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Effect of Thawing Process on the Quality of Chicken Thigh Meat

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ABSTRACT

Frozen meat handling, especially during the thawing stage, can affect meat quality and influence the final product. This study aimed to evaluate the effects of thawing method and duration on the quality of frozen and steamed chicken thigh meat. The experiment was arranged in a completely randomized design with two replications. The thawing methods included room temperature (4, 5, 6 h), blast thawing (75, 105, 135 min), and cold temperature (18, 21, 24 h). The observations included drip loss, total plate count (TPC), total free fatty acids (FFA), and soluble protein content. The effect of thawing on steamed meat quality was evaluated for the texture, protein content, fat content, and hedonic scores. The data were statistically analyzed using one-way ANOVA test continued by independent sample t-test. The results showed that thawing duration within the same method did not significantly affect drip loss or TPC, but longer thawing times increased FFA across all methods. Prolonged thawing at room and cold temperature significantly reduced soluble protein content. Thawing at cold temperature for 18 h was the most effective with the lowest drip loss (1.12%) and the highest soluble protein content (34.4 mg/g). Results of steamed meat analysis showed significant differences in texture and fat content between thawed and fresh meat, but no significant differences was observed in protein content or hedonic scores.

1. INTRODUCTION

Chicken meat is one of the most widely consumed animal protein sources in Indonesia. Based on data from the Central Statistics Agency, the highest average per capita meat consumption per week for districts/cities in Indonesia in 2023 is chicken meat (broiler and free-range) reaching 0.134 kg, while for beef it is 0.006 kg, and goat meat 0.0003 kg (BPS, 2023). Chicken meat is the main choice because the price is relatively cheaper than red meat, easy to obtain, abundant supply, and ease of processing preparation (Augustynska-Prejsnar *et al*., 2019). Meat that goes through a long process from slaughter to carcass to processing is susceptible to contamination which can reduce its quality (Aini & Pranoto 2021; Muttalib *et al*., 2025). Meat is also categorized as a perishable food and has a relatively short shelf life (Dewi *et al*., 2016).

Freezing is one of the handling methods to maintain meat quality. The principle of freezing is to reduce the temperature of the product to below freezing point with the aim of inhibiting the growth of microorganisms, slowing down enzyme activity and food chemical reactions (BPOM, 2021). Chicken meat, which can only last for 9 hours at room temperature, can have a longer shelf life at a freezing temperature of -18 °C, between 7 and 18 months (Edi & Rahmah, 2018; Kaewthong *et al*., 2019). Before processing frozen chicken meat, a stage of melting ice crystals, which is called thawing, is required. The aim of thawing is to restore the properties of the meat to a condition that resembles fresh meat (Augustynska-Prejsnar *et al*., 2019). The thawing can reduce meat quality due to microbial growth during the process, melting of ice crystals formed in extracellular tissue, protein denaturation, and oxidation of fats and proteins which affect meat texture and protein functionality (Oliveira *et al*., 2015; Augustynska-Prejsnar *et al*., 2019).

Research examining thawing methods on meat quality was conducted by Xia *et al*. (2012) on frozen pork longissium muscle sections using the refrigerator thawing method (4 °C), room temperature (20 °C), water immersion (14 °C), running water (9 °C), and microwave which showed that all methods caused protein and fat oxidation but the lowest refrigerator thawing caused a loss of quality and the physicochemical characteristics were closest to fresh pork. Other research on chicken meat from upper thighs, wings, breasts and lower thighs shows that thawing has a significant impact on water content, pH, cooking loss, water holding capacity and drip loss. Thawing at low temperatures can minimize changes in quality of chicken pieces, while thawing at higher temperatures in the oven has a negative influence on meat quality (Jemziya & Rifath, 2022). The effect of thawing on the final product in the form of chicken steak from the meat of rejected laying hens shows that the levels of protein, soluble protein and fat decrease as the thawing temperature increases so that the best treatment is thawing by soaking in water at a temperature of 20 °C (Mardhika *et al*., 2020).

