P - 143

A Numerical Modeling of Thawing Rate for Frozen Pork using High Pressure Assisted Thawing Technique

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Abstract

The objective of this study was to provide the optimum thawing condition under different level of high pressure(50, 100, 150 and 200 MPa) using high pressure assisted technique which can improve the quality of frozen and thawed pork. The calculated thawing rate from the results depending on the high pressure showed the strong trend of increased thawing rate under pressurized condition($P<0.05$). And then, the numerical modeling was executed to predict the thawing rate influenced by the pressure level using exponential regression, $LnY=0.70623 + 0.00433 \cdot P$ ($R^2=0.9985$), and it was fairly fit for the functional relation between the thawing rate(Y) and pressure(P) with comparatively high coefficient, R^2 of determination.

Introduction

In the food freezing technology, the thawing process takes relatively more long lag time for phase transition than freezing due to the different thermal conductivity between water and ice, and so it causes further detrimental physicochemical changes on frozen food. Therefore, optimum thawing procedures should be of concern to food industry and it is commonly accepted that quick thawing at low temperature to avoid notably rising in temperature and excessive dehydration of food is desirable to assure food quality(Bing Li and Da-Wen Sun, 2002). Accordingly, there have been the developments of new methods to accomplish rapid thawing of food at low temperature like high-pressure thawing. High-pressure thawing technique is especially considered as promising one which can improve frozen food quality. The objective of this study was to provide the optimum thawing condition under different level of high pressure(50, 100, 150 and 200 MPa) using high pressure assisted technique which can improve the quality of frozen pork.

Materials and Methods

Preparation of sample

After purchasing post rigor of pork *M. logissimus dorsi* that had been stored for 24 hours at 4℃, they were trimmed free of excessive fat, bone and connective tissue and then samples of cylinder type(50×100 mm) were respectively vacuum packed in polyethylene pouch.

Freezing and frozen-storage process

Freezing was carried out at the coolant temperature of -20℃ in cryostat(FP-80, Julabo, Germany), progressed to the geometric center temperature of -20℃, and monitored with the data logger(MV-100, YOKOGAWA, Japan). After freezing process, they were stored in the deep freezer(Daesung, Korea) at -20±1℃ for 5 days until thawing experiment.

High pressure assisted thawing(HPAT)

HPAT experiment was carried out in high-pressure experimental device(QFP-6, ABB Metallugry, Sweden). HPAT was progressed with pressurizing and thawing medium at the intended temperature of 15℃ and maintained the respective pressure level(50, 100, 150 and 200 MPa) during experimental procedure. During pressure induction, pressurization rates were 10, 4, 5.56, and 6.67 MPa/s at 50, 100, 150 and 200 MPa, respectively.

Statistical analysis

The experimental results were statistically evaluated using *Nalimov Data Analysis Program*(simplified *t-test*) and then *Duncans Multiple Range Test* was conducted to compare the significance differences among the means of respective experimental conditions using *SAS statistics software(version 8.2)* at the confidence level of 95%.

Results and Discussions

Thawing profiles under the increased pressure level

Fig. 1 represents the temperature transition of pressurizing and thawing medium during HPAT. The temperature change of medium and duration time at the respective stage during HPAT are presented in Table 1. During pressurization, there was the increment of medium temperature and it showed the tendency of increasing temperature rise(ΔT) at higher pressure level due to increasing enthalpy(H). The maximum temperature of medium indicated 22℃ at the pressurization course(A→B). This temperature was lower than the level of myofibril coagulation(40℃), and so the direct influence of temperature increment on the protein denaturation could be neglected coupled with the relative short duration time(maximum: 30s) during pressurization procedure. Most of thawing occurred pressure dwell course(B →C), and so it had the most potential influence on the thawing process. In the depressurization stage(C →D), the medium temperature rapidly decreased after the immediate release of pressure.

Table 1. Temperature transition of medium and duration time at each pressurizing step during HPAT

Pressure (MPa)	Pressurization A→B		Pressure dwell B→C		Depressurization C→D	
	Duration (s)	Temperature increment (℃)	Duration (s)	Temperature range (℃)	Duration (s)	Temperature increment (℃)
50	5	1.7	3582	15.4 - 16.9	18	1.7
100	25	2.9	2869	16.9 - 18.5	92	2.7
150	27	4.6	2332	18.2 - 21.9	24	4.1
200	30	6.1	1916	17.2 - 21.0	9	4.9

Calculated thawing time and rate during High Pressure Assisted Thawing Process

In this experiment, thawing time was obtained from the reduction ratio(defined in Eq. 1) having the interrelation with the decrement of freezing point and latent heat in water under the pressurized condition. Regarding this phenomena, LeBail et al.(2002) proposed the polynomial regression equation expressed in Eq. 3 and 4. Its result is presented in Table 2 thawing time was obtained from the reduction ratio having the interrelation with the decrement of freezing point and latent heat in water under the pressurized condition.

