Freeze-Thaw Stability of Prefermented Frozen Lean Wheat Doughs: Effect of Flour Quality and Fermentation Time

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ABSTRACT

Cereal Chem. 72(6):637–642

The effects of fermentation time and flour quality on the baking quality of prefermented frozen wheat doughs were studied. The doughs were baked from six different flours and fermented optimally (40 min) and less than optimally (25 min) before freezing. After frozen storage (1–14 days), the baking quality was evaluated and the structure of the doughs was studied by microscopic and rheological methods. Fermentation time had a dramatic effect on the freezing and thawing stability of the doughs. With one-day storage, the loaf volumes were, on average, 20% greater after shorter than after longer fermentation time. Moreover, with interrupted fermentation the change in loaf volume due to freezing was almost independent of flour quality. Microstructural and rheological studies showed that the reason for these improvements was a thicker gluten network and greater amount of small gas bubbles. However, the interrupted fermentation did not reduce the deterioration of loaf volumes during longer storage times. The most significant decrease (11% of the fresh volume) occurred during the first week but continued during the second week of frozen storage (up to 15% of the fresh volume).

Frozen doughs have been of great interest since the 1960's. Today these doughs are widely used in industrial bakeries, making fresh bread available to consumers for the whole day; transportation is facilitated, labor costs are reduced, and skilled bakers are not as essential as before. On the other hand, loaf volumes are smaller and quality poorer for breads baked from frozen doughs than from the fresh ones, especially when storage times are long.

The problems with baking frozen doughs are the decrease in CO_2 retention due to a damaged gluten network and the loss of the yeast viability (gassing power). Many hypotheses have been suggested for these changes. The deterioration of the gluten network has been attributed to the ice crystals formed in freezing, which cause physical breakage of the gluten, weakening of hydrophobic bondings, and redistribution of water in the gluten structure (Varriano-Marston et al 1980, Berglund et al 1991, Inoue and Bushuk 1991, Autio and Sinda 1992). The loss of yeast viability could be caused by ice crystals that physically puncture the outer membrane of the yeast cells or to the accumulation of metabolic products resulting in the autolysis of yeast cells (Kline and Sugihara 1968, Hsu et al 1979). The studies of Autio and Sinda (1992) do not support the latter hypothesis.

Hosomi et al (1992) suggest three different ways to solve these problems: 1) find a new yeast strain or improve the old ones to make them more resistant to freezing; 2) use prefermented doughs; or 3) find suitable additives and ingredients for frozen doughs. The use of prefermentation before freezing may be the best solution for yeast viability after frozen storage because it reduces the need for a dough to ferment after thawing. In this way thawing is less time-consuming and, in fact, it can be accomplished directly in a programmed oven (Brümmer and Neumann 1993). On the other hand, the gluten, especially at the air-cell interface, is under extension and very sensitive to damage from ice crystals. This being the case, the dough should be made from high protein flour (>16% protein content) (Benjamin et al 1985) or gluten-containing additives should be used (Wang and Ponte 1994).

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In this work, we studied the effects of fermentation time and flour quality on the baking quality of prefermented frozen doughs stored for a short time (up to 14 days). A short frozen storage time was chosen because the deterioration of frozen products occurs in two stages: during freezing-thawing and during frozen storage. The structure of the fermented doughs was studied by microscopic and rheological methods.

MATERIALS AND METHODS

Flour Samples

Six different flours were milled (Bühler MLU-202, Germany) from pure wheat cultivars with 60% flour yield, or flours were purchased as commercial mixtures. Determinations were made of moisture, protein content, falling number, wet gluten content, and farinograph absorption at 500 BU (AACC 1983). All the analyses were performed in duplicate and the results were calculated on a dry matter basis.

The amount of water solubles was determined according to Izydorczyk et al (1991) by adding 15 ml of distilled water at 30°C to 5 g of flour. After 3 min of shaking and centrifuging, the supernatant was evaporated and the water soluble index (WSI) was calculated.