The thawing methods that are often used are cold temperature and room temperature (Benli, 2016). Several industries that have blast equipment with thawing features also use these devices for thawing frozen meat. Determining the duration of thawing is usually done with inaccurate time estimates, resulting in the potential for the thawing process to take an excessive amount of time. There are still limited studies that directly compare the effect of different thawing methods and duration, especially room temperature, cold temperature and thawing blast methods on the quality of frozen chicken thigh meat, so it is necessary to conduct a study on this matter. The aim of this research was to: (1) evaluate the effect of thawing methods (room temperature 28 ± 2 °C, thawing blast 28 ± 3 °C, and cold temperature 3 ± 2 °C) and variations in duration on the physical (drip loss), chemical (total free fatty acid and soluble protein content), and microbiological (TPC) quality of frozen chicken thigh meat; (2) determine the best thawing method based on meat quality characteristics; and (3) determine the impact of the thawing method on the quality of frozen meat after being processed into steamed meat (texture, fat content, protein content, and hedonics).

2. MATERIALS AND METHODS

The research was carried out at PT XX, West Jakarta for six (6) months in 2024. TPC testing was carried out at the DKI Jakarta Veterinary Public Health Lab., FFA and soluble protein were analyzed at the PPKS (Palm Oil Research Center) Lab. (Bogor), meat texture was analyzed at the BRIN Puspiptek Serpong Lab., and fat content and protein content testing was carried out at the Saraswanti Indo Genetech Laboratory (Bogor).

2.1. Materials and Chemicals

The material included frozen chicken thigh meat obtained from PT. X, Serang which was packaged in 1 kg using polyethylene packaging. Fresh meat as a control sample to compare the quality of the thawing treatment was obtained from the market in North Meruya, West Jakarta. The fresh meat come from whole chickens, cut by the seller into boneless thighs. The marinade ingredients used to prepare steamed meat consisted of salt, sugar and pepper.

The chemicals included 0.1% buffered peptone water (BPW) solution and plate count agar (PCA) media, chloroform (Merck), ethanolic phenolphthalein 1% (Merck), NaOH solution (Merck), coomassive brilliant blue G-250, bovine serum albumin (BSA), ethanol solution (Merck), phosphoric acid solution (Merck), distilled water, hexane solvent (Fisher), solvent Concentrated H2SO4, boric acid solution (Smart Lab), hydrochloric acid solution (RCL Labscan), Sodium tetraborate decahydrate (Merck), methyl red (Merck), bromocresol green (Merck), bromothymol blue (Merck) and selenium reagent mixture (Merck).

2.2. Laboratory Tools and Equipment

The equipment involved walk-in chiller for cold temperature meat thawing process, and blast (IRINOX model ICY M, Italy) for blast thawing. Temperature and humidity was recorded using datalogger (Krisbow). Steamed chicken meat was processed using steamer (Philips HD9140) with an aluminum foil base. Laboratory equipment included incubator (IN110 Memmert), laminar air flow (Esco), bagmixer, acolyte colony counter, blender (Philips), vortex (Corning), centrifuge (Eppendorf 542R), coarse filter paper, Whatman filter paper no. 1, oven (Universal Oven Memmert),UV-VIS spectrophotometer (Thermoscientific, MultiskanGO), soxlet apparatus, fat flask, water bath (Memmert), Kjeldahl digester (Bucchi, unit K-449), distillation (Bucchi, unit K-355), scrubber (Bucchi, unit K-415), Kjeldahl tube (Bucchi), tirando auto-titrator (Metrohm), and texture analyzer TA.XT plus C.

