Changes in Gas Production and Retention in Non-Prefermented Frozen Wheat Doughs[1]

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ABSTRACT

The effect of freezing conditions, flour protein content, yeast type, water amount, and freeze-thaw cycles during storage on rheological properties and gas production in non-prefermented frozen wheat doughs were examined. Freezing the dough with high air velocity (3 m/sec) at –20°C, and after one week storage at the same temperature, gave the highest yeast activity and the best bread quality, while the least activity was in case of freezing with high air velocity (3 m/sec) at –30°C and storage at –20°C for the same period. The risograph total gas production was decreased by 33.4% for frozen dough after four weeks storage. Moreover, the reduction was 49.7% as a result of subjecting the dough to three freeze-thaw cycles. The rheological behaviors measured by rheofermentometer changed during storage. The activity of compressed yeast was less than that of instant active dry yeast in frozen dough. The decrease of added water from 58.8 to 56.8% improved the bread characteristics.

The utilization of frozen doughs for the production of small baked goods as well as bread has increased from year to year all over the world. Different countries developed their own specific freezing systems, mostly for dough pieces with a weight between 50 and 100 g.

Freezing of bread doughs with weights of 500 g and higher causes more problems; therefore, we studied the influence of different raw materials and recipes, the conditions of freezing, thawing, and fermentation on frozen bread doughs for the production of wheat bread. The frozen dough stability has been related to dough formulation, yeast quality, sulfhydryl (SH) compounds released by yeast, fermentation before freezing, and freeze-thaw rates. In this article, the variation in gas production and rheological changes in non-prefermented frozen wheat bread doughs are investigated.

Effect of Freezing Conditions on Frozen Dough Stability

The two basic freezing systems that are available commercially are the cryogenic process, which involves the use of liquid nitrogen and the mechanical refrigeration by air blast. Bender and Lamb (1977) studied the effect of freezing rate and storage temperature on the gassing activity of yeast in thawed frozen dough. They reported that increasing the freezing rate from 0.05 to 0.5°C/min caused a reduction in yeast activity during storage. However, Hsu et al (1979b) stated that the final freezing temperature had a greater effect than did the freezing rate on frozen dough stability. Marston (1978) found that minimum damage to yeast and best overall product quality were obtained when the initial freezing was done within 20 min. He added that the frozen dough pieces should be maintained within a temperature range of –15°C to –20°C throughout storage and distribution. Hsu et al (1979a) reported that freezing at different temperatures caused different levels of damage to yeast. The freezing rate apparently was responsible for the damage, but two other factors could affect the results: either the lowest temperature reached or the temperature change from freezing to storage might affect yeast viability. The same authors also reported that the slow dough freezing at –20°C was better than freezing at –40°C. Frozen doughs were less stable when the storage temperature was lower than the freezing temperature. Linko and Karhunen (1984) reported that most of product water crystallized at –12°C to –14°C, although it has been shown that some water remains unfrozen at much lower temperature. Inoue and Bushuk (1991) reported that the final proofing time increased and loaf volume decreased during frozen storage at –20°C for one week and with increasing number of freeze-thaw cycles (FTC). They concluded from their results in the bread dough, that weakening took place during frozen storage and successive FTC. Such weakening could result from an increase in reducing substances leached from yeast or from redistribution of water caused by a change in the water-binding capacity of flour constituents. Neyreneuf and van der Plaat (1991) studied the freezing rate at –34°C in a blast freezer within 20 min after mixing for a piece of dough weighing 350 gm. They found that the dough temperature was decreased 1°C/min throughout the refrigeration (from nearly +20 to +2°C) and undercooling zones (from nearly –6 to –30°C). Freezing rates within the freezing zone (from nearly +2 to –6°C) and storage temperature (–20°C) were appropriate to describe the dough as deep frozen.