Baking Test

Dough formulation was 100% flour, 4% yeast (compressed baker's yeast from Finnish Yeast Ltd.), 2% sugar, 1.5% salt, 4% shortening, and 4% additive (S-kimo from Puratos, Belgium), plus water to achieve optimum consistency.

Yeast was added as a suspension in water at 37°C. The mixing was done with a blade mixer (Original Diosna) to optimum mixing time determined with a farinograph. To minimize the differences that arise from mixing, the same dough was used for fresh breads and prefermented frozen doughs.

After 20 min of floor time at 28°C, the dough was divided into 150-g pieces that were molded into rolls with an extensigraph. Three or four dough pieces were prepared from each flour for each test.

The final proofing was performed at 34°C and 80% rh for either 40 or 25 min. The dough pieces were frozen with a blast freezer to a final core temperature of ≈–20°C. After one day of frozen storage in a chest freezer at –20 ± 2°C, the doughs were thawed in a fermentation cabinet at 34°C and 80% rh and then baked at 200°C for 25 min (internal temperature at 10 min over 98°C).

TABLE I
Characteristics of Flour Samples

Quality Tests	Flour A	Flour B	Flour C	Flour D	Flour E	Flour F
Protein content (N × 5.7), %	11.35	12.74	17.29	11.67	12.43	14.10
Ash content, %	0.54	0.58	0.54	0.49	0.49	0.47
Falling number value	222	304	508	317	236	316
Wet gluten, % (a)	28.45	27.2	40.7	33.8	30.7	44.2
Water soluble index, % (b)	5.15	5.64	4.64	4.63	4.67	4.79
b/a	0.18	0.21	0.11	0.14	0.15	0.11
Farinograph						
Absorption, %	50.0	58.8	62.5	53.5	54.0	56.0
Dough development time, min	2.0	2.5	12.0	2.3	3.0	2.5
Stability, min	6.0	16.5	12.0	9.0	12.5	18.8

TABLE II
Effect of Prefermentation and Frozen Storage Time on Loaf Volumes

	Percentage Changes of Loaf Volumes (%)											
	Flour A		Flour B		Flour C		Flour D		Flour E		Flour F	
Loaf volume (ml)	549	±	540	±	629	±	543	±	566	±	588	±
40 min / 0 day	0.0	5.2	0.0	0.9	0.0	0.6	0.0	2.3	0.0	2.4	0.0	4.7
40 min / 1 day	−16.9	3.6	−18.0	2.3	−14.1	1.9	−11.6	1.0	−15.5	3.1	−16.0	1.8
25 min / 1 day	5.6	5.7	12.8	0.7	3.0	1.2	4.6	0.4	4.2	0.4	3.4	0.4
25 min / 7 days	−10.6	1.8	−14.6	3.4	−13.2	1.7	−2.0	1.6	−13.4	2.0	−15.3	1.0
25 min / 14 days	−16.6	3.3	−13.9	2.6	−17.3	2.6	−8.5	2.7	−15.5	4.5	−22.6	0.4

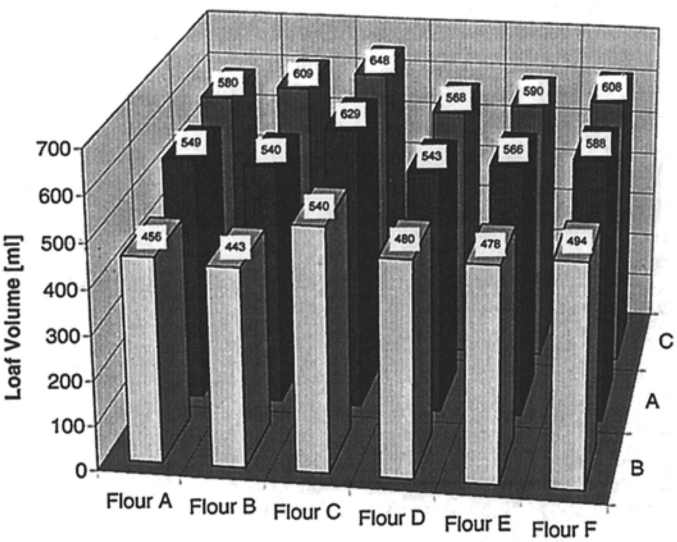

Fig. 1. Loaf volumes of fresh bread fermented 40 min (A), and bread frozen one day fermented 40 min (B) and 25 min (C).

