EFFECT OF PHOSPHATE SALTS AND TRANSGLUTAMINASE IN PREVENTION OF FREEZE CRACKING IN FROZEN DICED BROILER BREAST

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ABSTRACT

Raw broiler breast meat was cooked and diced to 1.5 × 1.5 × 1.5 cm^3 *then frozen under air-blast, still-air and cryogenic conditions. It was found that freezing with cryogenic at −70C at a rate of 37.50 cm/h produced 38.34% cracked pieces and increasing the freezing rate produced more cracked pieces. Cracking could be found on up to four sides of the dice. A small increase in the moisture of the dice drastically increased the cracking. Tumbling the meat with 1% sodium triphosphate solution prior to cooking and freezing at −70C reduced the amount of freeze cracking in the product from 47.50 to 24.17%. Tumbling the meat with 0.5% transglutaminase (TGase) reduced the cracked product to 25.84%. Increasing TGase not only increased the moisture content of the products but also reduced the number of cracked products. The TGase-treated dices had narrower and shorter cracks than phosphate-treated and without treatment dices.*

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INTRODUCTION

Frozen-cooked broiler breast dice is requested in food services, and its demand is increasing recently because it provides fewer steps in preparation and cooking (Sebrenek 1995). However, many cracked pieces are often found after the freezing step. The cracked pieces are unwanted and usually discarded as waste or sold as low-quality products.

Freezing is one of the effective food preservation methods. However, the volume of the ice expands after the crystals are formed. This creates internal pressure in the food matrix.

Cryogenic freezing provides fast freezing rate. Even though a fast freezing rate has the advantage of turning water in food materials into small ice crystals, a very fast freezing rate can also cause visible cracking from the inside of the food materials (Hung and Kim 1996). The freeze cracking identified by Hung (1997) on the surface of the food materials had two types. One type included small cracks with large numbers on the surface, and the other type included big cracks with small numbers occurring inside the food materials.

The broiler meat is composed of muscle fibers, which are bundled together with connective tissues. These connective tissues lose their strength when cooked. They can be torn with less force than uncooked ones. These muscle fibers also lose their ability to hold water. The processes for encouraging muscle fibers to swell and hold water might involve pH adjustment and addition of binder, emulsifiers or spices.

Sodium triphosphate (STPP) is an additive that is commonly used for water retention and flavor protection in meat and poultry products. Transglutaminase (TGase) is an enzyme that can be applied as a binder in food. The TGase is applied when a piece of meat is reformed from many small pieces of meat to gain strength during heat and physical forces (Motoki and Kumazawa 2000). Even though these additives are commonly used for cooking, their effects may be useful in preventing freeze cracking.

This article aimed to investigate the effects of moisture content on cracking as well as the effects of STPP and TGase on the prevention of freeze cracking of diced broiler breast.

MATERIALS AND METHODS

Sample Preparation, Cooking and Evaluations

The breast part of a 45-day-old Cobb broiler was trimmed of fat and skin. The average size of each piece was 140–160 g. It was randomly taken for proximate analysis (AOAC 1995). Prior to cooking, some samples were subjected to treatments described later.

The broiler breast was steam-cooked until the center of the piece reached 80C. The sample was cooled to −1C. Then, it was diced to $1.5 \times 1.5 \times 1.5$ cm^3, while the temperature of the meat was controlled at below 5C. The broiler breast dice was subjected to different types and conditions of freezing, which included air-blast freezing at −20C with air velocity at 6 m/s, still-air freezing at −40C and cryogenic freezing at −70, −80, −90 and −100C. The cryogenic freezing was achieved by applying liquid N_2 vapor on the samples. The sample was subject to freezing until its center temperature reached −18C, and the freezing rate was determined using the equation (Pan and Yeh 1993):

$$\text{Freezing rate (cm/h)} = \frac{\begin{array}{c}\text{Minimum distance from the}\\ \text{surface to the thermal center of shrimp (cm)}\end{array}}{\text{Thermal arrest time (h) to reach }-18\text{C}}$$

Appearance of the crack on the frozen dice was observed and characterized. The crack was measured in length (cm) and width (mm) of the gap opening. The broiler breast dice was analyzed for % freezing loss, % thawing loss and % moisture content, and was examined histologically under a light microscope (Nikon UFX-DX, Japan). All measurements were done in triplicate. All means were compared using Duncan's Multiple Range Test (Cochran and Cox 1965).