TABLE I
Quality of Two Wheat Flours

	Flour A	Flour B
Ash content, % dm	0.53	0.56
Protein content (N × 5.7), % dm	11.9	13.2
Maltose content, % dm	1.8	1.7
Wet gluten content, %	28.1	31.7
Sedimentation value, units	31	34
Falling number, sec	380	395
Water absorption, %	58.5	58.6

TABLE II
Recipe for Bread Production

Wheat flour	100.0 parts
Fat	2.0 parts
Salt	1.5 parts
Sugar	1.0 parts
Skim milk powder	1.0 parts
Compressed yeast	4.0 parts
Water addition[a]	

[a] According to water absorption in farinograph.

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Effect of Wheat Flour on Frozen Dough Stability

The flour used for frozen dough should have a stronger protein content than that normally used in regular bread production (Wolt and D'Appolonia 1984a,b). Neyreneuf and van der Plaat (1991) demonstrated that the flour with a falling number in the region of 300 sec and over was desirable.

Effect of Yeast on Frozen Dough Stability

The selection of the right strain of yeast and the optimum processing conditions is critical for the production of frozen doughs with the required shelf life. Brümmer and van Lengerich (1979, 1980) mentioned that active dry yeast might be superior to compressed yeast in maintaining shelf life in frozen dough. Theoretically, the longer lag-phase with dry yeast minimizes fermentation before freezing and thus gives a more stable frozen dough. Hsu et al (1979a) mentioned that the quality of yeast directly influenced the stability of the frozen doughs. Good yeast performance after freezing was associated only with yeast with protein contents >57%. The amount of yeast, used in frozen doughs, depends on the average time of frozen storage, the formulation of the dough and the desired proof time after thawing (Bruinsma and Giesenschlag 1984).

Effect of Water Addition on Frozen Dough Stability

Water affects the structural nature of the product due to its wetting properties and is normally used at slightly lower levels in frozen dough than in normal bread recipes (Brümmer 1993).

MATERIALS AND METHODS

Wheat Flour

A wheat flour (type 550) was milled from two German wheat cultivars (flour A and B). The analysis of these wheat flours are presented in Table I. Data have been obtained mainly by German standard methods (AGF 1978) and ICC standards (ICC 1992).

Yeasts

We used fresh compressed baker's yeast (CY) produced by Deutsche Hefewerke GmbH, Hamburg. We used instant active dry yeast (IADY) type (Saf instant) produced by S. I. Lesaffre, Marcq en Bareul, France. The moisture content of the CY was ≈72%; the moisture content of the IADY was ≈4%.

Preparation of the Dough

The dough was prepared by the straight-dough procedure using the formula given in Table II. The water addition was based on a farinograph test using line 500 BU. For IADY, we increased the water addition to an amount equal to its weight.

All dough ingredients were combined and mixed in a laboratory mixer (Diosna, 100 Upm) for 5 min. The final dough temperature was 26°C ± 1°. The dough was taken immediately after mixing without preproof, divided into 500-g pieces, rounded, and molded. The molded doughs were put directly in aluminum pans with the capacity of 640 cm^3 (20.3 × 9.3 × 5.2 cm). The diameter of the molded dough was ≈5 cm. The aluminum pans were placed on trays and frozen. Four doughs were prepared for each treatment.

Doughs were prepared using flour A (11.9% dm protein), flour B (13.2% dm protein), CY, IADY, and water additions (500 and 600 BU).

Freezing Conditions

The trays were arranged in the freezing chamber in such a manner to allow maximum air circulation. The temperature in the center of the dough was measured during freezing by thermocouples. We used five different freezing conditions (Table III).

TABLE III
Freezing Conditions of Dough

Freezing Technique	
1	Low air velocity (1 m/sec) and direct freezing using −20°C ± 2° freezing temperature.
2	High air velocity (3 m/sec) and direct freezing to −20°C ± 2° freezing temperature.
3	High air velocity (3 m/sec) and direct freezing to −30°C ± 2° freezing temperature.
4	High air velocity (3 m/sec) during freezing down to −10°C and then freezing to −20°C ± 2° with low air velocity (1 m/sec).
5	Low air velocity (1 m/sec) during freezing to −10°C and then freezing to −20°C with high air velocity (3 m/sec).