After 2 hr of cooling, the bread loaf volumes (determined by rapeseed displacement), weight, and form ratio (height/width) were measured. The specific volume was calculated by dividing volume by weight. The baking tests were performed at least twice for all flours.

Microscopy

To analyze the microstructure of prefermented frozen doughs, the whole dough was sliced and freeze-dried. A small sample was taken from the middle of the slices and embedded in Historesin Embedding medium (Reichert-Jung, Germany). Sections 10 µm thick were cut with a microtome (Leica, Germany) and stained with 0.1% Light Green and 25% Lugol solution. The sections were rinsed with distilled water and dried. The bright-field microscopy and photography were performed with an Olympus BX-50 microscope. The porosity of frozen doughs was examined in micrographs (total area 275 mm^2) with an image analyzer (Cue-3, Olympus).

Rheology

A Bohlin rheometer (VOR) with parallel plates was used to measure the rheological parameters of the frozen doughs. The dough was thawed before samples were taken. The samples were weighed and slowly compressed with the upper plate to a 1.5-mm gap between the plates (diameter 25 mm). To prevent the samples from drying, an O-ring was used in the lower plate. The measurements were made at 25°C in a high-temperature cell and the strain was 0.6×10^{-3}. Each measurement took 10 sec. Tan δ was calculated from G''/G'.

RESULTS AND DISCUSSION

Flour Analyses

The results of the flour analyses are shown in Table I. The flour samples were selected to cover as many different flour types as possible. The protein content (N × 5.7) varied between 11.4 and 17.3%, the falling number value between 222 and 508, and the wet gluten content between 27.2 and 44.2%. There were also great differences in farinograph values; for example, absorption varied between 50.0 and 62.5%, dough development time was 2.0–12.0 min, and stability was 6.0–18.8 min.

Effect of Prefermentation Time on Freeze-Thaw Stability

The loaf volumes of fresh breads and breads baked from doughs stored frozen for one day are reported in Table II and Figure 1. The prefermentation time had a dramatic effect on the freezing and thawing stability of doughs: the shorter fermentation time favored larger loaf volumes. Fermentation time of 40 min was selected to ensure an almost optimal fermentation for all flours before freezing and to avoid over-fermentation; 25 min was chosen as an example of interrupted fermentation. The optimal conditions are not, of course, necessarily the same for all flours. According to Hanneforth et al (1994), the fermentation time for interrupted fermented frozen doughs should be one-half to two-thirds of the optimal time for fresh doughs.

The loaf volumes of doughs fermented 40 min were decreased by 15%, on average, because of the freezing and thawing, whereas the volumes of the doughs fermented 25 min were retained or even increased by 3–13%, relative to fresh baked loaves. These results are not consistent with those of Kräft et al

TABLE III
Effect of Prefermentation and Frozen Storage Time on Form Ratio

	Form Ratio											
	Flour A		Flour B		Flour C		Flour D		Flour E		Flour F	
		±		±		±		±		±		±
40 min / 0 day	0.62	0.01	0.56	0.00	0.48	0.01	0.55	0.01	0.59	0.02	0.55	0.01
40 min / 1 day	0.49	0.03	0.44	0.01	0.33	0.01	0.43	0.00	0.45	0.01	0.42	0.01
25 min / 1 day	0.51	0.05	0.50	0.02	0.37	0.00	0.48	0.01	0.47	0.01	0.39	0.01
25 min / 7 days	0.51	0.00	0.48	0.00	0.35	0.02	0.45	0.00	0.47	0.01	0.45	0.01
25 min / 14 days	0.49	0.00	0.47	0.01	0.37	0.00	0.48	0.02	0.46	0.02	0.46	0.02