Effect of Moisture on Cracking of Broiler Breast

The moisture content of the broiler breast was adjusted by tumbling. The broiler breast and water was put in a tumbling bag, with the ratio of breast : water at 1:2, and tumbled at 5 rpm for 0, 10 and 40 min. The sample was then cooked, diced and frozen under cryogenic condition at −70C until the center of the dice reached −18C. The frozen sample was determined for % moisture content and amount of cracking. All measurements were done in triplicate.

Effect of STPP and TGase on Cracking of Broiler Breast Dice

Instead of water, the STPP solution at 1, 3 and 5% and TGase solution at 0.5, 1.0 and 1.5% were used for tumbling. The broiler breast was tumbled for 10 min at 5 rpm. After that, the broiler breast was cooked, diced and frozen under cryogenic condition at −70C until the center of the dice reached −18C.

The moisture content, weight gain and cooking, freezing and thawing losses of the samples were determined. All measurements were done in four replicates.

Freezing Loss Determination

The freezing loss of the broiler breast dices was determined from the known weight of the dices before and after freezing and expressed as (AOAC 1995):

$$\% \text{ Freezing loss} = \frac{\begin{array}{c}(\text{weight of cooked broiler breast} \\ -\text{ weight of frozen cooked broiler breast}) \times 100\end{array}}{\text{weight of cooked broiler breast}}$$

Thawing Loss Determination

The thawing loss was determined from the weight of the frozen dice broiler breast before and after thawing and expressed as:

$$\% \text{ Thawing loss} = \frac{\begin{array}{c}(\text{weight of frozen cooked brolier breast} \\ -\text{ weight of thawed cooked broiler breast}) \times 100\end{array}}{\text{weight of frozen cooked broiler breast}}$$

Moisture Content Determination

The moisture content of the cooked broiler dice was determined from the weights of cooked and dried cooked broiler dices. The cooked broiler dice was dried at 100C until its weight had not changed after repeated drying. The moisture content was expressed as:

$$\% \text{ Moisture} = \frac{\begin{array}{c}(\text{weight of cooked brolier breast} \\ -\text{ weight of dried cooked broiler breast}) \times 100\end{array}}{\text{weight of cooked broiler breast}}$$

Histological Examination

The broiler breast dice was prepared for microscopic analysis using the modified method of Pan and Yeh (1993). A light microscope (Nikon UFX-DX) and camera (Nikon FX-35DX) were used for observation.

RESULTS AND DISCUSSION

Study of Cracking Characteristic after Freezing

The broiler breast was composed of $75.12 \pm 0.08\%$ moisture, $21.24 \pm 0.20\%$ protein, $1.72 \pm 0.05\%$ fat, $1.10 \pm 0.96\%$ ash and $0.92 \pm 0.05\%$

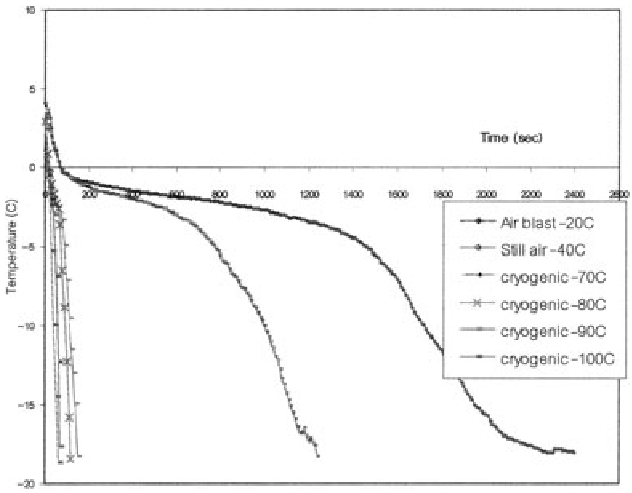


FIG. 1. FREEZING CURVES OF BROILER BREAST DICES FROZEN AT VARIOUS CONDITIONS

TABLE 1.
AMOUNT OF CRACKING OF BROILER BREAST DICES FROZEN AT VARIOUS FREEZING RATES

Freezing conditions	Freezing rate (cm/h)	Amount of cracking (%)
Air-blast freezing – 20C	2.35 ± 0.07	0.00
Still-air freezing – 40C	5.33 ± 0.08	0.00
Cryogenic – 70C	37.50 ± 1.09	38.34 ± 6.94
Cryogenic – 80C	52.82 ± 0.79	45.00 ± 5.77
Cryogenic – 90C	84.81 ± 1.56	65.83 ± 5.69
Cryogenic – 100C	129.43 ± 0.46	82.50 ± 3.19

carbohydrate. The broiler breast dices were frozen under various freezing conditions. Freezing curves are shown in Fig. 1.

