A THESIS FOR THE DEGREE OF MASTER OF SCIENCE

Effects of freezing rate and terminal freezing temperature on frozen croissant dough

냉동 속도와 냉동 종료 온도가 냉동 크루아상 반죽에 미치는 영향

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석사학위논문

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이 논문을 석사학위 논문으로 제출함

2015년 8월

서울대학교 대학원 농생명공학부

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2015년 8월

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ABSTRACT

Freezing process has an adverse effect on bread obtained from frozen dough. Croissant is one of the representative breads produced by freezing process to improve the productivity and reduce laboring cost. In this study, the quality of croissant was evaluated by various combinations of freezing rate and terminal freezing temperature (T_t). Firstly, the croissant dough was frozen with 0.72 to 3.56°C/min as the freezing rate, while T_t was set to -20, -40, and -55°C, respectively. In DSC thermogram, the peak was the broadest at the fastest freezing conditions indicating that ice crystals were evenly distributed during phase transition in the dough. Additionally, SEM images showed that the microstructure was kept intact at the fastest freezing rate. However, the yeast viability was higher at slow freezing rates. Moreover, the minor peak in the thermogram of yeast indicated that ice crystals were grown within cell and cell membrane. Intracellular ice crystals negatively influenced on both cell membrane and cytoplasm. Therefore, the yeast viability was decreased by the reduction of T_t. During storage, the bread qualities such as specific volume and firmness were deteriorated as increasing storage time. The poor quality was caused by damaging gluten network and yeast viability because of changes of ice crystal redistribution during storage periods. The obtained results showed that the dough frozen at

1.84°C/min to -20°C was the best freezing method to produce the fresh quality of croissant from frozen dough. Further work should be required to graft this freezing process onto other types of bread, which might provide better and improved process for the frozen bakery industry.

Keywords: frozen dough; freezing rate, terminal freezing temperature, ice crystal, yeast viability, croissant

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I. INTRODUCTION

Manufacture of frozen bread dough is increasing in bakery industry since frozen dough is convenient for baking. Bake-off technology can reduce processing time and labor consuming, increase shelf life, produce large quantities, and facilitate delivery to distant location (Chen et al., 2013; LeBail & Goff, 2008). Currently, the frozen dough market has been increasing steadily since croissant, sweet roll and tart account for large portion of the market share (Giannou & Tzia, 2007). However, freezing process gives rise to negative influence on bread quality after baking compared to fresh products (Casey & Foy, 1995). The poor bread quality is directly caused by damaged gluten network, and the low yeast viability and activity. Thus, a number of studies have been being focused on keeping yeast survival rate and gluten network during freezing step intact, in other words, gas productivity of yeast and gas retention capacity from gluten network (Wolt & d'Appolonia, 1984).

Freezing rate is one of the parameters to regulate the ice crystal size and distribution in case of food freezing process (Petzold & Aguilera, 2009). During freezing, the formation and growth of ice crystals severely damage gluten network resulting in low yeast viability (Jeremiah, 1996). The gluten network is less distorted with a rapid freezing rate. Dough damage is

correlated with the mechanical reaction of large ice crystals disrupting the gluten network (Berglund, Shelton, & Freeman, 1991). The damaged gluten network retains gas poorly thereby reducing loaf volume. However, at the slow freezing rate, yeast survival rate and activity were well-preserved (Le Bail et al., 1998). To enhance the yeast viability during freezing, the formation of ice crystal in the cells should be prevented (S. Seki, F. W. Kleinhans, & P. Mazur, 2009). When yeast was frozen at fast freezing rate, the ice crystals were formed, resulting in severe damage to yeast cells. The small size ice crystals formed in yeast cells result in fracture of cell membrane by the ice crystals (Singh & Heldman, 2001). As a result, cell membranes were damaged critically, then the yeast-leavened dough was not proofed due to the loss of gas productivity. Dough stability and bread volume were affected negatively by freezer air temperature at -37 and -45°C than -20 and -29°C using American dough pieces (Lehmann T.A., 1981). In addition, yeast-leavened dough was recommended to be stored above -50°C because long-term exposure to temperature below -50°C results in overfreezing phenomena in the yeast cell (Marston, 1978). Consequently, The slow freezing rate, which dehydrates the yeast cell by osmotic pressure and prevents cell-rupture by the increase in ice crystal size, is required to protect yeast in the frozen dough (Le Bail et al., 1998; Neyreneuf & Delpuech,

1993). Therefore, it is essential to determine the optimal conditions of freezing process.

Freezing conditions in this study were freezing rate and terminal freezing temperature of croissant dough. The effects of freezing rate for general frozen bread dough have been actively studied (George, 1993). However, the final temperature of common frozen dough during freezing has not been introduced yet. Additionally, there is no report stating the correlation between freezing rate and end freezing temperature for the croissant dough. In addition to the undesirable changes on the dough, frozen storage was attributed to produce inferior quality bread. The frozen storage allowed to grow and recrystallize ice crystals. Grown and recrystallized ice crystals resulted in the separation of water from gluten matrix and destruction of yeast cell membrane and cell contents (Bache & Donald, 1998; Esselink, van Aalst, Maliepaard, & van Duynhoven, 2003; Mazur & Schmidt, 1968; Rojas, Rosell, De Barber, Perez-Munuera, & Lluch, 2000).

Therefore, I investigated the combined effect of freezing rate and T_t during freezing, and storage time on frozen dough especially for croissant dough. In addition, I suggest the optimal freezing method to produce frozen croissant dough from obtained results. The bread properties were evaluated by specific volume and firmness, and dough properties were determined by

DSC thermogram to confirm the ice crystal distribution. Furthermore, the interior structure was visualized by scanning electron microscopy (SEM). Finally, yeast viability measurement was carried out to confirm gas productivity, and heat flow measurement was conducted to observe the freezing point of fresh yeast.

II. MATERIALS AND METHODS

2.1. Croissant dough preparation

Dough was prepared with 275 g strong flour (Samyang Genex, Inchoen, Korea), 150 g medium flour, 40 g white sugar, 6.25 g refined salt, 20 g fresh yeast (Ottogi, Seoul, Korea), 100 g egg, 162.5 g water, 12.5 g butter, and 250 g cold butter for roll-in. The dry ingredients were blended for 2-3min using mixer (Kenwood titanium major kitchen machine, KM020, Hamsphire, UK), then water and egg were added, and the dough mixed for 2-3 min until the dough holds together. Then the butter added, and mixed more 3 min, then the dough was placed in refrigerator for 1st resting for 30min. The cold butter for dough layering was placed on 30 cm × 30 cm shaped dough after 1st resting, then the dough was folded three times with cold layering butter, resting 5, 15, and 30 min in refrigerator between each step. After 4th resting, the dough was rolled into a rectangle shape and cut in triangle shape and rolled overlap three times.