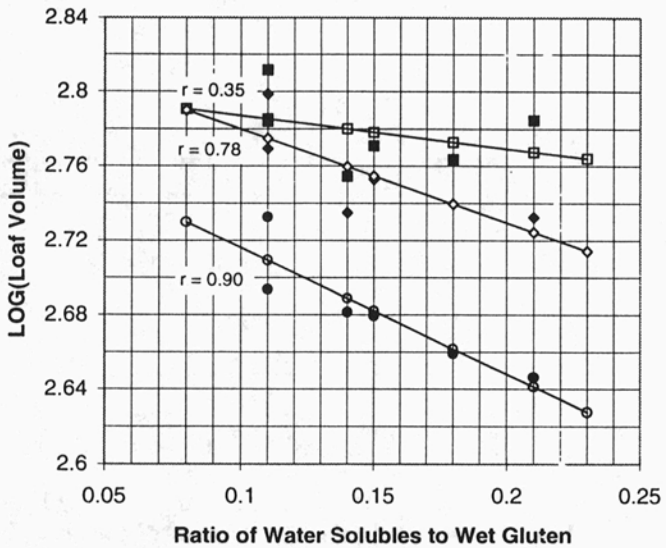

Fig. 2. Correlations of log(loaf volume) and ratio of water solubles to wet gluten in bread fermented 40 min and baked immediately (◆ data points, ◇ regression) and in breads fermented 40 min (● data points, ○ regression) and 25 min (■ data points, ❑ regression) and frozen one day.

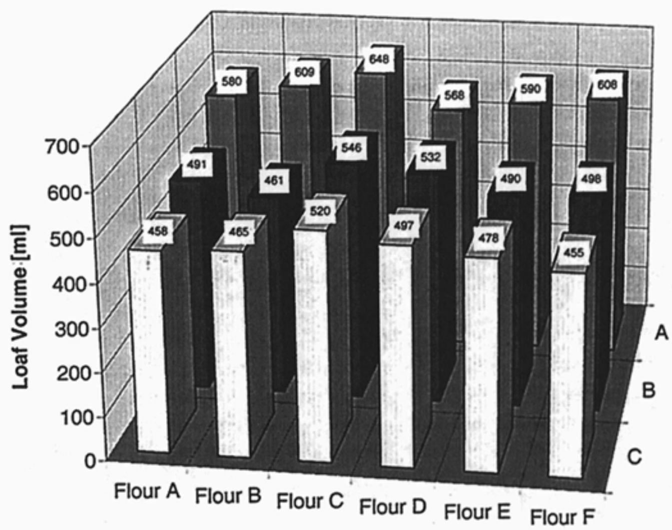

Fig. 3. Loaf volumes of breads fermented 25 min and stored frozen for 1 (A), 7 (B), and 14 days (C).

(1994), who reported that the loaf volumes of interrupted (80% fermented) frozen doughs, baked directly in a programmed oven, were on average only 87.5% of the volumes of fresh baked breads. The disagreement may be due not only to flour quality but to different recipes or process conditions, such as thawing conditions and the length of fermentation time. Brümmer et al (1993) found that interrupted fermentation (75% fermented) and freezing decreased loaf volumes even more, by 23% relative to fresh breads. According to Brümmer et al (1993), the optimal conditions were 60 min of thawing at 20°C, followed by 45 min fermentation at 32°C and 70% rh, which decreased the loaf volumes less than thawing directly in a programmed oven.

As can be seen from the lower form ratio, the breads baked from frozen doughs were flatter than those baked from fresh doughs regardless of the fermentation time (Table III). The breads fermented 25 min had somewhat greater form ratio than the breads fermented for 40 min. The great difference in the form ratios of fresh and frozen breads may have been due to too high thawing temperature creating a large temperature gradient and over-proofing of the outer part of the dough (Dubois and Blockcolsky 1986).