From the freezing rate measurement, it was found that the air-blast freezing at –20C had the slowest freezing rate among the six freezing conditions (Table 1). The air-blast freezing at –20C and still air freezing at –40C had fast freezing rates while all cryogenic freezing were in the range of rapid freezing. Cracking was found when the broiler breast was frozen with the rapid freezing rate. This was because the cryogenic freezing with liquid nitrogen had very low temperature at –196C. It removed heat from food matrix very fast and caused cracking in the products.

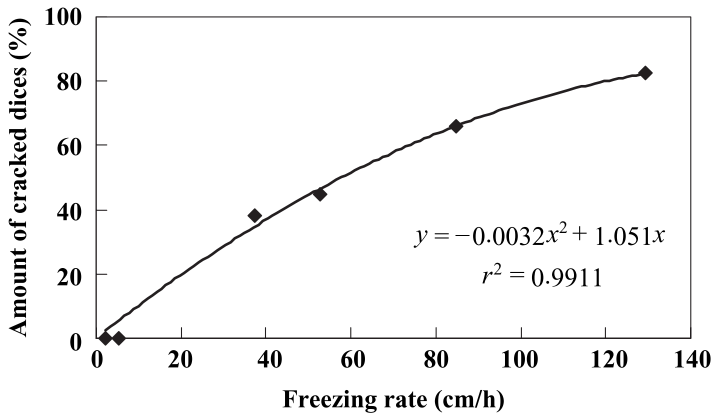


FIG. 2. AMOUNT OF CRACKED BROILER BREAST DICES FROZEN AT DIFFERENT FREEZING RATES

An increase in freezing rate increased the amount of cracked dices. The relationship of freezing rate and amount of cracked dices are shown in Fig. 2 and could be expressed in the form of Eq. (1) with $r^2 = 0.991$:

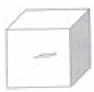
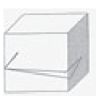
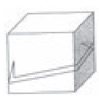
$$y = -0.0032x^2 + 1.051x - 3.7362 \tag{1}$$

where y is the number of cracked dices and x is the freezing rate (cm/h).

From the observation, it is shown that the cracking marks of the broiler breast occurred along the muscle fiber. The cracking marks could be found running on one, two, three and four sides of the dice. The crack was hairline-like when it was on one side, and it became a large gap after having extended to two or more sides of dice. The cracking lines in the diced broiler breast could occur by internal stress. This stress was the result of forming and expansion of ice crystals (Pham 2005). The crack was the same as the one on frozen turkey ham described by McCambridge *et al*. (1996). The crack in the frozen broiler breast is described in detail in Table 2.

The cracks that appeared only on one side of the dice showed the smallest gaps with widths from 0.1 to 1.0 mm, and the cracking line could be found at the center of that side. This kind of freeze-crack was found only when freezing at −70C. When freezing at the faster freezing rate, the cracking lines appeared to be longer and run from one corner of the dice to the other corners. The faster freezing rate caused the cracking line to be longer and wider in gap. In this experiment, there was no dice cracked and split into two pieces. The long cracking lines with wide gaps could easily split into two pieces during further processing and transportation.

TABLE 2.
NUMBER AND APPEARANCE OF CRACKED BROILER BREAST DICES FROZEN UNDER CRYOGENIC CONDITION AT VARIOUS FREEZING RATES

Number of sides that cracked	Width of the gap (mm)	Number of cracked dices (%) Freezing rate (cm/h)			
		37.5	52.82	86.81	129.43
One side	0.01–0.50	5.84 ± 1.67			
	0.51–1.00	4.17 ± 1.67			
Two sides	0.51–1.00	7.50 ± 1.67	5.00 ± 1.93		
	1.01–1.50	8.34 ± 1.82	5.00 ± 1.93	5.84 ± 1.67	5.00 ± 1.93
Three sides	0.51–1.00	7.50 ± 1.67	17.50 ± 3.19	23.33 ± 2.72	32.50 ± 4.20
	1.01–1.50	5.00 ± 1.93	9.17 ± 1.67	19.17 ± 1.67	14.92 ± 2.03
	1.51–2.00			5.84 ± 1.67	5.84 ± 1.67
Four sides	0.51–1.00		5.00 ± 1.93		9.17 ± 1.67
	1.01–1.50		8.34 ± 1.92	7.50 ± 1.67	8.34 ± 1.92
	1.51–2.00			3.33 ± 0.00	4.17 ± 1.67