2.2. Freezing and storage conditions

Croissant dough pieces were frozen in freezer (Ultra low temperature freezer, Unique Daesung Co., Ltd, Pocheon, Korea). The freezing rate was designed

by the combination of different freezing air temperature (-20°C, -40°C, and -55°C) with either natural or forced convection. The terminal temperature was set to -20°C, -40°C, and -55°C. When the dough sample had reached the terminal freezing temperature, the frozen sample was packaged and stored for 1 day, 1, 3, 5, and 7 weeks at -18°C freezer. T_t regarded as another factor in this study was controlled, and sample names were coded according to each condition. For instance, sample with N-20-20 was expressed as convection type (N for natural and F for forced convection, respectively), freezing air temperature, and terminal freezing temperature (T_t).

2.3. Croissant preparation

Sample was removed from freezer and thawed at room temperature for 90 min. The dough was placed in fermenter at 35°C, 85% relative humidity for 60 min. Proofed dough was baked at 180°C for 20 min (LG DIOS, LG, Seoul, Korea).

2.4. Croissant quality

2.4.1 Specific volume

The specific volume of croissant was evaluated using a Volscan

Profiler 600 (Stable Micro Systems, Surrey, UK). The croissant volume was calculated by dividing volume by weight.

2.4.2 Firmness

The firmness of croissant samples was measured using a texture analyzer (TA-XT2i, Stable Micro Systems) with AACC method 74-09. Firmness was carried out with return-to-start mode at the test speed of 1.7 mm/s with a strain of 40% of compression and 50 mm diameter cylindrical probe.

2.5. Differential scanning calorimetry

2.5.1 Ice crystal formation temperature change during freezing

The ice formation enthalpy in dough was measured by differential scanning calorimetry (DSC). Small sample was removed from the unfrozen dough center and weighed (14.8 to 24.2 mg) into an aluminum pan (Perkin Elmer, Norwalk, CT, USA), and empty pan was a reference. The freezing rate was calculated with six levels (0.72, 1.43, 1.5, 1.84, 3.19, and 3.56°C/min) from freezing temperature profile. N-55-55 and F-55-55 conditions were frozen using 1.5 or 3.56°C/min to -40°C and 0.2°C/min

from -40°C to -55°C because of freezer capacity, respectively. The exothermic peak was integrated from the beginning to ending point, showing onset, peak, end temperature and enthalpy of the peak.

2.5.2 Exothermic curve of fresh yeast

The freezing point of fresh yeast was measured by DSC. Fresh yeast was weighed with 20.2 mg in an aluminum pan and hermitically sealed. Sample was cooled to -55°C at the most rapid freezing rate (3.56°C/min). The peak and end points were used to determine the end of freezing point obtained by the inflection point and baseline.

2.6. Scanning electron microscopy (SEM)

The dough pieces were cut from the center of the frozen dough using hammer in the freezing room to avoid thawing. The sample was observed at frozen state (-20°C) using Deben cool stage (Deben, Suffolk, UK) with a Hitachi S-3500N scanning electron microscope at an accelerating voltage of 20 kV and Robinson detector.

2.7. Yeast viability

Yeast viability was measured using the direct viable counts in AACC method 89-01(2000). The frozen dough was removed from freezer and thawed at room temperature for 90 min. Dough sample (30 g) and 270 g of 0.2% peptone water were placed into filtra-bag (Filtra-bag, Labplas, Canada), mixed for 2 min, and diluted The diluted suspension (1 mL) was cultured on Petri dishes using Sabouraud dextrose agar base medium. Incubation was lasted for 48h at 25°C and the results were expressed by log CFU/g of dough.

2.8. Statistical analysis

The data reported were means of triplicate determinations. Tukey's test was conducted by SPSS statistics 21 for Windows program (SPSS Inc., Chicago, IL, USA) to evaluate significance differences of 95% level among treatment means. All experimental points were performed three times each freezing condition and storing period.

III. RESULTS AND DISCUSSION

3.1. Freezing curve

Freezing conditions, which are freezing rate and terminal temperature of frozen croissant dough, were main control factors in this study. The freezing rate of the dough was observed as representative temperature profiles in Fig. 1(a). For all samples frozen at each temperature, croissant dough frozen with forced (F) convection method was frozen more rapidly than that with natural (N) convection method.. In other words, the freezing rate of the dough was in the order of N-20, N-40, N-55, F-20, F-40, and F-55.

Freezing rates F_r (°C/min) were determined according to Eq. (1), based on the definition the International Institute of Refrigeration (L. B. Sørensen, 1986):

$$F_r = \frac{(T_2 - T_1)}{(t_2 - t_1)} \quad (1)$$

where T_1 is the initial freezing temperature, T_2 is the terminal freezing temperature (-20, -40, and -55°C), and (t_2 - t_1) is the time elapsed between the beginning and end of freezing. N-55-55 and F-55-55 samples possessed a distinguishing point of inflection around -40°C, which was the point reflecting the temperature slope changes due to freezer capacity. Because of the mimic of dough freezing with DSC (section 3.3), I controlled the freezing rate of N-55-55 and F-55-55 samples to from -40°C as 1.50/0.2 and

3.56/0.2°C /min, respectively.

All temperature profiles indicated two distinguishing points of inflection around -10°C. The temperature section between the two points was used for the zone of maximum ice crystal formation in the dough (Kiani & Sun, 2011). Fig. 1(b) illustrated the average time of the zone of maximum ice formation. The maximum ice formation time was reduced with the drop of freezing temperature and increase in freezing rate. Therefore, the maximum ice formation time with natural convection freezing was longer than that with forced convection freezing. Depending on the zone of maximum ice crystal formation, a freezing method broke down to rapid freezing or slow freezing. In case of slow freezing, it takes over than 30 min to be reached to a maximum ice crystal zone. At this point, most ice crystals exists out of the cells and its diameter is somewhat high. In contrast, it took less than 25 min for rapid freezing to pass a maximum ice crystal zone in which ice crystals remain in the cells and out of the cells, and its crystal showed the small size The size of the ice crystal was determined undergoing the zone of maximum ice crystal formation, and influenced on the structure of bread (Li & Sun, 2002) . During freezing, heat is removed from the inside of dough by conduction to environmental cool air by convection. Since all samples were the same size, the maximum ice crystal formation was dependent of the rate of convection. In case of forced convection, the freezing rate becomes faster

with lowering the freezing temperature and increasing flow rate of cool air. Therefore, at the same freezing temperature, the freezing time was reduced with faster freezing rate.