Effect of Flour Quality on Freeze-Thaw Stability

Loaf volumes for doughs fermented 40 min decreased by 11.6% (flour D) to 18.0% (flour B) after one-day storage time (Table II). The average decrease for flours A, C, E, and F was 15.6 ± 1.0%. In studies reported by Slade et al (1988), the loaf volumes of frozen doughs increased as the ratio of water solubles to wet gluten decreased. They obtained a correlation ($r = -0.84$) between the log of loaf volumes and the ratio of water solubles to wet gluten after three-months frozen storage time. In our study (Fig. 2), the correlation for 40-min fermented doughs after one-day storage was higher than for fresh breads ($r = 0.90$ vs. $r = 0.78$). Thus, in the case of 40-min fermented frozen doughs, the flours with a smaller ratio of water solubles to wet gluten were more resistant to changes of freezing and thawing.

Irrespective of the flour type, the loaf volumes of all breads after one-day frozen storage were higher than those of fresh breads when the fermentation time was 25 min. As can be seen in Table II, the increase was 5.6% on average and for flour B as much as 13.2%. The ratio of water solubles to wet gluten had a clearly weaker effect on the loaf volumes at shorter fermentation time ($r = 0.35$) than at longer fermentation time. Our results also showed that the length of fermentation was more important than the flour quality for the change in loaf volumes due to freezing. The final loaf volumes of frozen doughs were dependent on flour quality in about the same way as the fresh ones.

In all experiments, the specific volumes (Table IV) and loaf volumes were the highest for the flour C, which also had the highest protein content. However, the form ratio of flour C (Table III) was the smallest. For other flour samples, the form ratio results were mostly opposite to the specific and loaf volumes. It is interesting that flour A, which had the highest form ratio, also had the lowest protein content and farinograph water absorption.

Effect of Prefermentation Time on Frozen Stability

The loaf volumes of doughs fermented 25 min decreased as the frozen-storage time increased (Table II, Fig. 3). The reduction was greatest during the first week of storage. Relative to the volume of the fresh loaves, the volumes decreased in the first week by 11% and by 15% altogether after two weeks of frozen storage. Thus, two weeks frozen storage resulted in a reduction of the loaf volumes of doughs fermented 25 min that was almost down to the values of doughs fermented 40 min and doughs frozen one day. Evidently, interrupted fermentation does not affect the stability of frozen storage as dramatically as it does freezing and thawing. According to Brümmer and Neumann (1993), interrupted fermented doughs should not be stored for longer than five days. In their study, the difference in loaf volumes after five days of storage was 15–20% relative to the fresh ones. Brümmer et al (1993) also discovered that the greatest changes in loaf volumes occurred in frozen storage between one and four days.

The specific volumes of interrupted fermented breads stored one or two weeks (Table IV) behaved like the loaf volumes. The form ratio (Table III) did not follow the same trend, but, on average, the form ratio of breads fermented for 25 min did not change during longer frozen storage. Thus, the major reduction in the form ratio occurred during the freezing and thawing. Even after two weeks of frozen storage, breads fermented 25 min had better shape than breads fermented 40 min and stored one day.

Effect of Flour Quality on Frozen Stability

Loaf volumes of doughs prepared from different flour samples, fermented for 25 min and stored for one and two weeks, followed the pattern of the fresh breads (Table II). However, flour D had the greatest stability to frozen storage; the volumes decreased by only 2% from that of the fresh baked breads after one week of storage and 8% after two weeks storage. The maximum error of loaf volumes of 5% should be kept in mind, however. The longer

TABLE IV
Specific Loaf Volumes at Different Fermentation and Frozen Storage Times

	Specific Loaf Volumes (ml/g)											
	Flour A		Flour B		Flour C		Flour D		Flour E		Flour F	
		±		±		±		±		±		±
40 min / 0 day	4.20	0.26	4.12	0.06	4.89	0.04	4.16	0.08	4.31	0.11	4.48	0.21
40 min / 1 day	3.45	0.15	3.38	0.09	4.21	0.12	3.65	0.05	3.63	0.11	3.78	0.05
25 min / 1 day	4.45	0.29	4.66	0.06	5.03	0.05	4.23	0.07	4.48	0.00	4.65	0.03
25 min / 7 days	3.48	0.15	3.50	0.14	4.19	0.25	4.04	0.06	3.72	0.06	3.81	0.09
25 min / 14 days	3.45	0.12	3.56	0.10	4.02	0.09	3.77	0.12	3.66	0.16	3.38	0.06