The faster freezing rate of the diced broiler breast applied, the wider the gap and the longer the cracked appeared. The arrangement of the muscle fiber in each bundle was covered with a connective tissue, and many of these bundles were gathered in a bigger bundle with epimysium (Johnston *et al.* 1991). During fast freezing, crust formed on the surface and prevented the expansion of material (Kim 1993 cited in Pham *et al*. 2005). As the liquid in the muscle turned into ice crystal, it created stress in the muscle bundles and caused the dice to crack. The histogram of the broiler meat also showed the gap between the muscle bundles to be wider as it was frozen at the faster rate (Fig. 3).

Freezing affected the quality of the broiler breast muscle. The air-blast and still-air freezings had quite slow freezing rates. They took longer time to reach −18C. Freezing loss of these two freezing rates was greater than that of the cryogenic freezing. The big ice crystals that appeared in the slow freezing rate resulted from higher freezing and thawing losses (IIR 1972). The cryo-

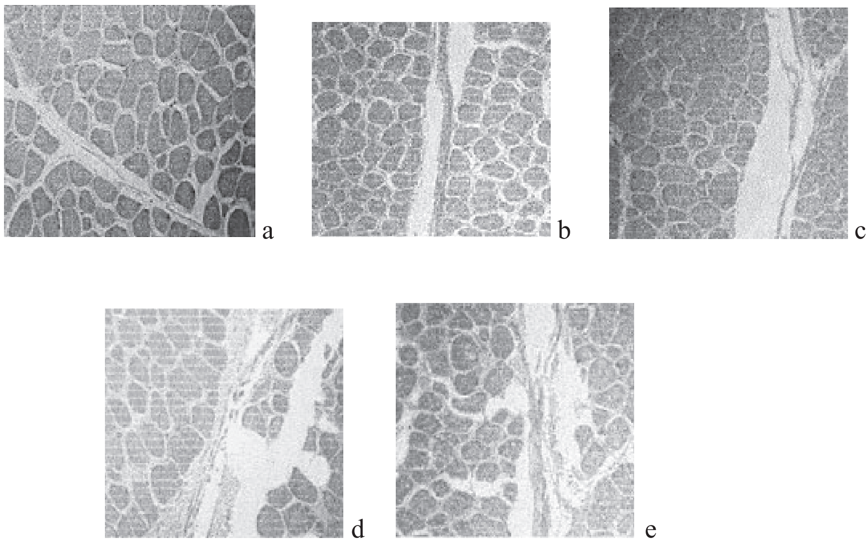


FIG. 3. HISTOGRAM OF BROILER BREAST MUSCLE STRUCTURE SUBJECTED TO CRYOGENIC FREEZING
(a) before freezing; (b) −70C; (c) −80C; (d) −90C; and (e) −100C (magnification 360×).

genic freezing provided faster freezing rate and smaller ice crystals, which reduced the loss during freezing. As the very fast freezing rate was applied, bigger gaps in the broiler breast muscle were found. These big gaps caused greater thawing loss than that in slow freezing (Table 3).

Effect of Moisture on the Cracking of Broiler Breast

The broiler breast meat was subjected to tumbling in order to increase the moisture content of the meat. Forty-minute tumbling caused breast meat to have a moisture content of 70.56% after cooking, while the 10-min tumbled dice caused 68.6% moisture content. These dices were frozen under cryogenic condition at −70C until their centers reached −18C. The amount of moisture content in the meat affected the number of cracked pieces as shown in Fig. 4. Even a small increase in moisture drastically increased the number of cracked pieces. The freezing of the water at the surface could appear as a case on the sample that would prevent the expandability of the freezing dices. The expansion in volume of the ice caused high pressure inside the dices (Pham 2005). The bigger gaps were affected by a rapid increase in pressure from the expansion of ice crystals (Watanabe *et al*. 1996).

