NOTE

Freezing Experiments on Yeasted Dough Slabs. Effects of Cryogenic Temperatures on the Baking Performance

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ABSTRACT

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Yeasted dough slabs were frozen under very controlled and different cooling velocities (conventional mechanical refrigeration at −40°C, used as a reference, and cryogenics from −40 to −120°C). Cooling velocity at the core of the dough slabs was about seven times higher with cryogenics at −120°C than with blast-freezer treatment at −40°C. Throughout three months of storage, the baking performance of dough slabs was not affected by the −40 and −60°C cryogenic treatments, whereas decreasing the freezing temperature successively to −80, −100, and −120°C involved a gradual drop in bread volumes (about 15% per operation). Freezing at −60°C yielded the best results in terms of quality (bread volumes) and productivity (freezing time). Cryogenics in closely controlled conditions should permit a gain in productivity without affecting baking performance.

Properly prepared frozen dough can bridge the gap between baker and consumer and offers the possibility of suspending time. Turning the promise into reality, however, is difficult because the ability of yeast to produce CO_2 is not always maintained when yeast cells dispersed within a dough mass are frozen (Hsu et al 1979, Wolt and D'Appolonia 1984, Neyreneuf 1990). On examining the effects of different freezing conditions on yeast-raised doughs throughout storage, some workers noticed a decrease in the gas production level of yeast (Godkin and Cathcart 1949, Lorenz 1974, Bender and Lamb 1977, Hsu et al 1979, Lehmann and Dreese 1981), whereas others found a weakening of the gas retention properties of the gluten network (Varriano-Marston et al 1980, Berglund et al 1991, Inoue and Bushuk 1991).

In this work, we froze yeasted dough slabs under very controlled and different cooling velocities (conventional mechanical refrigeration at −40°C, which was taken as a reference, and quick cryogenics from −40 to −120°C). We analyzed the influence of these processes on the baking performance of dough slabs after overnight defrosting and throughout three months of storage. Assumptions were made to explain the differences in performance among our dough slabs.

MATERIALS AND METHODS

Preparation of Yeasted Dough Slabs

The basic dough formula consisted of an ordinary type 55 French flour (protein content = 11.2%, Chopin $W = 212$, falling number = 290 sec), a specific compressed yeast (32.35% dry matter, 46.25% protein, 16.2% trehalose; Gist-brocades, Prouvy, France) at a dose of 6%, and a bread improver (1%) conforming with the French legislation regarding standard bread. Kneading took place in a spiral mixer (Kemper, Rietberg, Germany) with a final dough temperature of 20°C (Neyreneuf and Van der Plaat 1991). From each dough, four 30-g balls were prepared for use as proofing indicators. Samples used as baking tests included 72 rectangular slabs (200 × 100 × 15 mm) of 165 g, which were produced using a hydraulic box divider and a pastry cutter.

Freezing Conditions

Freezing took place within 20 min after mixing. Mechanical freezing at −40°C in a blast-freezer (Pierre Pont, Villefranche, France) was used as a reference. The effects of increasing cooling velocities were studied by spraying liquid nitrogen on dough slabs in a cryo-unit (L'Air Liquide, Jouy en Josas, France) with the thermostat successively set at −40, −60, −80, −100, and −120°C. For each freezing operation, one slab was monitored by inserting five stainless steel thermocouple probes at different locations to record local temperature and freezing rate and to detect when the geometric center of the slab had reached the desired core temperature (−15°C). Frozen samples were thereafter stored in sealed plastic bags at −20°C.

Baking Performance of Dough Slabs Throughout Frozen Storage

Slabs were defrosted overnight according to Neyreneuf and Van der Plaat (1991) immediately after freezing (0 day) and after 30, 60, and 90 days of storage. For assessing the baking performance of dough slabs, one proofing indicator and 18 slabs were removed from the freezer per defrosting operation. Piling together two slabs of 165 g inside a pan allowed preparation of nine dough pieces of 330 g. Doughs were proofed to a predetermined constant height, with the blast-frozen proofing indicators used as references (70-mm height). A gas-fired two-deck oven equipped for steam injection (Pavailler, Valence, France) was used for baking (25 min at 225°C). Loaf volumes (in milliliters) were measured in pairs by seed displacement after the breads had cooled for 30 min.

RESULTS AND DISCUSSION

Thermal Characteristics of Dough Slabs Throughout Freezing

In our work, complete temperature histories of the dough slabs were characterized (Table I). Freezing time of the slabs varied depending on the freezing treatment. Since the shape, size, and nature of the heat transfer within the slabs were equivalent throughout the experiment, freezing time depended on the temperature of the cooling medium (the regulation temperature) and the heat transfer process between the cooling medium and the slabs. For the core of the slab to reach −15°C, 13 min 51 sec of freezing time in the cryo-unit was needed when the slab was frozen at −120°C, whereas 100 min 34 sec was required with cold air of −40°C as the heat transfer medium (in the blast freezer). Cooling velocities at the core or the surface were defined as the rate of change between 20°C (dough temperature) and the local temperature at the core or surface of the slabs. Both cooling velocities were assessed when the geometric center of the slabs had reached −15°C.