A
B
C

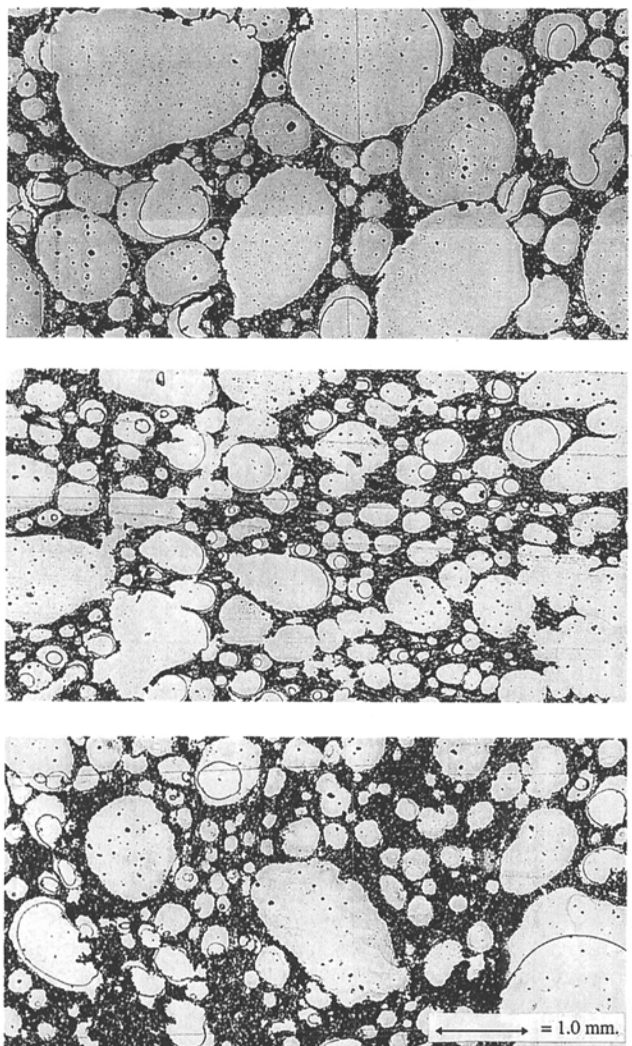

Fig. 4. Light micrographs of prefermented doughs made from flour C. **A,** 40-min fermented after one day; **B,** 25-min fermented after one day; **C,** 25-min fermented after 7 days frozen storage.