2.3. Design of Experiment and Data Analysis

This research was prepared using a single factor Completely Randomized Design consisted of three thawing methods, namely room temperature, blast thawing, and cold temperature. Each method was run for three duration variations and each treatment was repeated 2 times. Statistical analysis was carried out to evaluate the effect of thawing method and duration on meat quality parameters. The research was carried out in five main stages, namely: (1) determining the thawing duration; (2) thawing treatment of frozen chicken thigh meat; (3) testing quality parameters of raw chicken thigh meat; (4) processing steamed chicken thigh meat; and (5) testing the quality of steamed chicken thigh meat. The experimental data were analyzed using SPSS version 29. Data from raw meat was tested using one-way ANOVA (analysis of variance) and 5% DMRT (Duncan multiple range test). Data from steamed meat was tested using the independent sample *t*-test with a *p*-value < 0.05 used as the significance limit.

2.3.1. Determination of Thawing Duration

Initial observations were carried out to determine the optimal duration for thawing frozen chicken thigh meat using three methods, namely room temperature (28±2 °C), thawing blast (28±3 °C), and cold temperature (3±2 °C). Thawing is considered complete when the meat is no longer firm upon gentle pressure and its internal temperature exceeds 0 °C (Prehatini *et al*., 2020). The results of these observations were used to determine three thawing duration time intervals per method.

2.3.2. Thawing Treatment of Frozen Chicken Thigh Meat

Frozen chicken thigh meat was then melted using a melter: (1) room temperature (28±2 °C) for 4, 5, 6 h; (2) thawing blast (28±3 °C) for 75, 105, 135 min; and (3) cold temperature (3±2 °C) for 18, 21, 24 h. Each treatment was carried out in two repetitions. Fresh meat was used as a control for comparison. Quality testing was carried out on raw meat.

2.3.3. Testing Quality Parameters of Raw Chicken Thigh Meat

After thawing, the meat was tested for four parameters: (1) drip loss: calculated from the difference in meat weight before and after thawing (Zhou & Xie, 2021); (2) Total microbes (TPC): using PCA media referring to SNI ISO 7218:2007; (3) total free fatty acids (FFA): through titration against chloroform extract from chicken thigh meat (SNI 01-3741-2002); (4) dissolved protein content: using the Bradford method with a spectrophotometer at a wavelength of 595 nm (Bradford, 1967). The results were then analyzed to determine the differences between treatments and determine the best thawing method.

2.3.4. Processing Steamed Chicken Thigh Meat

Chicken thigh meat was only processed using meat from the best thawing method. The meat was marinated using a mixture of 11 g salt, 4 g pepper and 6 g sugar for every 1 kg of meat. Well marinated meat was put in a container, covered tightly, and stored in the refrigerator for 2 h. The steamer was heated until temperature >85 °C. The meat was put in a steamer that has been lined with aluminum foil and steamed for 20 min (Riyanti & Dakhlan, 2022). The steamed meat was then tested for the texture, fat content, protein content, and sensory preferences.

2.3.5. Testing the Quality of Steamed Chicken Thigh Meat

Tests were carried out on: (1) texture: using a TA-XT plus C texture analyzer with test settings of 2 compression cycles using a 75 mm probe with a trigger force of 5 g, and speed according to Deng *et al.* (2022); (2) fat content: Soxhlet method (SNI 01-2891-1992); (3) protein content: Kjeldahl method (AOAC 2001.11, 2005); and (4) sensory test: carried out by 40 consumer panelists aged 18-55 years with a hedonic scale of 1-7 on the attributes of color, aroma, texture, taste and overall acceptability (BSN, 2006; Subakir *et al*., 2022). Analysis was carried out to compare the quality of melted steamed meat and fresh meat.

3. RESULTS AND DISCUSSION

3.1. Duration of Thawing Frozen Chicken Thigh Meat

Cold-temperature thawing required up to 18 hours to completely thaw frozen chicken thigh meat (Table 1). This result is similar to the research results of Kassem *et al.* (2024) which shows that cold temperature thawing has the longest thawing time in frozen beef. This is because the air around the meat provides low heat transfer which causes the thawing duration to take long time (Svendsen *et al*., 2022). The duration of thawing occurs faster in room temperature, which is 4 h and the blast thawing method is 75 min because both methods have a higher temperature than cold method. Based on temperature data recorded from the datalogger, the temperature during the room temperature thawing process was 28±2 ℃ and blast thawing was 28±3 ℃. Blast thawing has a shortest duration in thawing frozen meat because the continuous air circulation in the cabin causes the entire surface of the meat to be isolated with warm air (Ragnarsson & Vioarsson, 2017).