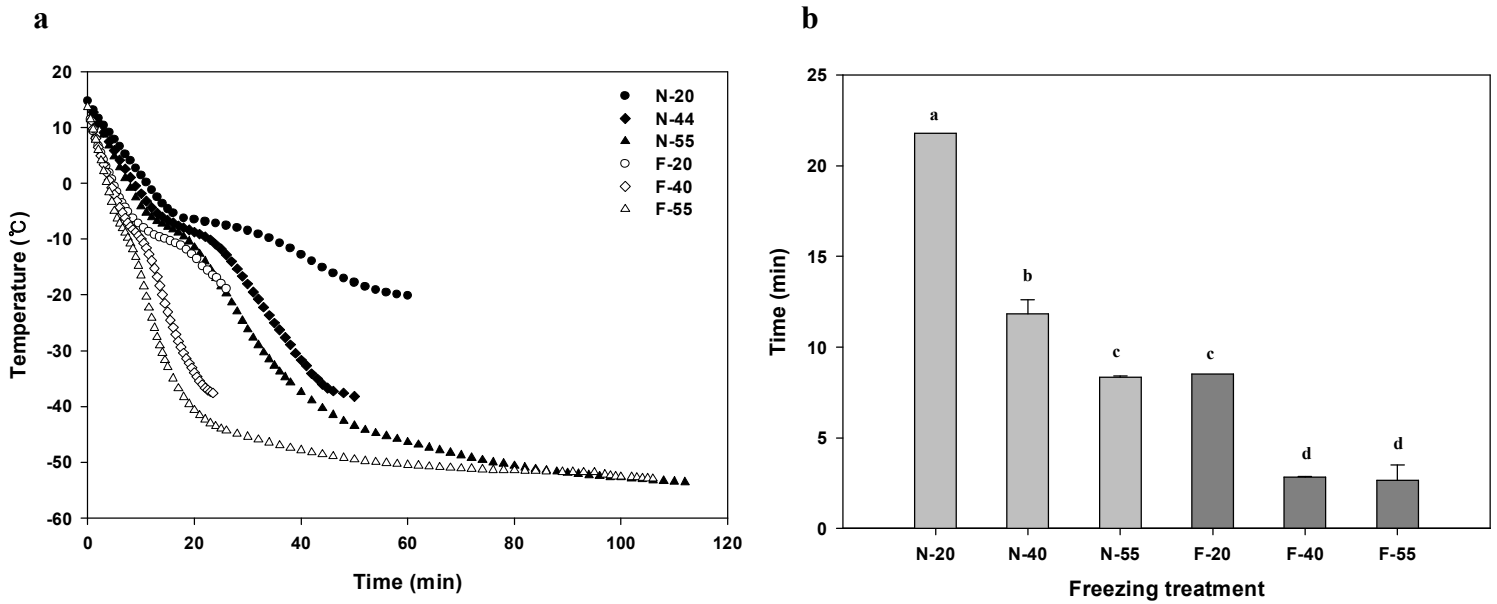

Fig. 1. (a) Freezing profiles of croissant dough frozen by natural (N) and forced (F) convection with different freezing air temperatures (-20, -40, and -55°C) and (b) the time of maximum ice crystal formation. Different letters at the bar are significantly different at $p < 0.05$.

3.2. Croissant quality

3.2.1 Specific volume

Figure 2 indicated the croissant specific volumes with different freezing conditions. These results demonstrated that freezing process considerably affected bread quality by both freezing rate and T_t. Specific volume is one of the most important bread quality factors since it exhibited the dough rising capacity and oven spring. The large bread volume, as much as fresh, gave desirable texture because of proper open pore structure. On the other hands, too small specific volume gave its stiff texture from compact matrix (Sharadanant & Khan, 2003). The specific volume of bread from fresh dough was 4.66 mL/g, and N-20-20, N-40-20, and F-20-20 bread volumes were not significantly different from control one (p = 0.03). The specific volume was considerably inflated at -20°C of T_t. This result indicated that rapid freezing process at the low T_t negatively influenced on the quality of dough. In Figure 3, the results were consistent with 1, 3, 5 and 7 weeks storage. The frozen storage affected bread volume almost doubled reduction after 7 weeks. The specific volume was gradually decreased in process of time. The bread frozen N-40-20 and F-20-20 conditions indicated the highest level of specific volume after 7 weeks frozen storage as same 1 day storage duration.

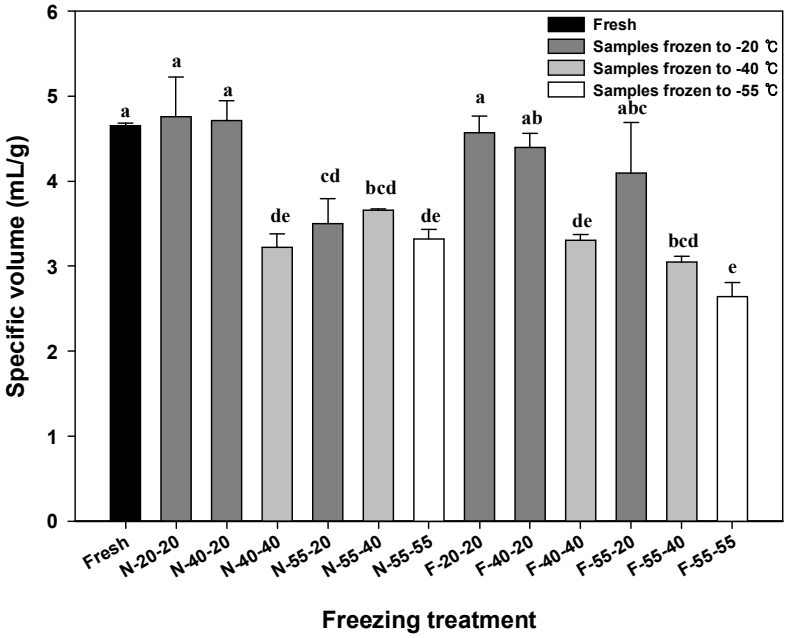

Fig. 2. Specific volume of croissants baked from frozen dough prepared at different freezing conditions and stored at -18°C for a day. Different letters at the bar are significantly different at $p < 0.05$.