Storage Time and FTC During Storage

The frozen dough was stored at −20°C ± 2° at three different times: one week for studying the freezing conditions, four weeks for studying the effect of FTC, 12 weeks for studying the yeast type, water addition, and flour quality.

We also studied the thawing and refreezing cycles on frozen dough and bread quality. Each FTC was accomplished by allowing the dough to thaw partially at room temperature (+22°C ± 1°) for 2 hr. Then the doughs were refrozen for a minimum of one week before the next thawing cycle. The procedure was repeated for each FTC.

Baking of White Pan Bread

The fermented doughs were baked in a baking oven (Werner and Pfleiderer, Stuttgart) with four floors for 30 min with 220°C ± 10° baking temperature with steam (30 sec steam treatment at the beginning of baking). After baking, the bread samples were removed from pans and cooled at room temperature (+22°C ± 1°). After 15 hr, the bread quality was evaluated. The calculation of

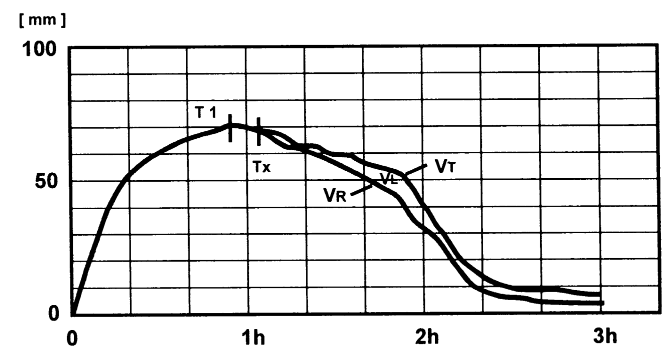

Fig. 1. Evaluation of rheofermentometer curves. T_1 = total time until highest gas production; T_X = time of gas release; V_T: = area below the higher curve, total gas production; V_R: = area below the lower curve, total gas retention; V_L: = area between the two curves, $V_T - V_R$ = gas release; R_C = retention coefficient = $(V_R{:}V_T) \times 100$.

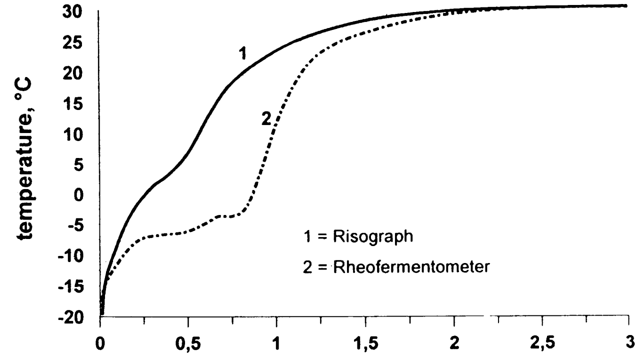

Fig. 2. Temperature curves during thawing and fermentation.

the baking score is described in Arbeitsgemeinschaft (1978). The score is mainly based on volume, pictures of pores, and crumb elasticity.

Measurement of Gas Production and Rheological Behavior

Risograph (R-Design, W. 700 Main Street, Pullman, WA). To measure the gas volume produced, dough samples were prepared from 40 g of flour. After mixing, the doughs were placed immediately in the fermentation jars, and the gas volume was recorded every 15 min. The total testing time was 180 min. For evaluating the gas production, results were extrapolated to an equivalent of 100 g of flour.

For the determination of gas from frozen dough, the samples were removed from the freezer and the polyethylene bags and put directly in the fermentation jars. The thawing and fermentation occurred at the same time in the jars. The experiment was completed when doughs are unfrozen after 3 hr.

Rheofermentometer (Chopin S.A - Groupe Tripette & Renand, Vielleneuve la Garenne, France). With this equipment, the gas volume from the yeast activity and also the rheological behavior of the dough was measured. A dough with the mentioned formula equal to 100 g of flour was put in the fermentation vat, adjusted to 30°C ± 0.1°. The fermentation vat was tightly closed and the results were recorded for a period of 180 min. The procedure for using the rheofermentometer was described by Brack (1996).