A
B
C

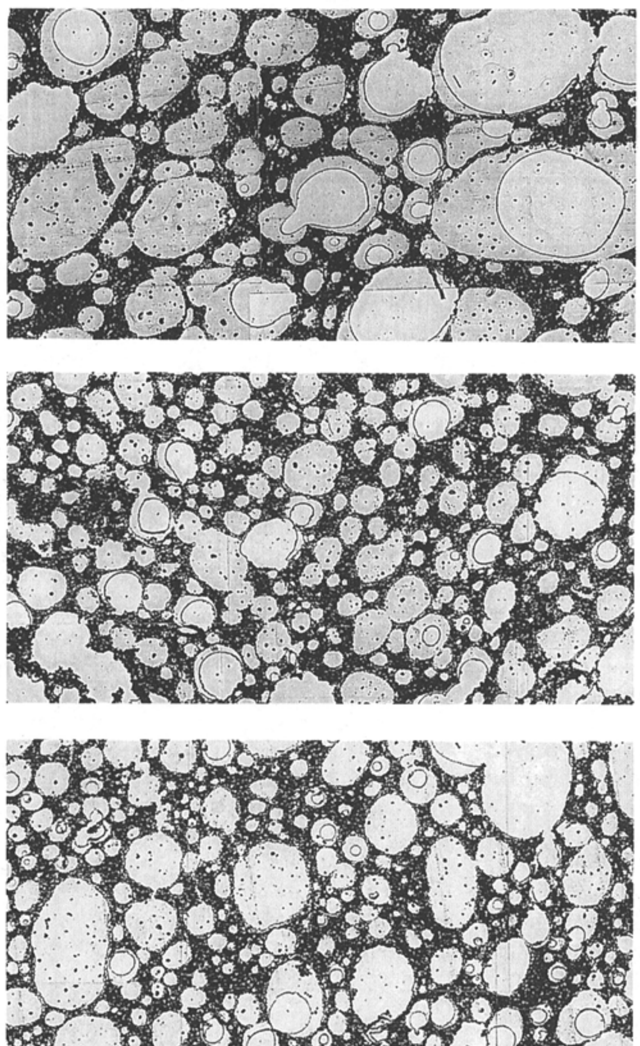

Fig. 5. Light micrographs of prefermented doughs made from flour D. **A,** 40-min fermented after 1 day; **B,** 25-min fermented after 1 day; **C,** 25-min fermented after 7 days frozen storage.

frozen storage time also increased the correlation (results not shown) between loaf volume and the ratio of water solubles to wet gluten. Thus, the effect of flour quality became more important during storing.

The fact that the average form ratio of interrupted fermented breads did not change during frozen storage and that a poor correlation was found between loaf volumes and the ratio of water solubles to wet gluten after two weeks storage suggests that the yeast viability may have an important role in the frozen stability of interrupted fermented breads.

Microscopy

Microscopic analyses were conducted to determine the reasons for better freezing stability of the interrupted fermentation. Differences between flour samples were also studied by analyzing flours C (high protein) and D (low protein) fermented and stored for different times. The results revealed that the interrupted fermentation left a thicker network of gluten around the air bubbles and the average size of the gas bubbles was smaller (Figs. 4 and 5). Thus, the walls of the air bubbles were more resistant to the stress of freezing (for example, the formation of ice crystals) than those of optimally fermented doughs. This was also found when frozen doughs were baked without thawing (Fig. 6). In the hot oven, the outer part of the dough dried and a layer impermeable to gases was formed. Figure 6 shows that the internal appearances of optimally and interrupted fermented breads are strikingly different. The optimally fermented bread had a dense crumb with a large bubble under the crust. Thus, the destruction of the gluten network released most of the CO_2, something that did not occur with interrupted fermented breads.

Differences between the flour samples C and D were less clear, but flour D seemed to contain fewer large bubbles and had a denser structure of gluten (Table V). This would explain the better stability to freezing and frozen storage of flour D. Micrographs and image analysis of the doughs stored frozen for seven days also revealed that the number of small air bubbles decreased during storage as larger ones (1–20 mm^2) formed. This change was clearer for dough C, which also had a greater reduction in loaf volumes than dough D. Thus, the reason for the marked reduction in loaf volumes during the first seven days of storage could be due to changes in the gluten network, though other changes, such as yeast viability could also have an effect. We shall study yeast viability in more detail in future work.

A

B

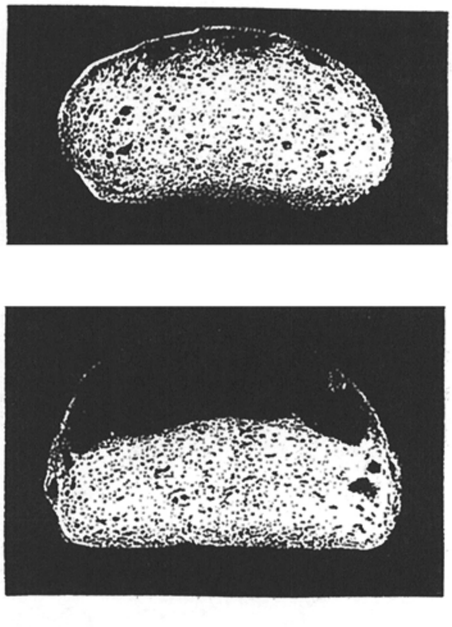

Fig. 6. Effect of fermentation time on internal appearance of breads made from frozen doughs without thawing. **A,** interrupted fermented; **B,** optimally fermented.