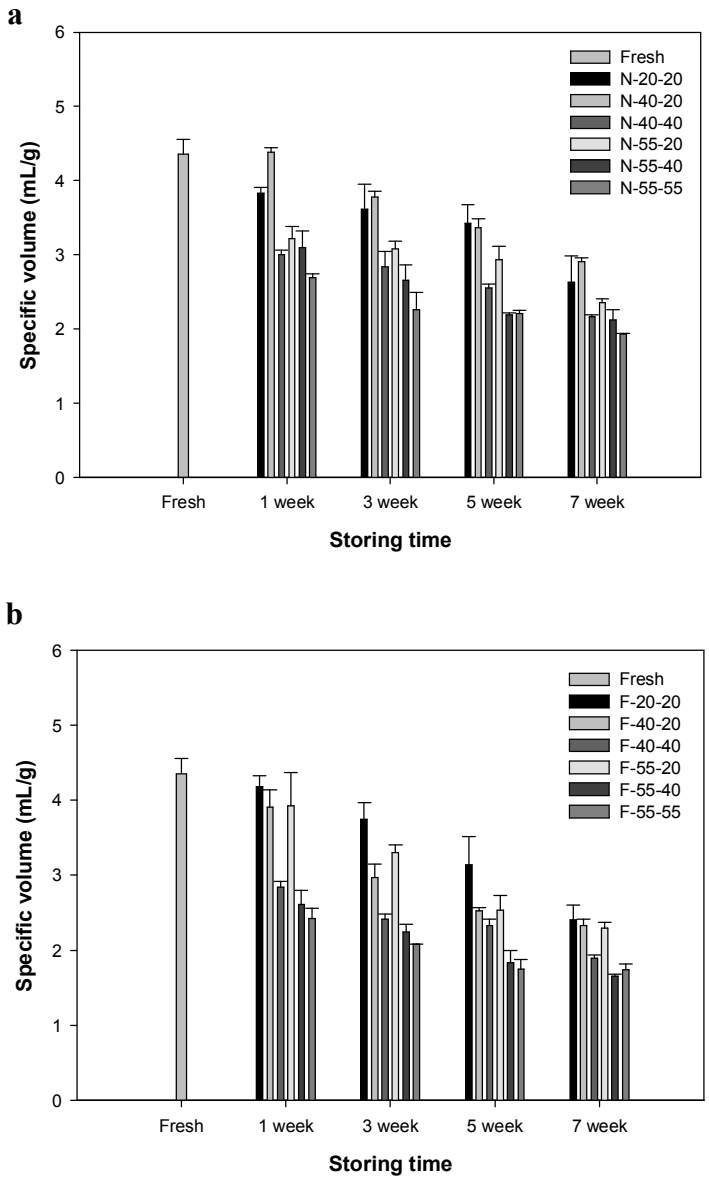

Fig. 3. Specific volume of croissants baked from frozen dough prepared at different freezing condition and stored at -18°C from 1 to 7 weeks. (a) is natural convection type and (b) is forced convention type freezing condition.

3.2.2 Firmness

Figure 4 showed that the firmness of bread produced from frozen croissant dough. The fresh bread showed the desirable texture as 5.66 N. All the samples from frozen dough were harder than the fresh bread. Most of the samples showed no significant differences ($p < 0.05$) with control, while N-55-55 was the hardest among the samples. Moreover, T_t affected significantly on firmness at the same freezing rate. The results indicated that T_t triggered yeast activity or degraded the rheology of dough. Firmness of the samples was increased slowly in a time-dependent manner. The results showed that prolonged storage time influenced negatively on bread quality. Generally, tender texture was considered a desirable quality of bread. The fresh croissant was softer and the croissants from frozen dough were harder during frozen storage. According to the other publications, the yeast viability became lower with increasing freezing rate (Le Bail et al., 1998; Neyreneuf & Delpuech, 1993). Moreover, gluten network structure was disrupted by degrading substances from damaged yeast. The bond of gluten network was reduced by glutathione, causing the decrease of gas retention capacity (Verheyen et al., 2015). Therefore, carbon dioxide molecules was not captured within gluten network. As a result, the firmness increased although freezing rate was equal.

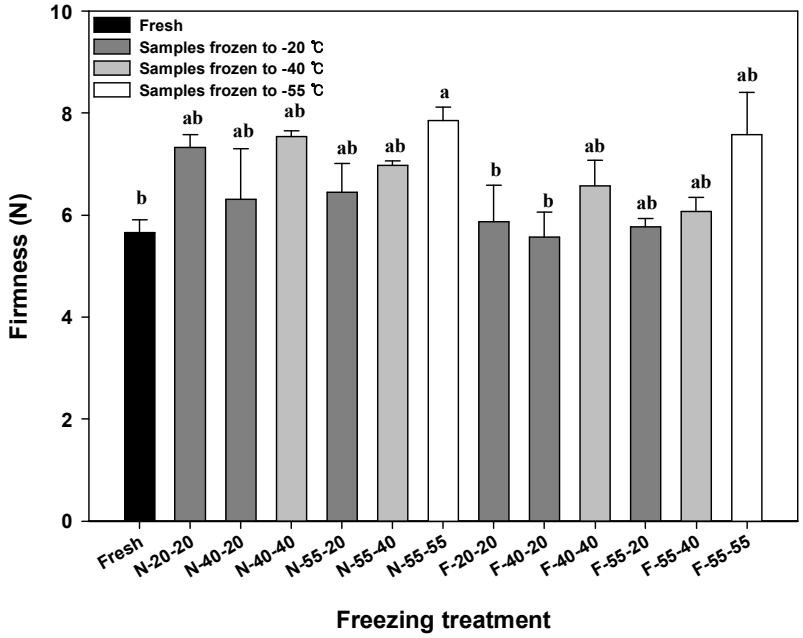

Fig. 4. Firmness of croissants made from frozen dough prepared at different freezing conditions and stored at -18°C for a day. Different letters at the bar are significantly different at $p < 0.05$.

3.3. Ice crystal formation during freezing (DSC)

The formation of ice crystal during freezing step was measured using the freezing rates calculated from the freezing temperature profiles in Figure 1. Figure 5 showed water-freezing exotherms from unfrozen croissant dough in a sealed pan. The thermograms of the sample were shifted to the left with increase of freezing rate. It appears that the phase transition temperature was lowering because of depression of freezing point by existence of solid contents and rapid freezing rate. Moreover, the peak width ($T_{onset} - T_{end}$) became wider gradually.

In Figure 6 (a), onset temperature and peak temperature was not significantly different all freezing conditions. On the other hand, with increase in freezing rate, it was observed that only end freezing temperature was lowered. Based on the results, the gap between initial freezing temperature and end freezing temperature was much wider with increasing freezing rate. The phase transition temperature range was shown in Fig 6 (b). No significant differences were found among natural convection type conditions, however, the width between onset and end temperature during forced convection type freezing was increased significantly). The gap of onset-end temperature was increased when sample had a same amount of water, which can be explained by removing rate of latent heat in the sample. Long-term freezing process gives ice crystals a chance to grow larger in the

warmer bulk of the fluid (Hartel, 2001). However, the dough sample frozen by fast freezing rate induced rapid ice crystal nucleation, therefore, ice crystal size was small and the number of ice crystals was increased (Drewett & Hartel, 2007; Russell, Cheney, & Wantling, 1999).