For measuring the gas volume and the rheological properties in frozen doughs, dough equal to 100 g of flour was frozen by the same methods. The frozen dough samples were taken from the freezer and put directly in the fermentation vat. Both thawing and fermentation occur at the same temperature during the experimental time (3 hr). For studying the effects of freezing conditions, storage time, FTC, yeast type, flour type, and water additives on gassing power and rheological behavior of the frozen doughs the same procedure was used (Fig. 1).

RESULTS AND DISCUSSION

Effect of Freezing Conditions on Yeast Activity

Figure 2 illustrates the center temperatures of the dough samples in the two apparatus (risograph and rheofermentometer) dur-

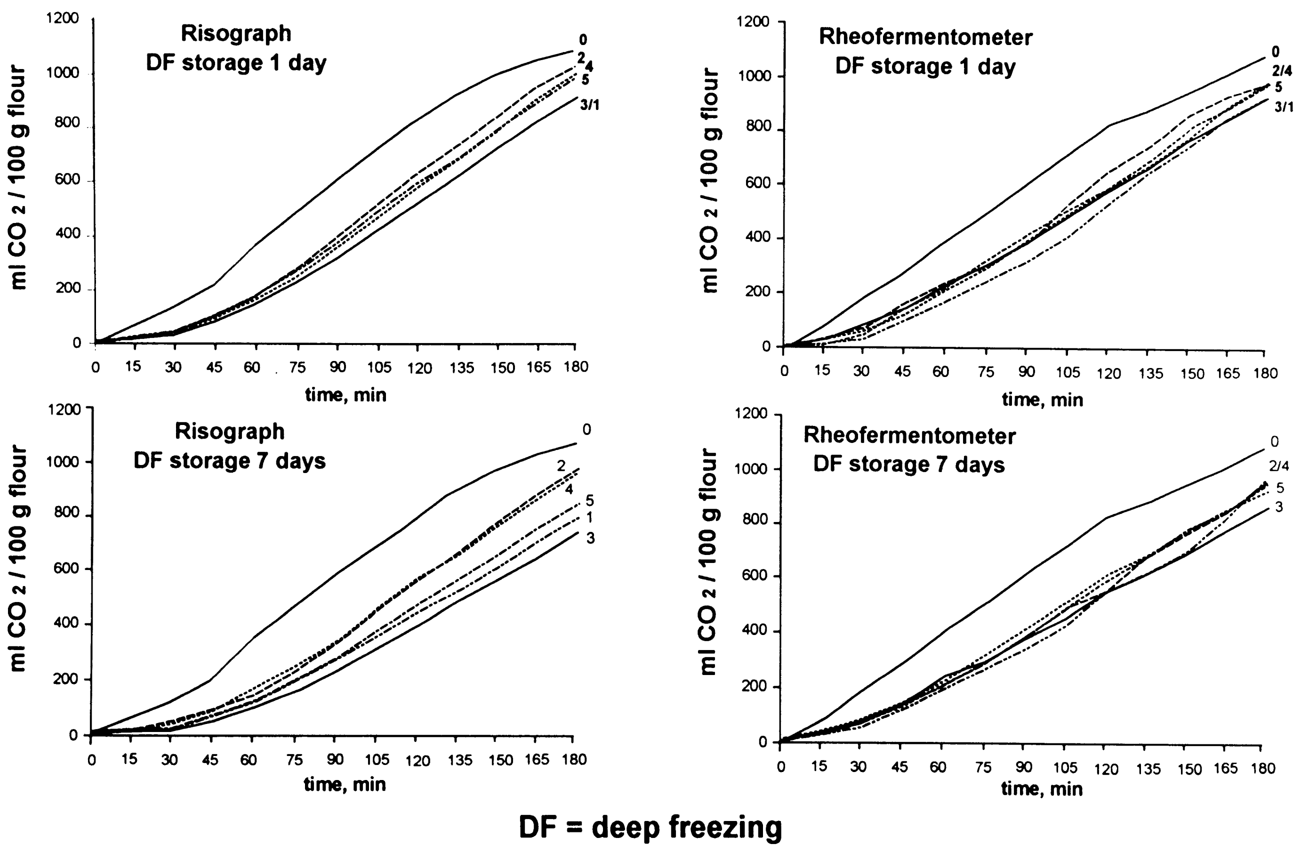

Fig. 3. Gas production of unfrozen and frozen doughs during thawing and fermentation (0 = without deep freezing; 1–5 = freezing conditions as given in Table III).

TABLE IV
Freezing Conditions and White Pan Bread Quality[a]

Freezing Condition	Final Proof (min)		Loaf Volume (cm³/100 g of flour)		Pictures of Pores		Final Baking Score	
	1 Day	7 Days	1 Day	7 Days	1 Day	7 Days	1 Day	7 Days
Unfrozen	45	45	465	465	6	6	121	121
1	110	140	415	370	7	7	108	71
2	100	110	425	400	7	7	111	97
3	90	120	390	380	7	7	91	90
4	130	140	400	390	7	7	101	92
5	100	110	410	390	6–7	6–7	99	87

[a] Stored for 1 day or 7 days at –20°C.