Table 1. Duration of thawing 1 kg of frozen chicken thigh meat

Thawing Method	Thawing Duration
Room temperature (28±2 ℃)	4 h
Blast thawing (28±3 ℃)	75 min
Cold temperature (3±2 ℃)	18 h

The thawing duration at room temperature uses a time interval of one hour, namely 4, 5 and 6 h. The maximum duration of thawing at room temperature is 6 h to avoid bacterial contamination in the meat within the SNI standard threshold of 1.0×10^6 CFU/g (Ristanti *et al*., 2017). The time interval for blast thawing is 30 min because the bacterial population doubles every 30 min (Ristanti *et al*., 2017; Siswantoro *et al*., 2023). For example, *Escherichia coli* divides in 20-30 min under conditions that support their growth (Pollack-Milgate *et al*., 2024). Thus, the duration for blasts thawing is varied into 75, 105, and 135 min. Generally, people melt the frozen meat in the refrigerator for 12-24 h (Benli, 2016). Therefore, cold temperature thawing is conducted for duration of 18, 21 and 24 h.

3.2. Quality of Thawed Meat

3.2.1. Quality of Meat Thawed at Room Temperature

The results in Table 2 (A–C) indicate that drip loss tended to increase with longer thawing duration at room temperature; however, the differences were not statistically significant ($p > 0.05$). Research conducted by Kassem *et al*. (2024) showed that the drip loss results of thawing 100 g of frozen beef at room temperature for 2.5 hours were 3.34 ± 0.38% and research conducted by Sujiwo *et al*. (2025) in frozen chicken breast meat at room temperature for 5 hours was 3.13 ± 0.62%. Things that need to be considered about thawing at room temperature are the risk of exposure to high temperatures, increased humidity, and nutrients from the exudate formed from the thawing process which supports microbial growth (Akhtar *et al*., 2013). The effect of the duration of thawing meat at room temperature did not make a significant difference based on statistical results, although from a thawing duration of 4 to 6 hours there was an increase in total microbes. Research conducted by Putri *et al*. (2024) showed that the total microbial yield of thawing boiler chicken meat at room temperature (27 ℃) was 4.2 log CFU/g. These results are linear with research that has been conducted with results of 4.2-4.3 log CFU/g.

The free fatty acids formed during the thawing process at room temperature were significantly different when varying the thawing duration of 6 hours (0.021%), which shows that the longer the thawing process tends to increase the total free fatty acids in meat. This is because higher temperatures during the thawing process cause the activity of several fat-breaking enzymes to increase. As a result, the longer the thawing process, the higher the free fatty acids formed and have the potential to trigger the rate of fat oxidation to increase (Wang *et al*., 2023). The dissolved protein levels during the process of thawing frozen meat at room temperature have a significant difference between the thawing duration of 4 and 6 hours, which shows that the longer the thawing process causes a decrease in the dissolved protein levels. This can be attributed to the increased drip loss that occurs during the process of thawing frozen meat at room temperature, which releases exudates containing nutrients, including protein. This accumulation of exudate shows that during the thawing process the protein loss is greater.