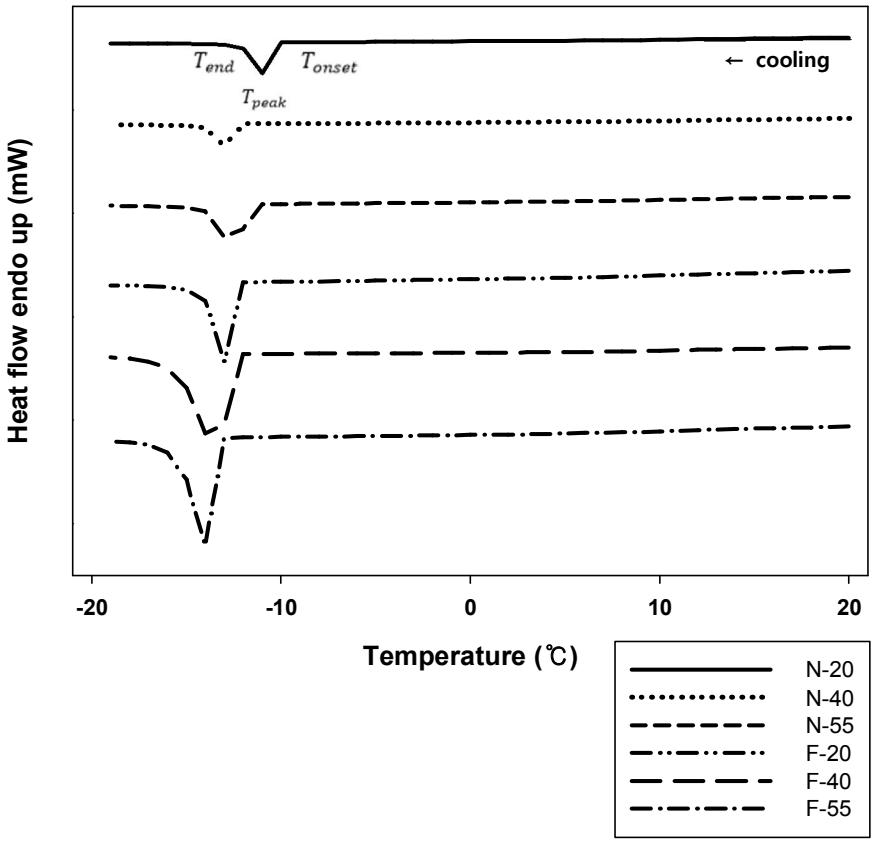

Fig. 5. DSC thermograms of dough samples at different freezing rates.

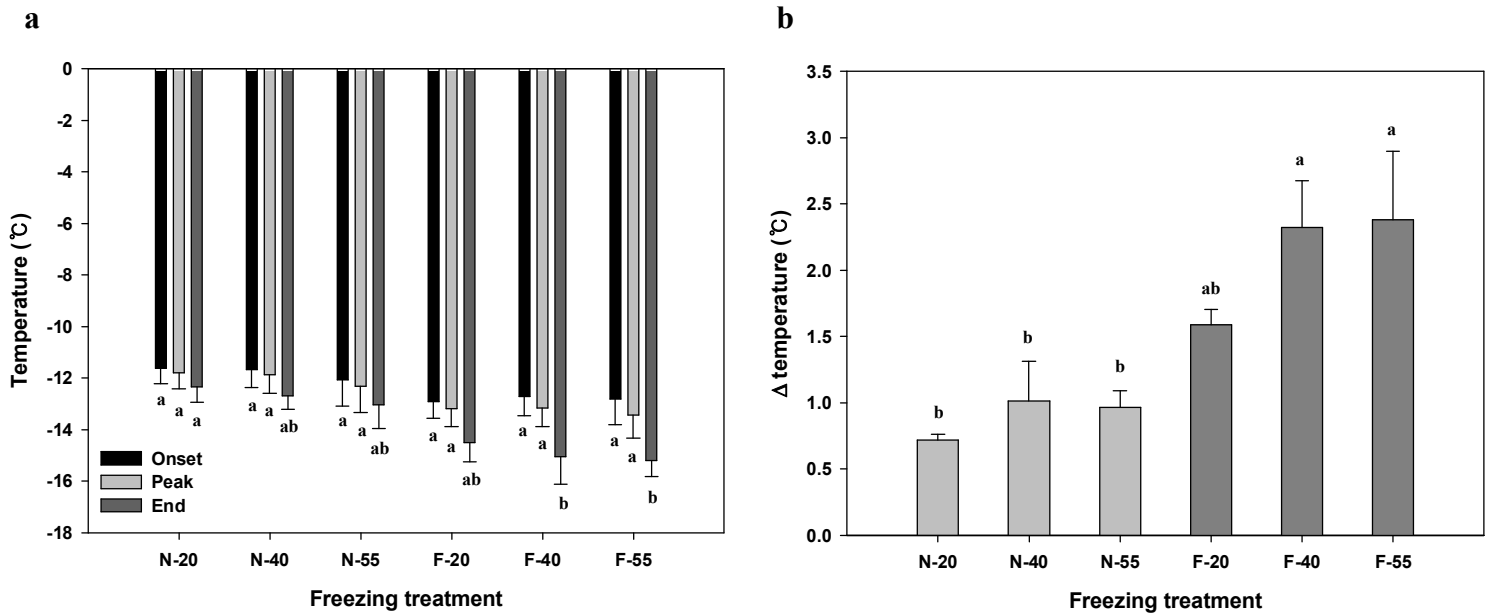

Fig. 6. (a) Remarkable temperatures for ice crystal formation in croissant dough during DSC freezing. (b) Difference between onset temperature and end temperature; difference of grey and dark sticks means N and F convection methods during freezing, respectively.

In the DSC thermogram, the width between onset and end temperature means phase transition. The width changes indicated the ice crystal size and its distribution indirectly in dough matrix (Montenegro, Antonietti, Mastai, & Landfester, 2003). In other words, the gap was narrow at slow freezing rate because dehydration level was high, while the gap was wider followed by increasing freezing rate. Therefore, the experimental results confirmed that ice crystal size and distribution were dependent of freezing rate. Moreover, the dough structure was investigated directly using the scanning electron micrographs (SEM), and the images were correlated with the DSC thermogram results.

3.4. Microstructure of the frozen dough

SEM was used to visualize the dough microstructure of frozen croissant dough using cooling stage for frozen state. The fractured surface was observed in the dough samples after storing at -18°C for 1 day. Figure 7 showed typical dough structure such as gluten network, voids, and starch granules. In addition, yeast cells and starch granules were not distinguished by this technique on the basis of appearance. Voids represent the space where ice crystals were formed during freezing (S. Zounis, K. J. Quail, M. Wootton, & M. R. Dickson, 2002). All the images showed various sizes of

voids depending on each freezing rate in matrix. Figure 7 (a) – (e) represent the dough frozen at freezing rate of) -0.72, -1.43, -1.84, -3.56, and -3.56°C/min, respectively, and (d) and (e) were different only T_t as -20 and -55°C. Fig. 7 (a), frozen at the slowest freezing rate, showed larger void diameter and thicker structure than the other samples. Freezing rate of Fig. 7 (c) was slightly faster than Fig. 7 (b), however, there is no structure difference between Fig. 7 (b) and (c) in the micrographs. Gluten network was more fibrillated and voids were also relatively compact as compared to Fig. 7 (a). Fig. 7 (d) and (e), frozen at the fastest freezing rate, showed that structures were the densest and gluten network was clear in the matrix. Freezing rate of Fig. 7 (d) and (e) was five times faster than the slowest freezing rate. .