ing thawing and fermentation. Thawing of frozen doughs in the risograph was faster than in the rheofermentometer. The difference is attributed to the variation in dough weight of the samples used; the dough weight in the rheofermentometer was 2.5 times more than in the risograph (158.5 g vs. 63.4 g).

Figure 3 presents the results on yeast activity using the risograph and rheofermentometer. There is a depression in yeast activity in frozen dough produced under all freezing conditions and stored for one day at –20°C ± 2° using the risograph. The total gas production after 3 hr decreased from 1,090 ml for unfrozen dough to 915, 1,030, 915, 1,000, and 980 ml for frozen dough produced under freezing conditions 1–5, respectively. This implies that the highest gas production was obtained from the frozen dough sample by method 2, the lowest by methods 1 and 3.

After frozen storage for seven days, the depression in total gas production increased for all samples produced by all freezing methods. The same relative ranking was maintained. The total gas volume (after 3 hr) obtained from these frozen doughs was 815, 1,000, 755, 985, and 865 ml for conditions 1–5, respectively.

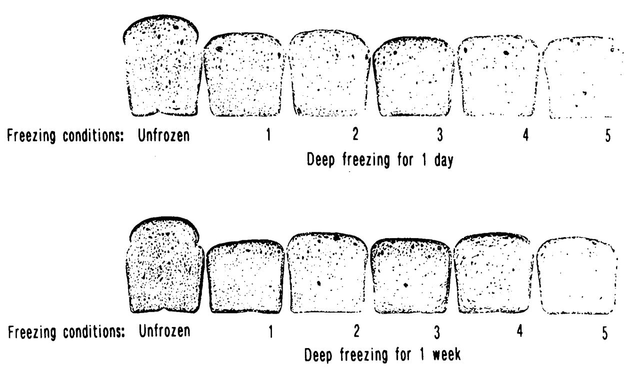

Fig. 4. Breads from unfrozen and frozen doughs (1–5 = freezing conditions as given in Table III).

The measurements with the rheofermentometer (Fig. 3) show good agreements with the results of the risograph. There was a depression in total gas volume after one day of storage; the comparison after seven days storage shows further depressions (±10%) for all freezing conditions.