Table 2. Effect of thawing method and duration on drip loss, TPC, free fatty acids, and soluble protein

Thawing Method	Drip loss (%)	TPC (log CFU/g)	Free Fatty Acids (%)	Soluble Proteins (mg/g)
A (Room temperature, 4 h)	3.18 ± 0.85[def]	4.23 ± 0.04[ab]	0.015 ± 0.002[a]	27.73 ± 2.12[bc]
B (Room temperature, 5 h)	3.98 ± 1.05[ef]	4.22 ± 0.06[ab]	0.015 ± 0.000[a]	24.48 ± 0.97[ab]
C (Room temperature, 6 h)	4.37 ± 0.52[f]	4.37 ± 0.16[ab]	0.021 ± 0.001[cd]	19.65 ± 1.16[a]
D (Blast thawing, 75 min)	2.29 ± 1.53[bcde]	3.78 ± 0.59[a]	0.018 ± 0.001[b]	26.41 ± 3.24[bc]
E (Blast thawing, 105 min)	3.02 ± 0.26[cdef]	4.20 ± 0.00[ab]	0.026 ± 0.001[f]	27.29 ± 1.29[bc]
F (Blast thawing, 135 min)	3.04 + 0.90[cdef]	4.27 ± 0.05[ab]	0.022 + 0.001[de]	24.19 ± 2.81[ab]
G (Cold temperature, 18 h)	1.12 ± 0.46[ab]	4.64 ± 0.22[bc]	0.019 ± 0.002[bc]	34.48 ± 4.89[d]
H (Cold temperature, 21 h)	1.30 ± 0.34[abc]	4.81 ± 0.64[bc]	0.021 ± 0.001[cd]	24.93 ± 4.03[ab]
I (Cold temperature, 24 h)	1.58 ± 0.97[abcd]	5.23 ± 0.16[c]	0.024 ± 0.003[ef]	25.29 ± 1.58[b]
J (Control, fresh meat)	-	7.22 ± 0.02[d]	0.025 ± 0.004[f]	31.56 ± 2.81[cd]

Note: Mean values followed by different superscripts in the same column are statistically different ($p \leq 0.05$) based on DMRT test at $\alpha = 5\%$.

Thawing can cause physical damage to meat muscle tissue so that the water produced from the melting of ice crystals cannot be completely reabsorbed into the meat fibers, resulting in moisture loss and resulting in a decrease in nutritional content (Sun *et al*., 2024). In addition, the decrease in soluble protein is also caused by protein deaturation which changes the protein structure into secondary and tertiary forms, as well as by the influence of the release of cellular enzymes which increase protein degradation and oxidation due to freezing (Lee *et al*., 2022). These reactions can increase during the thawing process.

3.2.2. Quality of Meat Thawed using Blasting Method

Blast thawing method with varying durations did not show statistically significant differences in drip loss values although there was an increase with increasing time (Table 2, D-F). Very rapid thawing tends to produce smaller drip losses because it can maintain better muscle structure for water reabsorption (Eastridge & Bowker, 2011; Stafford *et al*., 2024). This is why 75 min to 135 min of thawing does not trigger a significant increase in exudate. Variations in the duration of the thawing blast thawing process resulted in the number of microbes tending to increase with a range of 3.78 to 4.27 log CFU/g but statistically, there was no real difference. This is because the exposure of meat to critical temperatures is not long, thereby limiting the growth of microbes from developing rapidly. Research conducted by Malak *et al*. (2021) showed that food stored at temperatures of 25 and 37 °C for 30, 60 and 120 minutes did not trigger a significant increase in microbes but food samples stored for 120 minutes had the highest number of microbes.

Variations in the duration given during the thawing blast thawing process showed that the total free fatty acids were significantly different between thawing durations (0.018 to 0.026%). This is because during frozen storage, lipolytic enzymes remain active while the freezing and thawing processes trigger enzyme release due to the formation of ice crystals and cell damage (Wu *et al*., 2021). Research by Park and Kim (2024) reported an increase in free fatty acid oxidation in frozen beef with increasing thawing time. The results of this research also show that the longer the thawing blast thawing process tends to increase the total free fatty acids. In addition, the sharp increase in free fatty acids at a thawing duration of 105 minutes (0.026%) followed by a decrease at 135 minutes (0.022%) was caused by the release of fatty acids along with exudates and the change of fatty acids into other compounds due to further oxidation, thereby reducing the total free fatty acid levels.