The size of formed ice crystal was affected by the freezing rate thereby influencing the structure of the interior dough. During freezing process, water expands by about 9% as it freezes leading to separation between gluten network and ice crystals that induced stretching the gluten network (Nicolas et al., 2003). During freezing process, water in dough matrix is frozen and then the volume is expanded, leading to separation between gluten network and ice crystals that induced stretching the gluten network With increasing the number of broken gluten networks, the large amount of carbon dioxide was incapable of being captured in the network

since the gas retention capacity was significantly reduced (Baik & Chinachoti, 2000). The visualized microstructures of the dough can support the rheological properties of dough. The effects of prolonged frozen storage of dough have been widely studied with respect to water redistribution and ice crystal redistribution (Esselink et al., 2003; Inoue, Sapirstein, Takayanagi, & Bushuk, 1994; S. Zounis et al., 2002). These redistribution and recrystallization alter the physicochemical properties of the gluten-starch matrix and yeast activity. The dough structure was disrupted during storage period. This deterioration was originated from size increase in angular voids where ice crystal structure can be grown and separate gluten from starch with increasing time period. Storage at -20°C for several weeks resulted in slight structural damage caused by water migration and ice crystal growth. (S. Zounis, K. Quail, M. Wootton, & M. Dickson, 2002). The croissant dough frozen at fast freezing rate had high density of the structure and kept more intact gluten network. The dough structure was not influenced directly from terminal freezing temperature but yeast viability was affected.

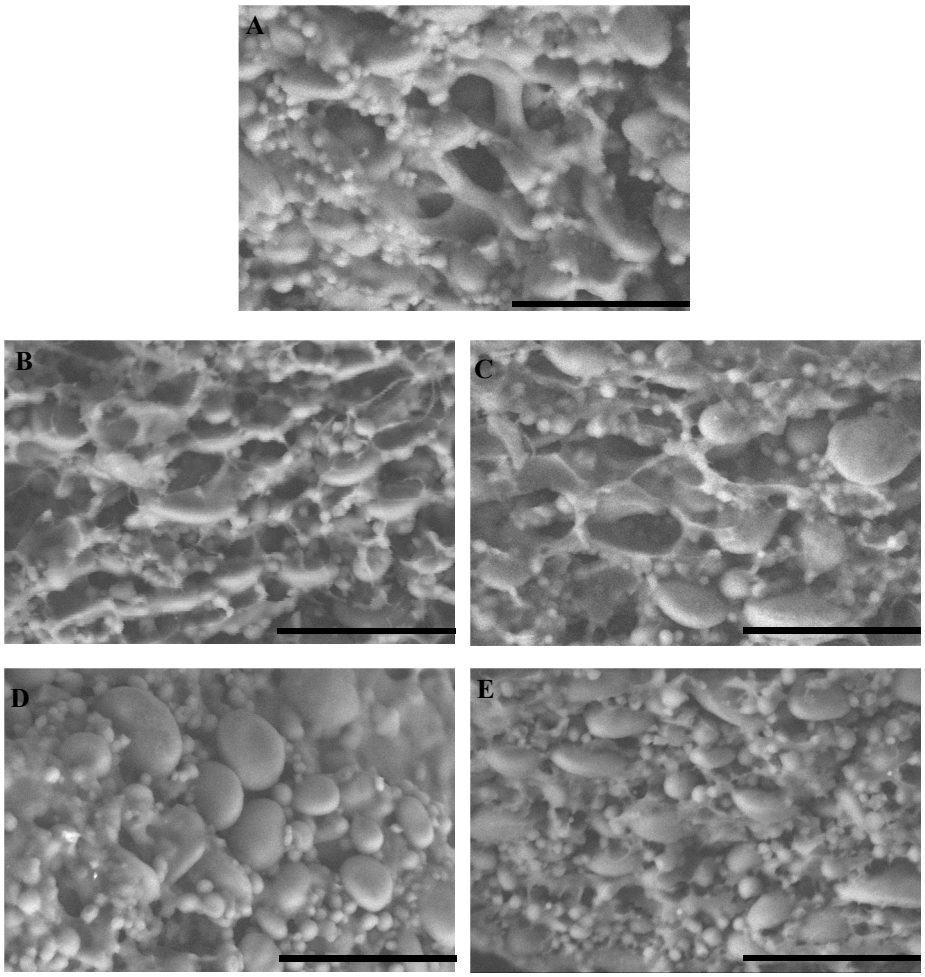

Fig. 7. Scanning electron micrographs of frozen fractured samples in frozen state of (a) N-20-20; (b) N-40-20; (c) F-20-20; (d) F55-20; (e) F-55-55. All samples were stored for a day at -18°C before observation. Scale bar = 50 μm.

3.5 Yeast viability as change of freezing condition

Yeast viability in frozen croissant dough at each condition was shown in Figure 8. N-20-20, N-40-20, N-55-20, F-20-20, and F-40-20 exhibited in the yeast viability statistically similar to the fresh croissant dough (control) while the number of viable yeast in frozen samples coded from N-20-20 to F-55-55 was lower than that of the control. However, the yeast viability of F-55-20 was lower than that of samples of N-20-20, N-40-20, N-55-20, F-20-20, and F-40-20 which were frozen to -20°C. This result implied that too much fast freezing induced the destruction of yeast cells in the croissant dough. Although rapid freezing method can minimize the damage on gluten matrix, too much fast freezing deteriorated the quality of frozen foods mainly due to death of yeast cell. This deterioration was originated not only chilling injury but intracellular ice crystal formation (Acker & McGann, 2000; Bruinsma & Giesenschlag, 1984; Mazur, 1961; Sharadanant & Khan, 2003). Water molecules in the dough was crystallized during freezing process, which makes that the rest of the unfrozen is concentrated with hydrophilic salts, sugar and so on. Thus, osmotic pressure and water activity of the frozen dough become high and low, respectively (Lorenz & Kulp, 1995; Stauffer, 1993). Additionally, the water is the only compound increasing the volume after freezing. The increase in volume

during freezing accelerated the inner pressure of yeast cells, and destructed the cell membrane in the dough (Muldrew & McGann, 1990). Therefore, the proper freezing rate is required to reduce the death of yeasts in the frozen dough (Zheng & Sun, 2006). The formed ice crystals puncture a cell membrane of yeast, resulting in the extraction of its cytoplasmic contents. The freezing yeast embedded in dough matrix is more susceptible than direct freezing of yeast since the osmotic pressure affected to the yeast (Lorenz, 1974). The yeast cell membrane is much more vulnerable to the external stimulus when the yeast is in a state of the active fermentation, resulting from the thin membrane. Furthermore, the organic compounds in dough system concentrated increasingly higher by the enrichment of the solid content in unfrozen medium, bringing about autolysis reaction of yeast cell (Stauffer, 1993). Therefore, the yeast viability was decreased during freezing of the dough.