The protein in the cooked broiler meat was denatured by the cooking process. The cooked meat lost its flexibility and could not stand the stress from

TABLE 3.
MOISTURE BEFORE FREEZING, AND FREEZING AND THAWING LOSSES OF BROILER BREAST DICES

Freezing rate (cm/h)	Moisture before freezing*(%)	Freezing loss (%)	Thawing loss (%)
2.35 ± 0.07	66.18 ± 0.38	2.28 ± 0.53[a]	3.90 ± 0.06[b]
5.33 ± 0.08	66.32 ± 0.56	2.30 ± 0.57[a]	3.82 ± 0.07[b]
37.50 ± 1.09	66.11 ± 0.33	0.58 ± 0.05[b]	2.88 ± 0.03[a]
52.82 ± 0.79	66.21 ± 0.43	0.86 ± 0.02[b]	3.03 ± 0.10[a]
84.81 ± 1.56	66.11 ± 0.44	0.85 ± 0.01[b]	4.26 ± 0.20[c]
129.43 ± 0.46	65.89 ± 0.39	0.84 ± 0.03[b]	4.77 ± 0.10[c]

Means with different superscript letters in the same column are significantly different ($P \leq 0.05$).
* Means are not significantly different ($P > 0.05$).

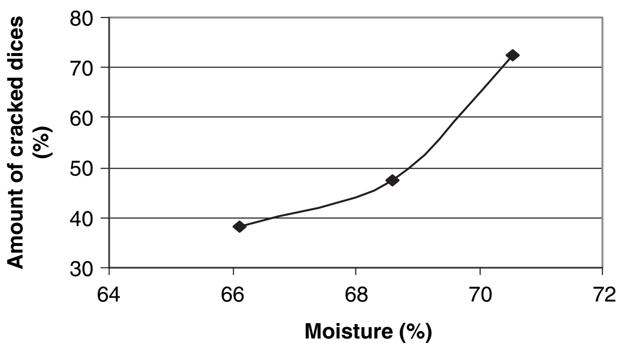


FIG. 4. EFFECT OF MOISTURE CONTENT ON THE NUMBER OF CRACKED BROILER BREAST FROZEN UNDER CRYOGENIC FREEZING (–70C)

volume expansion of the ice. A very small amount of moisture increase in the meat significantly affected the number of cracked dice, as food processors would like to have their broiler meat hold as much water as it could. At the same time, it also increased cracking, which was unwanted.

Study on STPP and TGase on the Freeze Cracking of Broiler Breast Dice

The STPP that was added to the soaking liquid during tumbling decreased the number of cracked dices when freezing under cryogenic conditions at –70C. The 1% STPP-soaked meat had the same moisture content as the water-soaked one, but it produced less cracked dices. The amount of phosphate found in the meat was 0.44%. As the content of STPP in soaking liquid increased, the number of cracked dices also increased (Table 4) . The 5% STPP

TABLE 4.
NUMBER AND CRACKING CHARACTERISTICS OF BROILER BREAST DICES TREATED WITH SODIUM TRIPHOSPHATE (STPP) AND FROZEN UNDER CRYOGENIC CONDITION AT –70C

Number of sides that cracked	Width of the gap (mm)	Number of cracked dices (%) STPP (%)			
		0	1	3	5
One side	0.01–0.50	7.50 ± 1.67	2.50 ± 1.67	5.64 ± 1.67	5.00 ± 1.93
	0.51–1.00	9.17 ± 1.67	8.34 ± 1.92	5.00 ± 1.93	8.33 ± 1.92
Two sides	0.51–1.00	7.50 ± 1.67	4.17 ± 1.67	7.50 ± 3.19	5.25 ± 2.84
	1.01–1.50	8.34 ± 1.92	4.17 ± 1.67	6.67 ± 0.00	5.84 ± 1.64
Three sides	0.51–1.00	7.50 ± 1.67	5.00 ± 1.93	5.84 ± 1.67	5.84 ± 1.67
	1.01–1.50	5.00 ± 1.93			2.50 ± 1.67
Total number of cracked dices		$47.50^{a} \pm 1.67$	$24.17^{d} \pm 1.67$	$29.17^{c} \pm 3.19$	$34.17^{b} \pm 1.67$

Means with different superscript letters are significantly different ($P \leq 0.05$).