Compared to mechanical refrigeration at −40°C, local cooling velocity was about seven times higher at the core of the slabs and approximately 11 times higher at the surface with cryogenics

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TABLE I

Effects of Freezing Temperatures on the Thermal Characteristics and Baking Performance of Dough Slabs

Freezing Temperatures (°C)	Thermal Characteristics: Freezing Time[a] min	sec	Cooling Velocity at Surface (°C/min)	Cooling Velocity at Core (°C/min)	Loaf Volumes (ml × 2) After Storage: 0	30 days	60 days	90 days
−40 Reference	100	34	0.363	0.348	4,350	4,265	4,285	4,275
−40	43	54	0.919	0.797	4,133	4,056	4,090	4,070
−60	35	45	1.267	0.978	3,963	3,985	4,010	4,020
−80	22	21	2.080	1.565	3,390	3,353	3,380	3,370
−100	17	40	2.933	1.980	2,751	2,731	2,750	2,760
−120	13	51	3.936	2.528	2,481	2,280	2,261	2,186

[a]To reach a core temperature of −15°C.

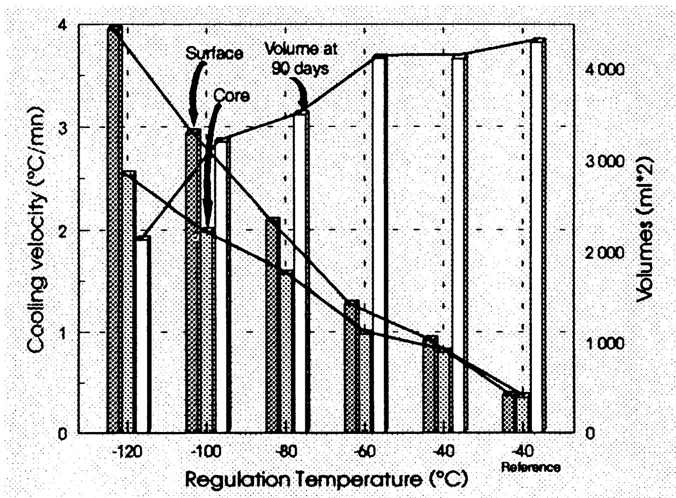

Fig. 1. Effects of freezing conditions (cooling velocity, regulation temperature) on the baking performance (bread volume) of the dough slabs after 90 days of storage.

at −120°C. The difference in temperature between surface and core was about 4°C at the end of the freezing treatment due to the thickness of the dough slabs.

Effects of Freezing Temperatures on the Baking Performance of Dough Slabs

Changes in the stability of frozen dough slabs were observed throughout storage. Table I gives information about the evolution of bread volumes throughout our experiment. Cryogenic freezing with regulation temperatures of −40 and −60°C did not affect bread quality compared to mechanical freezing. Decreasing the surrounding freezing temperature successively to −80, −100, and −120°C produced a gradual drop in loaf volumes (about 15% per operation), which finally resulted in 49% less volume following exposure to −120°C after three months of storage. Except for the −120°C treatment, the length of frozen storage did not affect baking performance, which remained quite stable throughout our experiment. However, "indirect chilling injury" (independent of cooling rate and taking place during storage) became apparent, since proofing time to reach a 70-mm height for the reference proofing indicators was 1 hr longer at the end of the study. With small dough pieces to be frozen (rolls, French sticks), Marston (1978) recommended avoiding prolonged exposure to temperature below −50°C (a cause of "overfreezing," resulting in severe initial damage that becomes more and more obvious as storage extends). With American dough pieces, blast-freezer temperatures of −37 and −45°C (Lehmann and Dreese 1981) were found to influence dough stability and bread volumes negatively compared to temperatures between −20 and −29°C, which produced consistent and high-quality breads.

Using rectangular dough slabs (19 × 9 cm) frozen by immersion, Hsu et al (1979) compared cooling rates of 0.57 and 1.94°C/min. These workers observed that, after one week of storage, proofing time was twice as long and bread volumes 10% less with the 1.94°C/min cooling rate. In our work, "direct chilling injury" caused by the −100°C treatment (resulting in a core cooling velocity of 1.98°C/min) was very detrimental to loaf volumes (36% less than our reference breads after immediate defrosting). Effects of freezing conditions on the baking performance of our dough slabs are presented in Figure 1. Compared to mechanical refrigeration at −40°C, cryogenics at −60°C yielded the best results in terms of productivity (a freezing time 65 min shorter) and quality (bread volumes not significantly different). In an additional test (*unpublished results*), we obtained equivalent results with −70°C, which should locate freezing temperatures harmful to frozen dough stability somewhere between −70 and −80°C.

CONCLUSIONS

In the frozen dough industry, protecting against the effects of freezing on yeast cellular viability is a main focus of attention. Therefore, slow cooling in a conventional freezer is the preferred technology instead of cryogenics, which gives much more rapid cooling but is supposed to be more detrimental to the survival of yeast cells in dough pieces.

From this work, it can be concluded that selecting cryogenics in closely controlled conditions should permit a gain in productivity without affecting baking performance. Further research in this area may explain the drop in leavening activity and baking performance of the dough slabs when the ambient freezing temperature is lower than −60°C. Are these phenomena caused by some deeper changes in the thermodynamic activity of water and in crystallization? If so, a more severe stress on yeast cells dispersed in the dough matrix could have taken place, involving an increase in their internal osmotic pressure and some impairment of their membrane functionality. Therefore, yeast viability could have been affected and gas production capacity greatly diminished (Lorenz 1974, Bender and Lamb 1977, Hsu et al 1979). Faster freezing rates could have yielded some deterioration of the dough matrix by ice recrystallization and therefore altered the rheological and gas-retaining properties of the gluten network (Varriano-Marston et al 1980, Berglund et al 1991, Inoue and Bushuk 1991). Recovering yeast cells from the dough matrix and analyzing their activity could help to promote one of these assumptions. This is a technique that still needs to be perfected to provide adequate information.

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