Effect of Freezing Conditions on White Pan Bread Quality

Table IV presents the results of bread quality of frozen doughs under different conditions. The final proof time (after 2 hr of thawing at room temperature) increased for all frozen doughs with different freezing conditions, and after one and seven days of storage in comparison with unfrozen dough. The loaf volumes decreased after one day of storage and even more after seven days of storage. The best results for proof time and loaf volume were

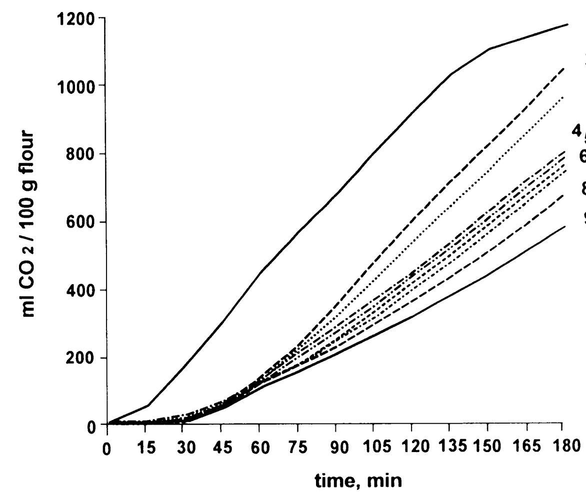

Fig. 5. Gas production (risograph) with storage time and freeze-thaw cycles (FTC) (1 = unfrozen; 2 = deep freezing at –20°C for 1 day; 3 = 1 week; 4 = 2 weeks; 5 = 3 weeks; 6 = 4 weeks; 7 = 4 weeks, 1 FTC; 8 = 4 weeks, 2 FTC; 9 = 4 weeks, 3 FTC.

