conversely, the gliadin derived from Prospect had a negative effect on the frozen dough baking quality of Glupro. Loaf volume decreased ( $-65 \text{ cm}^3$ ) and proofing time increased ( $+18 \text{ min}$ ).

### Effects of Interaction Among Fractions

To determine the effects of interactions among gluten and starch fractions on frozen dough baking quality, a second experiment was conducted. In this experiment, entire gluten and starch fractions were exchanged. The starch fraction consisted of the starch and water-soluble and water-insoluble materials. As with the previous experiment, a fractionation loss was evident (decreased loaf volume) when the unfrozen original flour control doughs were compared with the unfrozen reconstituted flour control doughs for each cultivar (Table V). For this experiment, the loss was substantially reduced (Glupro GG,  $882 \text{ cm}^3$  vs. Glupro GGGG,  $838 \text{ cm}^3$ ; Prospect PP,  $872 \text{ cm}^3$  vs. Prospect PPPP,  $637 \text{ cm}^3$ ) because the gluten was not further fractionated into gliadin and glutenin. Damage caused by freezing of the reconstituted doughs (shown by an increase or decrease in proofing time) was also reduced for the Prospect doughs ( $-29 \text{ min}$ ), when compared with the previous experiment. The reason for this reduction may be that fewer fractionation steps helped maintain the original interactions of the flour components of this weak gluten cultivar and thus contributed to reduced damage caused by freezing.

When the starch fraction of Glupro was replaced by the starch fraction of Prospect (GP, Table V), baking quality of the frozen doughs was better than for the frozen reconstituted flour control doughs (GG and PP, Table V). Loaf volume increased ( $+108$  and  $+135 \text{ cm}^3$ ) and proofing time decreased ( $-86 \text{ min}$  for both Glupro

and Prospect, respectively). The combination of Prospect gluten and Glupro starch (PG, Table V) showed poorer baking quality than both Prospect and Glupro frozen reconstituted flour control doughs (PP and GG, Table V). The importance of this observation is that it shows the complex effects of interactions that exist among the flour components. The interactions among the same fractions derived from various flours may produce different baking results. The nature of these interactions, to a certain degree, may determine the final baking performance of frozen doughs.

## CONCLUSIONS

The effects of different flour fractions on frozen dough quality varied with flour gluten strength. Generally, the fractions from the strong gluten flour (Glupro) had a positive impact on frozen dough baking performance, whereas the effects from the weak gluten flour fractions (Prospect) had a negative impact. Among the four isolated flour fractions, glutenin played a predominant role in frozen dough quality. The effects of the gliadin and starch fractions on frozen dough quality were also significant, however not as definite as those observed for the glutenin fraction. The effect of the water-soluble fractions was small but positive.

The contribution of each flour fraction to frozen dough quality depended on the interactions between the fractions and other flour components. For instance, substitution of a single fraction of Prospect for the same single fraction of Glupro, as in the first experiment, had a positive effect on frozen dough quality, but exchanging the entire gluten or starch fractions of Prospect with the same two fractions of Glupro, as in the second experiment, the effect was negative. This indicates that interactions among the flour components contribute to frozen dough quality.

## LITERATURE CITED

- American Association of Cereal Chemists. 1995. Approved Methods of the AACCC, 9th ed. Method 08-01, approved April 1961, revised October 1976 and 1981, reviewed October 1994; Method 38-12, final approval November 1995; Method 44-15A, approved October 1975, revised October 1981 and 1994; Method 46-13, approved October 1976, reviewed October 1982, revised October 1986, reviewed October 1994; Method 54-10, final approval November 1995; Method 54-21, approved April 1961, reviewed October 1982, final approval November 1995. The Association: St. Paul, MN.
- Autio, K., and Sinda, E. 1992. Frozen doughs: Rheological changes and yeast viability. *Cereal Chem.* 69:409-413.
- Bruinsma, B. L., and Giesenschlag, J. 1984. Frozen dough performance: Compressed yeast-instant dry yeast. *Baker's Dig.* 58(6):6-11.
- Brummer, J. M. 1995. Bread and rolls from frozen dough in Europe. Pages 155-165 in: *Frozen and Refrigerated Doughs and Batters*. K. Kulp, K. Lorenz, and J. Brummer, eds. Am. Assoc. Cereal Chem.: St. Paul, MN.
- Chakraborty, K., and Khan, K. 1988. Biochemical and breadmaking properties of wheat protein components. II. Reconstitution baking studies of protein fractions from various isolation procedures. *Cereal Chem.* 65:340-344.
- Inoue, Y., and Bushuk, W. 1991. Studies on frozen doughs. I. Effects of frozen storage and freeze-thaw cycles on baking and rheological properties. *Cereal Chem.* 68:627-631.
- Inoue, Y., and Bushuk, W. 1992. Studies on frozen doughs. II. Flour quality requirements for bread production from frozen dough. *Cereal Chem.* 69:423-428.
- Jelaca, S. L., and Hlynka, I. 1972. Effect of wheat-flour pentosans in dough, gluten, and bread. *Cereal Chem.* 49:489-495.
- Khan, K., and Bushuk, W. 1979. Structure of wheat gluten in relation to functionality in breadmaking. Pages 191-206 in: *Functionality and Protein Structure*. Akiva Pour-El, ed. Am. Chem. Soc.: Washington, DC.
- Kulp, K. 1995. Biochemical and biophysical principles of freezing. Pages 63-89 in: *Frozen and Refrigerated Dough and Batters*. K. Kulp, K. Lorenz, and J. Brummer, eds. Am. Assoc. Cereal Chem.: St. Paul, MN.
- Lu, W., and Grant, L. A. 1999. The effects of prolonged storage at freezing temperatures on starch and baking quality of frozen doughs. *Cereal Chem.* 76:656-662.
- McCleary-Bayley, J. S. 1992. End-use potential of a high-protein,

- diccoides-derived wheat. MSc thesis. North Dakota State University: Fargo, ND.
- MacRitchie, F. 1978. Differences in baking quality between wheat flours. *J. Food Technol.* 13:187-194.
- MacRitchie, F. 1985. Studies of the methodology for fractionation and reconstitution of wheat flours. *J. Cereal Sci.* 3:221-230.
- Varriano-Marston, E., Hsu, K. H., and Mahdi, J. 1980. Rheological and structural changes in frozen dough. *Baker's Dig.* 54(1):32-35.
- Wolt, M. J., and D'Appolonia, B. L. 1984a. Factors involved in the stability of frozen dough. I. The influence of yeast reducing compounds on frozen-dough stability. *Cereal Chem.* 61:209-212.
- Wolt, M. J., and D'Appolonia, B.L. 1984b. Factors involved in the stability of frozen dough, II. The effects of yeast type, flour type, and dough additives on frozen-dough stability. *Cereal Chem.* 61:213-221.

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