TABLE 5.
MOISTURE BEFORE FREEZING, AND FREEZING AND THAWING LOSSES OF BROILER BREAST DICES WHEN SOAKED WITH SODIUM TRIPHOSPHATE (STPP) AND TRANSGLUTAMINASE (TGase)

Treatment	Moisture before freezing (%)	Freezing loss (%)	Thawing loss (%)
Fresh broiler breast dices	68.60 ± 0.13^{d}	0.88 ± 0.02^{a}	3.12 ± 0.07^{b}
STPP (%)			
1.0	68.80 ± 0.56^{cd}	0.82 ± 0.03^{b}	1.96 ± 0.07^{b}
3.0	69.11 ± 0.13^{c}	0.83 ± 0.02^{b}	2.51 ± 0.03^{a}
5.0	71.75 ± 0.12^{a}	0.84 ± 0.02^{b}	2.57 ± 0.10^{a}
TGase (%)			
0.5	68.92 ± 0.44^{cd}	0.64 ± 0.01^{c}	1.68 ± 0.03^{c}
1.0	68.93 ± 0.39^{cd}	0.55 ± 0.03^{c}	1.60 ± 0.05^{c}
1.5	69.77 ± 0.09^{b}	$0.51 + 0.02^{c}$	$1.56 + 0.02^{c}$

Means in the same column with different superscript letters are significantly different ($P \leq 0.05$).

contained in the soaking liquid increased the moisture content of the meat by up to 4.6% into the cooked dice broiler meat. This meat containing 0.54% of P_2O_5 had the same moisture as the broiler meat that was tumbling for 40 min with about half the number of cracked dices found. The STPP held the fiber of the meat together and reduced the number of cracked dices. The STPP improved the water holding capacity of myosin and prevented denaturation of protein (Deman and Melnychyn 1971).

An increase in TGase in the soaking liquid also increased the moisture content in the broiler meat dice (Table 5). Not only did the TGase increased the moisture content of the dices, but it also decreased the number of cracked dices (Table 6). It was reported that the enzyme created a cross-link between lysine and glutamine in the meat, which bonded molecules of protein in the meat (Motoki and Kumazawa 2000). Motoki and Seguro (1998) reported that TGase bonded small pieces of meat together and provided the same texture as that obtained by using phosphate salts.

The 1.0 and 1.5% TGase had the same number of cracked dices and characteristic of the cracks. The cracked broiler breast meat soaked with TGase had smaller cracks when compared with untreated meat. Losses of weight from freezing and thawing were also less than the untreated and phosphate-treated meat. This indicated that the TGase prevented freezing damage in the meat products.

CONCLUSION

Fast freezing rate caused cracking in cooked diced broiler breast. Faster freezing rate provided wider gap and longer cracking line. The increased

TABLE 6.
NUMBER AND CRACKING CHARACTERISTICS OF BROILER BREAST DICES TREATED WITH TRANSGLUTAMINASE (TGase) AND FROZEN UNDER CRYOGENIC CONDITION AT −70C

Number of sides that cracked	Width of the gap (mm)	Number of cracked dice (%) TGase (%)			
		0	0.5	1.0	1.5
One side	0.01–0.50	7.50 ± 1.67	3.33 ± 0.00	7.50 ± 1.67	7.50 ± 1.67
	0.51–1.00	9.17 ± 1.67	7.50 ± 1.67	5.00 ± 1.93	5.00 ± 1.93
Two sides	0.01–0.50	7.50 ± 1.67	3.33 ± 0.00	4.17 ± 1.67	4.17 ± 1.67
	0.51–1.00	8.34 ± 1.92	5.00 ± 1.93	5.84 ± 1.67	4.17 ± 1.67
Three sides	0.51–1.00	7.50 ± 1.67			
	1.01–1.50	5.00 ± 1.93	5.84 ± 1.67		
Total number of cracked dices		$47.50^{a} \pm 1.67$	$25.84^{b} \pm 1.67$	$21.67^{c} \pm 1.92$	$20.83^{c} \pm 1.67$

Means with different superscript letters are significantly different ($P \leq 0.05$).

moisture in the meat also increased the number of cracked dices. Addition of STPP into the soaking liquid reduces the number of cracked dices. The high amount of STPP in the soaking liquid increased the moisture of meat, which also increased the number of damaged dices. TGase also increased the moisture content in the meat. The high amount of TGase, however, reduced the number of damaged dices.

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