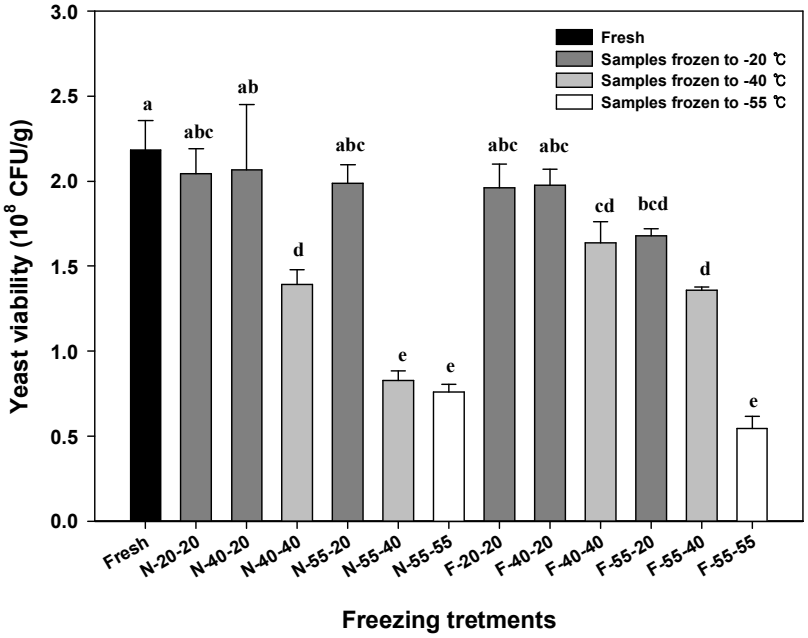

Fig. 8. The number of viable yeasts in frozen croissant dough after freezing and 1 day storage at -18°C.

The yeast viability was influenced by not only freezing rate but terminal freezing temperature. At the same freezing rate, the yeast viability was different significantly. The effect of T_t was observed obviously. In the most rapid freezing rate of F-55, as T_t was dropped, yeast viability was also decreased. The freezing point of fresh yeast was measured using DSC to understand the phenomenon. As shown in Figure 9, minor peak of exothermic curve indicated intracellular ice crystal formation. Initial freezing temperature was -16.3°C, the reaction was finished below -26°C. This result confirms that the T_t influenced yeast viability. When comparing the T_t levels (-20, -40, and -55°C) of the F-55, the numbers of yeast survived were increased with higher T_t. As yeast cell was cooled too fast, the contents in the cell was also supercooled. The cytoplasm and cell membrane were damaged by the increasing volume of the formed ice crystal (S. Seki, F. Kleinhans, & P. Mazur, 2009). The residual water inside the yeast is not dehydrated sufficiently to hold osmotic pressure, and nucleate small ice crystals in the plasma membrane because of rapid freezing rate (Muldrew & McGann, 1990).

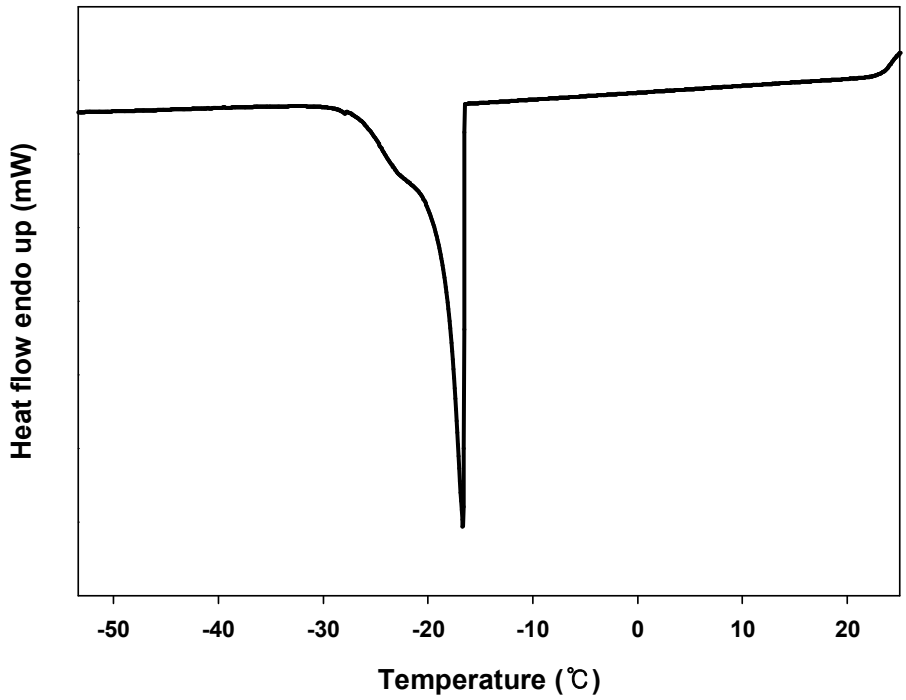

Fig. 9. Exothermic curve of fresh yeast during freezing. The data were taken for a yeast freezing point with a freezing conditions of F-55-55.

The yeast viability decreased rapidly during storage as the same trends of storage 1 day (Figure 10). The yeast activity was also affected by frozen storage. Fast freezing reduced the gassing power and the yeast survival rate (Autio & Sinda, 1992; El-Hady, El-Samahy, Seibel, & Brümmer, 1996; Lorenz, 1974). Moreover, rapid freezing also resulted in lower cell viability during storage while the maximum yeast activity was obtained by a slow freezing rate (Le Bail et al., 1998). Rapid freezing Dough weakening could be arisen from reducing glutathione released by lysed yeast during freezing-thawing process (Casey & Foy, 1995). The glutathione cleaved disulfide bond of gluten network, it deteriorated the rheological factor of bread quality (Hsu, Hoseney, & Seib, 1979; Kline & Sugihara, 1968; Selomulyo & Zhou, 2007). Therefore, at the F-55-55 condition, yeast viability was the least level of all the samples.