$$C_R=(T_a - T_{fp})/(T_a - T_f) \qquad (eq.1)$$

C_R: reduction ratio, T_a medium temperature, T_{fp} freezing temperature at high pressure, T_f freezing temperature at atmosphere pressure

$$t_{hp} = t_a/C_r \qquad (eq.2)$$

t_{hp}: thawing time at HPAT, ta thawing time at atmosphere pressure

$$L(kJ/kg)=333.549259-0.399369\cdot P-3.88x10^{-4}\cdot P^2 \qquad (eq. 3)$$

$$T_f(℃)=-0.072192\cdot P-0.000155\, P^2 \qquad (eq. 4)$$

(L: latent heat(kJ/kg), P Pressure(MPa), T_f Freezing point(℃))

By the research of Chourot et al.(1995), this reduction ratio is fairly confidential for HPAT and thawing time resulting their experiments realized with a thermal sensor installed at center of sample. Our results showed that thawing was effectively completed at t_{hp}/C_R(Jocelyn Rouille et al, 2002) and the result was fairly reliable for the reduction ratio because the core temperature of sample was nearly 0℃ after the immediate release of pressure that means calculated thawing time by reduction ratio. From the view point of heat transfer, large temperature difference enhances the driving force of thawing, and so it leads to the diminished thawing time like this experimental result.

Table 2. Calculated thawing time of sample pork at the HPAT process from the reduction of latent heat, freezing point in water due to increment of pressure, and reduction ratio

Pressure, P (MPa)	L Latent heat(kJ/kg)	T_{fp} Freezing point(℃)	C_R Reduction ratio	t_{hp} Thawing time(s)
0.1	333.51	-0.00722	1	4500±30[a]
50	312.61	-3.997	1.266	3554±24[b]
100	289.73	-8.769	1.584	2841±19[c]
150	264.91	-14.316	1.953	2304±16[d]
200	238.16	-20.648	2.375	1895±13[e]

Different subscripts in the same row indicate significant differences of the experimental result ($P<0.05$) among each pressure levels.

The changes in the calculated thawing rate from the results(Table 2) depending on the high pressure is presented in Fig. 2 which showed the strong trend of increased thawing rate under pressurized condition($P<0.05$). And then, the numerical modeling was executed to predict the thawing rate influenced by the pressure level using exponential regression(eq. 5), and it was fairly fit for the functional relation between the thawing rate(Y) and pressure(P) with comparatively high coefficient, R^2 of determination.

$$LnY = 0.70623 + 0.00433 \cdot P \qquad (R^2=0.9985) \qquad eq.5$$

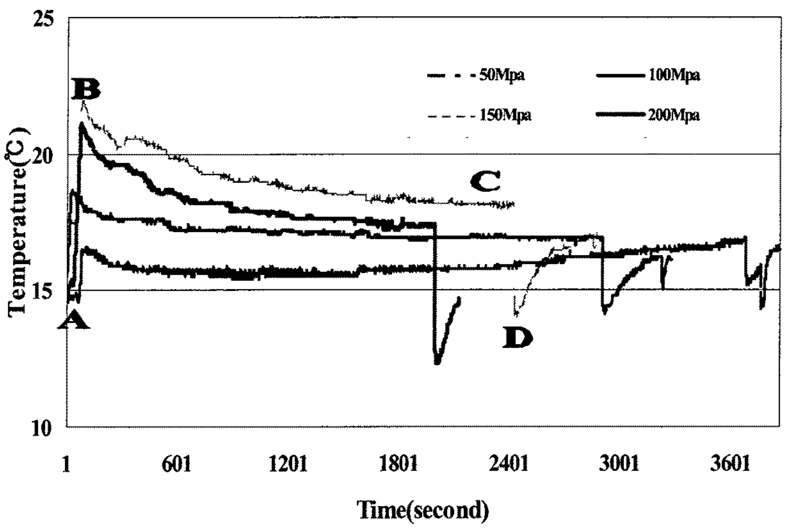

Fig. 1: Changes in temperature of thawing medium during pressurizing using HPAT technique.

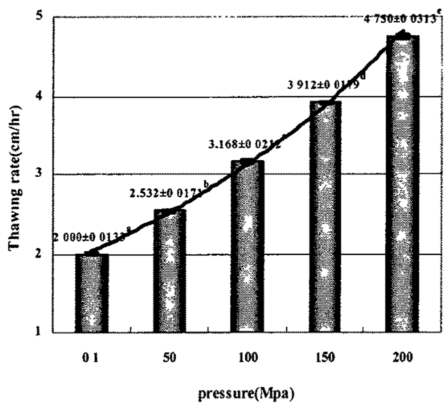

Fig. 2. Changes in thawing rate of frozen pork at the each pressure level during HPAT process.

Table 3. The comparison of thawing rate between experimental and exponential regression results

Pressure (MPa)	Thawing rate(cm/h) measured	Thawing rate(cm/h) calculated	Variance (△cm/h)
0.1	2.027	2.000	0.027
50	2.516	2.532	-0.016
100	3.125	3.168	-0.043
150	3.881	3.912	-0.031
200	4.819	4.750	0.069

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