Soluble protein is an important indicator of meat quality because it is related to oxidative damage to muscle proteins, denaturation of sarcoplasmic proteins, and a decrease in water holding capacity due to increased exudates during the thawing process (Zhang *et al*., 2017). Thawing blast thawing showed that dissolved protein levels were not significantly different between variations in thawing duration with results ranging from 27.63 to 25.81 mg/g. This is in line with the exudate produced during thawing blast thawing which does not show significant differences.

3.2.3. Quality of Meat Melted using the Cold Temperature Method

The results in Table 2 (G-I) show that variations in the duration of thawing at cold temperatures do not cause the amount of drip loss to be significantly different. Research conducted by Kassem *et al*. (2024) showed drip loss results in cold thawing of 1.302% and were similar to the results of this study which ranged from 1.12 to 1.58%. The cold temperature thawing method showed that the amount of TPC was not significantly different between variations in thawing duration, although the longer the thawing duration, the amount of TPC increased with results ranging from 4.63 to 5.23 log CFU/g. Longer exposure to meat at cold temperatures has the potential to increase the number of microbes with the presence of nutrients that support microbial development. These results are strengthened by research by Kim *et al*. (2013) which states that the accumulation of exudate that comes out during the thawing process has a positive influence on the number of microbes. However, microbial growth can be suppressed so that the increase is not significant due to the low temperature thawing.

Free fatty acids formed during the cold thawing process show significant results between 18 hours (0.019%) and 24 hours (0.024%) thawing. Even at low temperatures, the activity of lipase and phospholipase enzymes in meat does not completely stop (Wu *et al*., 2021). The accumulation of enzymatic activity over a longer period of time at cold temperatures causes an increase in the levels of free fatty acids formed. This condition risks accelerating the fat oxidation process over time, which can cause the quality of raw meat to become rancid in long-term storage (Wu *et al*., 2021).

Dissolved protein during the cold temperature thawing process showed significant results between 18 hours of thawing (34.48 ± 4.89 mg/g) and 24 hours (25.29 ± 1.58 mg/g). These results show that the longer the thawing process at cold temperatures causes a decrease in soluble protein levels in the meat. This is due to the release of exudates containing nutrients during the thawing process and proteolytic degradation activities which trigger a further decrease in soluble protein levels in meat. Qi *et al*.'s research (2012) showed a decrease in soluble protein when thawing frozen lamb longissimus dorsi muscle at cold temperatures (4 °C) due to the loss of exudate during the thawing process. In addition, frozen storage at -20 °C and thawing at 4 °C causes a decrease in protein due to proteolytic activity and will further decrease during the storage process (Kominami *et al*., 2021).

3.2.4. Overall Quality of Meat from Various Thawing Methods

The results of this research show that thawing at cold temperatures for 18 to 24 hours has a smaller drip loss value compared to thawing at room temperature for 4 to 6 hours and blast thawing for 75 to 135 minutes. This result is similar to research conducted by Benli (2016) which stated that the refrigerator thawing method at a temperature of 4 °C had the smallest drip loss value compared to other thawing methods such as room temperature, warm water, microwave and running water. Meanwhile, thawing at room temperature and thawing blast results in greater drip loss when compared to cold thawing because thawing at a rapid time makes it less likely for extracellular water to be reabsorbed (Eastridge & Bowker, 2011). In addition, increasing thawing speed will increase the amount of drip loss and the water holding capacity will decrease (Ali *et al*., 2016).

The total microbial results show that the cold thawing method for 18 to 24 hours tends to have a greater number of microbes with a range of 4.64 to 5.23 log CFU/g when compared to the room temperature thawing method and blast thawing. This is because the minimum temperature still allows the growth of microorganisms (Augustynska-Prejsnar *et al*., 2024). Meanwhile, during thawing, the liquid that comes out contains nutrients from the cells, making it more susceptible to microbial growth during the long cooling storage process (Durack *et al*., 2012). Even so, the total number of microbes still falls within the quality standards for chicken carcasses and meat based on SNI 3924:2009 with a maximum limit of 1 × 106 CFU/g or 6 log CFU/g (BSN, 2009). The high number of microbes in control samples is due to the fact that along the poultry supply chain, bacteria from the air and the environment can contaminate poultry meat (Augustynska-Prejsnar *et al*., 2023). Poultry pieces that come into direct contact with air and equipment surfaces are easily contaminated (Augustynska-Prejsnar *et al*., 2023).