Rheology

The results of rheological measurements (Table VI) made for the same doughs used in the microscopy study supported both the baking tests and the micrographs. As indicated by the G' values, the doughs made of flour C were, in all cases, significantly less rigid than those made of flour D, and the rigidity of both doughs was less at the longer fermentation time. These results are consistent with those of Kaufmann and Kuhn (1994), who reported that the longer fermentation time (10–50 min) increased the compressibility of fresh wheat dough. Similarly, tan δ values showed that the nonyeasted doughs were more elastic than the fermented ones, which became still more viscous with increased fermentation time. Although the optimal fermentation caused the most significant changes in the rheological properties, the longer frozen storage time also weakened the structure of both doughs.

The fermented dough D was more than twice as rigid as the fermented dough C, and relative to dough C, the rigidity of the nonyeasted dough D was decreased less during fermentation. These results agree with the microscopic examination of fermented doughs, which showed that dough D contained smaller air bubbles and a denser gluten film. Both these properties have a great influence on dough rheology. The greater rigidity of dough D is also in agreement with the smaller change in loaf volume of sample D during frozen storage. It should be noted, however, that the fragile structure of fermented doughs may change when the sample is placed between the two plates.

TABLE V
Effect of Prefermentation and Frozen Storage Time on Porosity of Doughs C and D

	Pores (Area %) mm^2			
	0.001–0.1	0.1–1	1–20	0.001–20
Flour C				
40 min / 1 day	9.9	30.6	30.3	70.8
25 min / 1 day	18.1	27.4	17.9	63.4
25 min / 7 days	12.9	27.9	25.7	66.5
Flour D				
40 min / 1 day	12.4	32.1	25.0	69.5
25 min / 1 day	17.8	30.3	12.0	60.1
25 min / 7 days	17.8	28.2	16.7	62.7

TABLE VI
G' and Tanδ Values at Different Fermentation and Frozen Storage Times

	G' (kPa)				Tan (δ)			
	Flour C		Flour D		Flour C		Flour D	
Non-yeasted doughs		±		±		±		±
0 min / 1 day	13.03	0.38	25.13	0.91	0.440	0.008	0.383	0.014
Yeasted doughs								
40 min / 1 day	8.04	0.33	18.18	0.38	0.460	0.025	0.427	0.010
25 min / 1 day	9.65	0.15	20.28	0.90	0.447	0.010	0.430	0.018
25 min / 7 days	9.10	0.13	19.58	0.58	0.450	0.009	0.406	0.016

CONCLUSIONS

Interrupted fermentation has a dramatic effect on the freeze-thaw stability of prefermented doughs. The loaf volume of prefermented doughs after one day of storage was improved, on average, by 20% by decreasing the prefermentation time from 40 to 25 min. This improvement was almost independent of flour quality. The reasons for these changes, according to the microscopic and rheological studies, are a thicker gluten network around the gas bubbles and a larger number of small gas bubbles. The thicker gluten structure is more resistant to the stress of freezing. The interrupted fermentation did not eliminate the flattening of breads and, thus, the form ratio decreased on average by 19% from the fresh values and almost independently of the fermentation time and flour quality.

The loaf volumes of the breads fermented 25 min after one week of storage were larger than those of optimally fermented breads after one day of storage. However, they were also, on average, 16% smaller than the volumes of breads fermented 25 min after one day of storage. Thus, the decrease in fermentation time did not improve the frozen storage stability of prefermented doughs over the longer term. The most dramatic decrease in volume occurred during the first week of storage and continued during the second week, altogether down to 15% below the volume of the optimally fermented fresh baked loaf. The micrographs and rheological measurements did not supply all the reasons for the large reduction occurring in the first week of storage.

ACKNOWLEDGMENTS

We thank the Finnish Food Research Foundation for financial support and Ritva Heinonen and Leena Pulkki for their skillful technical assistance.

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[Received July 14, 1995. Accepted March 4, 1995.]