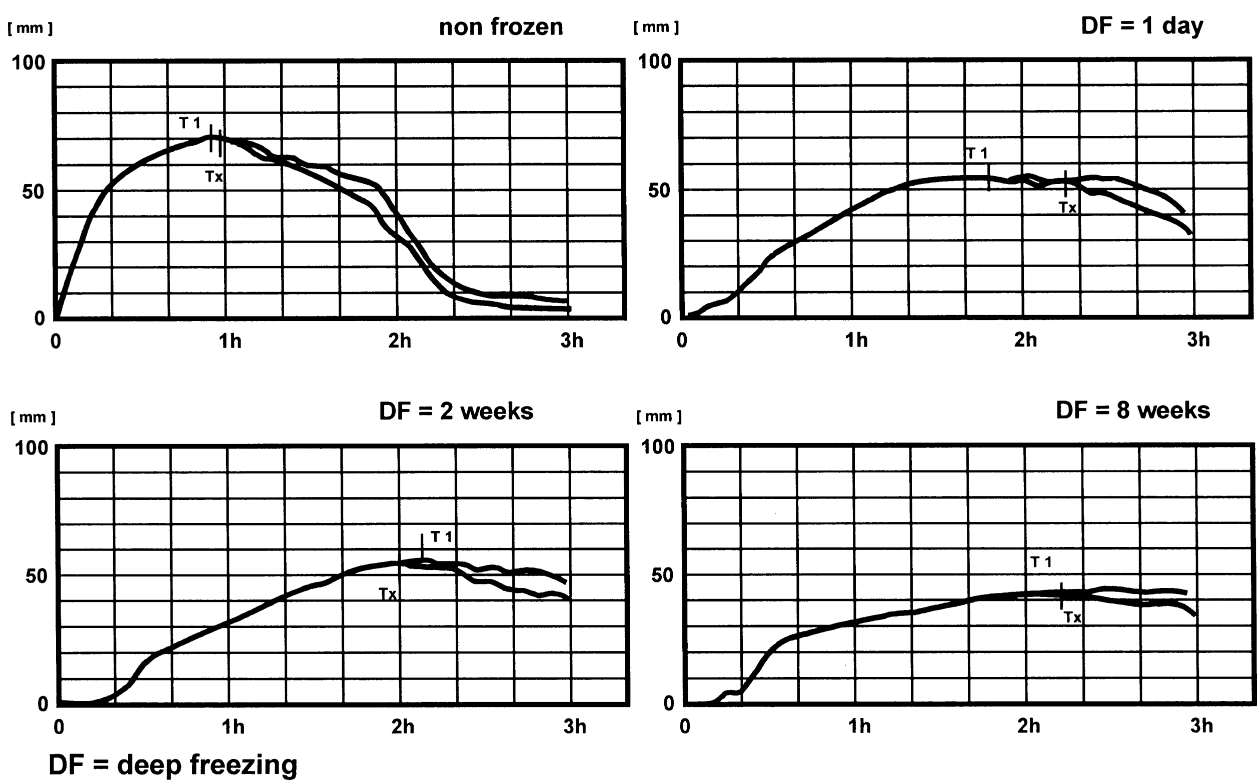

Fig. 6. Rheological dough behavior (rheofermentometer) and storage time (T_1 = total time until highest gas production; T_X = time of gas release).

TABLE V
Storage Time Conditions, Freeze-Thaw Cycles (FTC), and White Pan Bread Quality

Storage Time	Final Proof (min)	Loaf Volume (cm^3/100 g of flour)	Pictures of Pores	Final Baking Score
Unfrozen	45	465	6	121
1 day	100	415	7	113
7 days	115	405	7	110
28 days	126	385	7–8	95
28 days + 1 FTC	138	370	7–8	65
28 days + 3 FTC	166	320	7–8	17

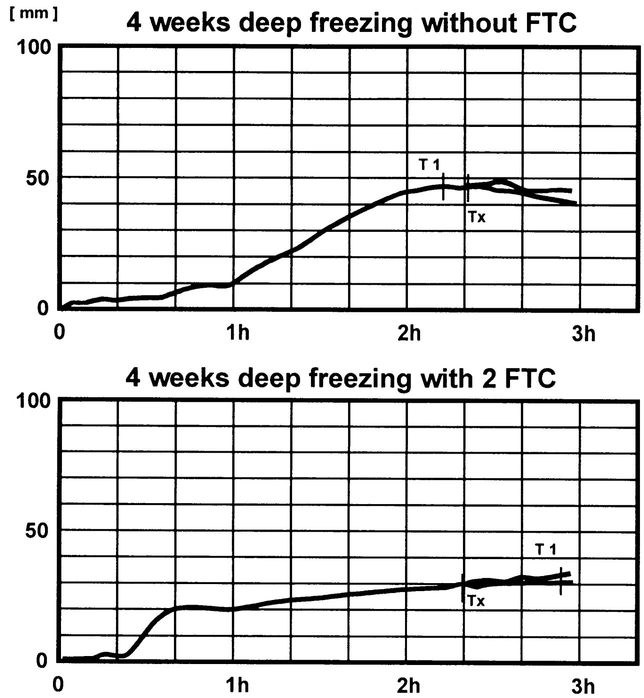

Fig. 7. Rheological dough behavior (rheofermentometer), storage time and freeze-thaw cycles (T_1 = total time until highest gas production; T_X = time of gas release).

obtained with freezing method 2, the worst results with freezing method 1 after seven days of storage. The final proof times after seven days of storage increased to 110–140 min, and the loaf volumes decreased to 370–400 cm^3 (Table IV).

Table IV shows that the grain (pictures of pores) of the bread produced from all frozen doughs was better when compared with the bread produced from unfrozen dough. Regarding the bread taste, no distinct differences could be observed by sensory evaluation between breads produced from unfrozen and frozen doughs. Sensory evaluation was done according to Arbeitsgemeinschaft (1978) by a panel with four trained persons.

Figure 4 shows all breads from unfrozen and frozen doughs (storage time: one day and one week) in comparison and demonstrate the differences in volume.

Effect of Storage Time and FTC on Gas Production

Figure 5 shows the total gas production during 3 hr of thawing and fermentation in the risograph. It is evident that the total gas production decreased with the increase of storage periods (from 1,170 ml for the unfrozen dough down to 780 ml) after four weeks of storage time. By applying FTC within the four weeks storage time, the gas production decreased from 750 ml (1 FTC) down to 590 ml (3 FTC).