The effect of the thawing method on total free fatty acids shows that the room temperature thawing method tends to have smaller results compared to cold thawing. The total formation of free fatty acids tends to be greater when thawing at cold temperatures for 18 to 24 hours due to the longer thawing time and lipase and phospholipase activities that continue to run at cold temperatures (Wu *et al*., 2021). Free fatty acids are also not only caused by the activity of degradation enzymes but are also the result of microbial activity (Rahman *et al*., 2015). This also causes the control sample to have high free fatty acids which can be seen in Table 2.

The thawing treatment of frozen meat has an influence on the soluble protein content of the meat (Arshad *et al*., 2023). Table 2 shows that the soluble protein levels that are close to the control are cold thawing for 18 to 24 hours (34.48-24.93 mg/g) and thawing blast for 75 to 135 minutes (27.29-24.19 mg/g). Meanwhile, thawing using the room temperature method for 4 to 6 hours tends to have lower levels of dissolved protein. This result is due to the influence between the amount of drip loss and the amount of dissolved protein in the meat due to the release of exudate during the thawing process. The results of the Pearson correlation test show that there is a negative relationship between dissolved protein levels and drip loss values ($p \leq 0.05$; $r = -0.523$) which shows that the higher the drip loss, the lower the dissolved protein levels in the meat. These results are also strengthened by research by Kim *et al*. (2013) which stated that there was a positive correlation between the increase in the amount of exudate and the total protein content in the exudate. Freezing and thawing cause damage to the ultrastructure of muscle cells which then releases mitochondrial and lysosomal enzymes, heme iron, and other pro-oxidants which can increase the intensity and speed of protein oxidation (Akhtar *et al*., 2013). This protein oxidation affects the stability of the protein matrix which leads to loss of protein solubility (Akhtar *et al*., 2013).

Based on this data, it is known that the best thawing method is thawing at cold temperatures for 18 minutes. This can be seen from the lowest drip loss value and the highest dissolved protein content. These two test parameters were chosen as determinants of the best thawing method because they are directly related to the nutrients contained in meat, especially protein as the main nutritional component in meat (Rakhmawati *et al*., 2023). Even though the amount of TPC and total free fatty acids in cold thawing tends to be high, the results are still below the total quality limit for chicken carcass microbes and the rate of free fatty acid formation is still relatively low. Research conducted by Park & Kim (2024) also shows a similar conclusion that cold temperature thawing is the thawing with the best meat quality with the lowest TBA and thawing loss values.

3.3. Quality of Steamed Meat from Thawing at Cold Temperatures

Steamed meat was analyzed from samples that had been melted at cold temperatures for 18 hours. Steamed meat from thawing at cold temperatures has a texture that is significantly different from fresh meat for all texture attributes which can be seen in Table 3. Thawing causes an increase in hardness (2531.69 ± 325.49 g) compared to the control (729.56 ± 54.26 g). Apart from that, there is also an increase in compactness and firmness as well as a decrease in the elasticity of the meat after steaming.