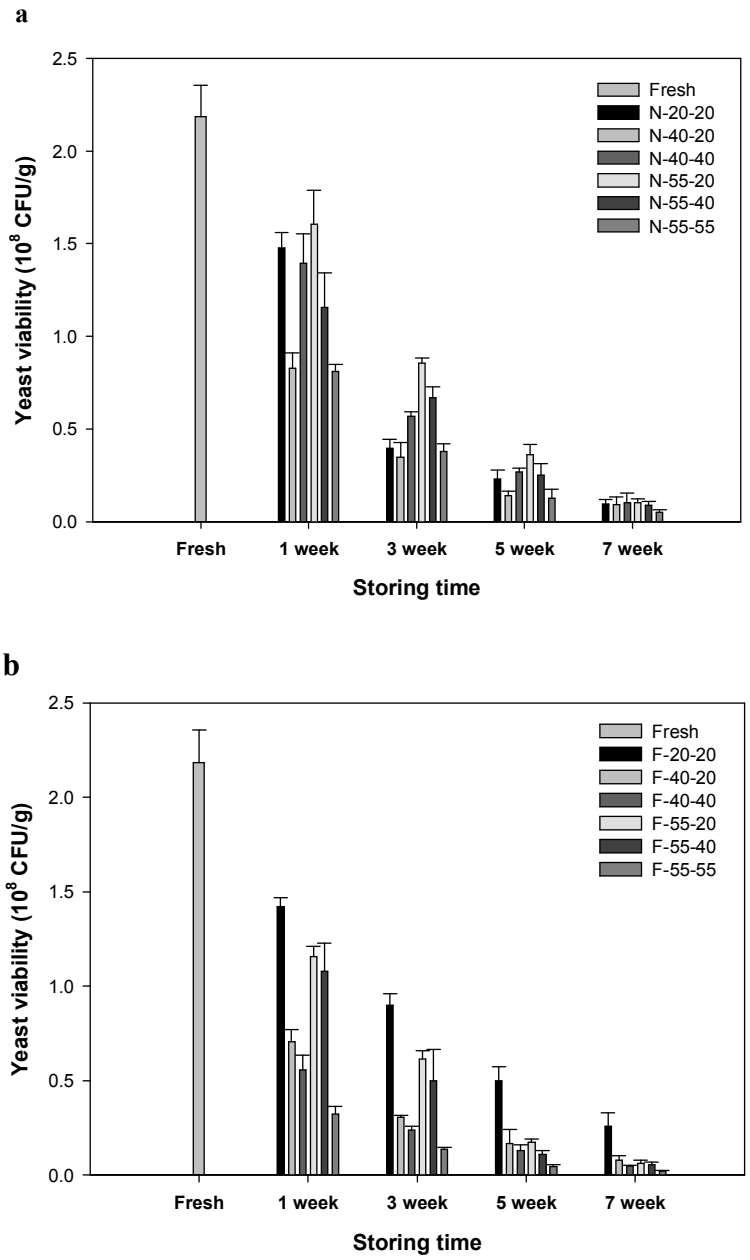

Fig. 10. The number of viable yeasts in frozen croissant dough stored at same temperature from 1 to 7 weeks. (a) is natural convection type and (b) is forced convention type freezing condition.

IV. CONCLUSIONS

The croissant quality produced from frozen dough was considerably influenced by freezing rate and terminal freezing temperature. The best quality was shown when the dough was frozen from -20°C of initial temperature to -20°C of terminal freezing temperature with forced convection. The freezing rate converted from freezing curve was calculated as 1.84°C/min where this value was neither too fast nor too slow rate. It was confirmed that three factors, optimized variables, freezing rate and T_t, were allowed to produce baked breads. In the conclusion, the optimal freezing rate was set at the ice crystal nucleation rate to balance the internal and external osmotic pressure in yeast cell. Moreover, the optimum freezing conditions allowed the minimal loss of the damage in gluten network because that ice crystal size and distribution in the optimum freezing condition does not damage the dough matrix, which could be a crucial result for being applicable to not only other formulation breads, but economical effect by means of combined freezing processes. In the future, the optimum freezing conditions investigated by this study could be successfully applied for the frozen bakery industrial purposes.

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VI. 국문초록

베이커리 산업은 국내외에서 소비량이 꾸준하게 상승함에 따라 규모가 증가하고 있다. 특히 냉동 반죽을 이용한 제빵기술은 소비자에게 신선하고 편리하게 계획생산이 가능하다는 장점을 가지고 있어 제빵 산업 분야에서 주목 받고 있다. 그 중 패스츄리 종류의 크루아상은 생산공정에서 많은 시간과 노동력을 요구하여 냉동 반죽으로서의 수요가 크게 증가하고 있다. 하지만 반죽의 냉동 공정으로 인해 제품의 품질을 저하시키는 문제점을 가지므로 구체적인 냉동 공정 조건에 대한 연구가 필요하다. 본 연구에서는 냉동 속도와 냉동 종료 온도가 냉동 크루아상 반죽에 미치는 영향을 확인하고 이를 통해 크루아상 냉동 반죽 생산을 위한 최적 냉동 조건을 확립하였다. 크루아상 반죽은 대류방법과 냉기온도의 결합으로 냉동 속도를 -0.72 ~ -3.56℃/min으로 설정하였고, 냉동 종료 온도는 -20, -40, -55℃로 각각 설정하였다. 냉동 속도를 시차주사열량계에 적용하여 냉동 유사실험을 수행한 결과 냉동 속도가 빠를수록 흡열 곡선의 너비가 크게 나타났다. 이는 곧 냉동 속도가 빠를수록 얼음 결정이 작은 크기로 분포되어 있다는 것을 보여준다. 냉동반죽의 내부구조를 시각적으로 관찰하기 위해 SEM을

이용하여 냉동 속도에 따른 반죽의 미세구조 변화를 살펴보았고 가장 빠른 냉동 조건인 강제대류로 -55℃에서 냉동한 반죽의 경우, 구조가 잘 유지되는 것을 확인하였다. 반면, 효모 생존율은 가장 빠른 속도에서 가장 많이 저하되었으며 강제대류로 -20℃를 넘지 않는 냉동 속도에서 높은 생존율을 보였다. 특히 냉동 종료 온도가 낮아짐에 따라 그 생존율 또한 저하되었고 이를 확인하기 위해 생효모의 어는점을 시차주사열량계로 측정하였다. 생효모의 흡열 곡선에서 상 변화가 -22℃ 이하에서 종료되는 것을 확인하였다. 이는 세포 내에 존재하던 자유수가 온도 강하로 인해 상변화가 일어나고 그 결과 얼음 결정의 형성이 세포막과 세포질을 파괴하여 효모의 생존율 저하를 일으키는 것으로 사료된다. 또한 7주동안 저장 실험을 통해 효모 생존율을 비롯하여 크루아상의 품질은 계속 저하되는 것을 확인하였다. 따라서 최상의 크루아상 품질을 위한 냉동 반죽의 최적 냉동 조건은 강제대류로 -20℃ 냉기온도에서 -20℃까지 냉동하였을 경우로 이 때 냉동 속도는 -1.84℃/min이었다. 이 결과는 크로아상을 비롯한 냉동 반죽 생산을 위한 최적 냉동 공정을 수립하는데 기초 데이터로서 활용될 것으로 기대된다.

주요어: 냉동 반죽, 냉동 속도, 냉동 종료 온도, 얼음 결정, 효모 생존율

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