Effect of Storage Time and FTC on Rheological Behavior

The changes in rheological behavior of frozen doughs of different storage times (unfrozen, one day, two and eight weeks) are

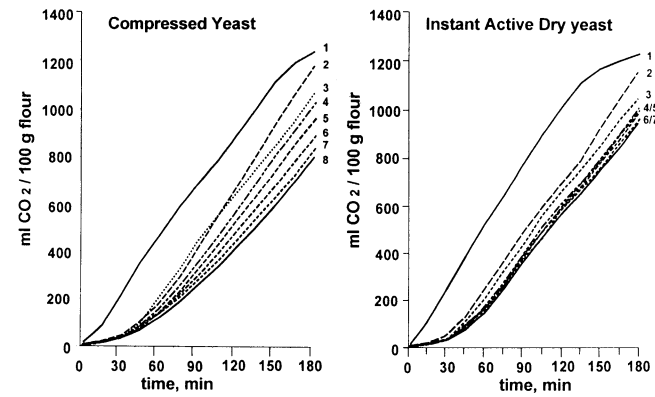

Fig. 8. Gas production (risograph) and yeast type (1 = unfrozen; 2 = deep freezing at –20°C for 1 day; 3 = 2 weeks; 4 = 4 weeks; 5 = 6 weeks; 6 = 8 weeks; 7 = 10 weeks; 8 = 12 weeks).

shown in Figure 6. The most remarkable changes exist between the unfrozen dough and the frozen dough after one day of storage. This changes can be observed in the dough height. The areas beneath the upper curves are decreasing, demonstrating a decrease in gas production. The reason for the lower bread volumes of frozen doughs is, therefore, not a decrease in gas retention but in gas production.

Figure 7 shows that the deterioration in the values of dough development factors increase with the number of FTC. The rheological behavior of a dough frozen four weeks decreases further by FTC.

Effect of Storage Time and FTC on White Pan Bread Quality

Table V shows that the bread volume decreases with increasing storage time (415–385 ml). Applying FTC, the volume decreases again from 370 to 320 ml. Regarding the pores structure, we confirm former results that the porosity is improved with breads from frozen dough; FTC further improve the porosity.

Effect of Yeast Type in Frozen Dough

Figure 8 shows depression in yeast activity in frozen doughs containing CY and IADY. The total gas production decreased from 1,220 to 790 ml with 4% CY in the dough and from 1,230 ml to 950 ml with 1.8 % IADY after storage time of 12 weeks.

Effect of Water Amount

The decrease of the water addition from 58.8% (500 BU) to 56.8% (600 BU) caused a lowered depression rate in the rheofermentometer figures. The total dough volume was higher for the lower water addition. In total, it can be stated that the reduced water amount was favorable for the overall rheological behavior of the dough and could be related to the amount of freezable water and, consequently, to a lower effect of ice on the gluten network and yeast cells.

Flour Quality

Table VI shows that there was a direct influence from the flour quality on the rheological properties of the doughs. The flour with

TABLE VI
Flour Quality and Rheological Behavior of Frozen Doughs

Flour	Storage Time	Total Gas Production (ml)	Retention Coefficient (%)
A	Unfrozen	1,220	92
	2 Weeks	1,040	94
	12 Weeks	740	98
B	Unfrozen	1,290	92
	2 Weeks	1,110	93
	12 Weeks	900	96

the higher protein content (B) always caused higher values in total gas production, especially with increasing storage time. This indicates that the higher protein level of the flour made the gluten network more resistant to the adverse effect of freezing and frozen storage.

CONCLUSIONS

Published data often contradict the effects of freezing rate on gas production, gas retention, and frozen dough quality. The reasons for these contradictions are based on flour quality, dough recipe, and dough handling. Under the mentioned data, our optimum freezing condition was high air velocity (3 m/sec) and direct freezing after dough mixing to –20°C ± 2°. It is very important to avoid temperature changes during frozen storage. The volume decrease is very high after one day of frozen storage. The porous structure always improves. The reason for the bread volume decrease is only a low gas production and not a lower gas retention. Consumers will accept frozen wheat bread doughs with storage times of up to four weeks.

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