Table 3. Quality of steamed meat between meat from cold thawing and fresh meat based on texture attribute parameters, protein content and fat content

Test Parameters	Steamed Meat	
	Cold Temperature Thawing	Control
Hardness (g)	2531.69 ± 325.49^{a}	729.56 ± 54.26^{b}
Springiness (mm)	0.64 ± 0.02^{a}	0.78 ± 0.03^{b}
Cohesiveness (rasio)	0.55 ± 0.04^{a}	0.43 ± 0.03^{b}
Chewiness (mJ)	743.62 ± 90.20^{a}	257.60 ± 34.03^{b}
Protein Content (%)	22.28 ± 0.24^{a}	22.15 ± 0.14^{a}
Fat Content (%)	3.44 ± 0.03^{a}	3.89 ± 0.04^{b}

Note: Mean values of each parameter followed by different superscripts are statistically different ($p \leq 0.05$) based on DMRT test at α = 5%

These results indicate that the meat becomes harder and denser and requires more effort to chew. Research conducted by Zhang & Ertbjerg (2018) shows that the activity of calpain-1, which acts to tenderize meat, decreases due to the freezing and thawing process. In addition, during the thawing process there is a loss of exudate which can affect the characteristics of the meat so that it becomes softer (Zhang & Ertbjerg, 2018). Freezing and thawing affect the texture of meat caused by irreversible changes in internal structure due to the formation of ice crystals and damage to muscle fibers (Chen *et al*., 2017).

The results for the protein content of steamed meat from cold thawing and fresh meat have results that are not significantly different which can be seen in Table 3. These results are in line with previous results which show that the soluble protein content from fresh meat and cold temperature thawing is not significantly different. Fat content shows significant differences between steamed meat from cold thawing and fresh meat. This is caused by the fat content coming out with the exudate during the thawing process and the influence of fat oxidation during the thawing process, thus affecting the fat content.

The preference test scores show that steamed meat from thawing at cold temperatures and fresh meat do not cause significantly different consumer preferences. The preference scores for texture (5.28 – 5.55), aroma (5.00 – 4.88), taste (5.65 – 5.35), and overall acceptability (5.45 – 5.33) were slightly favorable, while for the color attribute, consumer panelists chose neutral (4.45 – 4.33) for both steamed meats. Even though there are differences in instrumental texture, the results of the liking test show that these differences are still acceptable to consumers. The thawing and cooking process does influence textural characteristics such as juiciness and hardness but does not significantly change the overall sensory perception (Zhang *et al*., 2020; Sujiwo *et al*., 2025). This can be caused by the use of consumer panelists who are not trained in hedonic tests. Research by Sujiwo *et al*. (2025) also showed that the sensory characteristics of local Korean chicken breast meat that had been frozen and thawed had similar sensory results to fresh meat because consumer panelists were less able to differentiate which was influenced by the level of training and exposure to the sample.

4. CONCLUSION

Variations in thawing duration across the three thawing methods significantly affected total free fatty acid levels in chicken meat. In both room-temperature and cold thawing methods, prolonged thawing was associated with a significant decrease in soluble protein content. Cold thawing for 18 hours resulted in lower drip loss and higher soluble protein retention compared to other thawing treatments. In contrast, room-temperature thawing produced higher drip loss and reduced soluble protein retention. Processing frozen chicken thigh meat into steamed meat after cold thawing (18 h) significantly affected texture parameters (hardness, springiness, cohesiveness, and chewiness) as well as fat content. However, protein content was not significantly different from the control. Despite instrumental changes in texture, consumer preference based on hedonic evaluation (texture, color, aroma, taste, and overall acceptance) was not significantly affected. These findings indicate that cold thawing for 18 hours is a more suitable method for maintaining the physicochemical quality of frozen chicken meat without negatively affecting consumer acceptance. The results provide practical implications for improving thawing practices in both household and small-scale food industry applications.

AUTHOR CONTRIBUTION STATEMENT

Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
ARS	✓	✓	✓		✓	✓			✓		✓		✓	✓
WPR	✓	✓		✓		✓		✓		✓		✓		
UH	✓	✓		✓		✓		✓		✓		✓		

C: Conceptualization	Fo: Formal Analysis	O: Writing - Original Draft	Fu: Funding Acquisition
M: Methodology	I: Investigation	E: Writing - Review & Editing	P: Project Administration
So: Software	D: Data Curation	Vi: Visualization	
Va: Validation	R: Resources	Su: Supervision	

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