Sous-vide cooking as a practical strategy to improve quality attributes and shelf stability of reduced-salt chicken breast ham

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ABSTRACT The objective of this study was to evaluate the general quality attributes and shelf stability of reduced-salt and sous-vide cooked chicken breast hams during 4 weeks of refrigerated storage (4°C). Four treatment groups of chicken breast ham were prepared using a 2 (salt level, 1.5% NaCl (regular) and 0.75% (reduced)) × 2 (cooking method, conventional and sous-vide) factorial arrangement. Based on each chicken breast weight, 20% NaCl solution was injected. Conventional cooking was done at 80°C until the core temperature reached 71°C, whereas sous-vide cooking was conducted at 60°C for 2 h. Sous-vide cooking could decrease cooking loss and shear force of reduced-salt chicken breast ham ($P < 0.05$). As a result, sensory scores for juiciness and tenderness of reduced-salt and sous-vide cooked chicken breast ham were similar to those of regular-salt and conventionally cooked chicken breast hams ($P > 0.05$). No adverse impacts on lipid oxidation and microbial safety were found in reduced-salt and sous-vide cooked chicken breast ham during 4 wk of refrigerated storage. Therefore, this study suggests that sous-vide cooking could be a practical thermal process for improving the water-holding capacity and texture of chicken breast ham without adverse impacts on shelf stability. Further studies on the combined application of sous-vide cooking with salt replacers would be warranted to improve the sensorial acceptance of saltiness of sous-vide cooked low-salt meat products.

Key words: chicken breast ham, lipid oxidation, low-salt, shelf life, sous-vide cooking

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INTRODUCTION

Healthiness is one of the preferential concepts in developing meat products that fulfill the needs of modern consumers (Badar et al., 2021). In this regard, various strategies in the manufacturing process, including meat species selection, replacement or minimization of potentially harmful food additives with natural ingredients, and consumer-friendly processing procedures, have been considered. For example, the steady increase in global chicken consumption of nearly 15% over the last decade can clearly show the importance of raw meat selection for healthy meat products (Peña-Saldarriaga et al., 2020). Moreover, reducing potentially harmful food additives, such as sodium chloride, nitrites/nitrates, phosphates, and synthetic preservatives, has become common in processed meat products (Shan et al., 2017). From this perspective, health-conscious consumers prefer low-salt and -fat meat products due to their lower sodium, saturated fatty acids, and calorie contents.

A chicken breast has a dry and crumbling texture (Park et al., 2020), which is usually processed for manufacturing restructured chicken meat products (e.g., sausage, nugget, and patty). Recently, however, low-salt chicken breast ham consumption for protein intake has been increasing despite low satisfaction (Gullón et al., 2021). In practice, 1.0 to 1.6% sodium chloride (NaCl) is added to produce desirable quality attributes of processed meat products, such as water-holding capacity, myofibrillar protein extraction, flavor and taste, and microorganism growth (Petracci et al., 2013; Inguglia et al., 2017). Thus, it has been well-documented that a decrease in NaCl addition for sodium reduction could cause quality defects in water-holding capacity, texture, sensory satisfaction, and microbiological safety (Desmond, 2006). Therefore, improving water-holding capacity and texture would be fundamentally preceded in producing the acceptable quality characteristics of low-salt chicken breast ham.

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Sous-vide is a cooking method to heat vacuum-packaged food ingredients at relatively low temperatures for a long time. In particular, it has been reported that sous-vide cooking could improve the water-holding capacity, tenderness, and sensory properties (e.g., flavor, taste) of meat products without adversely impacting microbial safety (Przybylski et al., 2021). In this regard, previous studies have attempted to improve the quality attributes of chicken breasts using sous-vide cooking, which could make the cooked chicken breast redder, juicier, and tender than conventionally cooked chicken breast (Park et al., 2020; Przybylski et al., 2021). The positive efficacies of sous-vide cooking are dependent on applied time, temperature, and vacuum pressure (Baldwin, 2012). A recent study has found that sous-vide cooking at 60°C for 2 to 3 h could be an optimal condition for improving the sensory properties of cooked chicken breast (Park et al., 2020).

As mentioned above, salt level (usually NaCl concentration) is the most critical factor affecting the quality characteristics of processed meat products. However, most previous studies about the efficacies of sous-vide cooking have focused on its culinary effectiveness on unsalted chicken breast. Thus, there has been little to no information on the effect of salting level on the quality characteristics of sous-vide cooked chicken breast. Regarding the quality defects of chicken ham products with salt reduction, sous-vide cooking is expected to be one of the consumer-friendly technologies to improve the water-holding capacity and texture of low-salt meat products. Moreover, sous-vide cooking has a comparable impact on microbial safety to conventional cooking due to a relatively longer heating time (Joung et al., 2018). Therefore, this study evaluated the general quality attributes and shelf stability of reduced-salt and sous-vide cooked chicken breast hams during four weeks of refrigerated storage.

MATERIALS AND METHODS

Experimental Design

An experimental design used in this study was a completely randomized block design with a 2 (salt level, 1.5% NaCl (regular) and 0.75% (reduced)) × 2 (cooking method, conventional and sous-vide) arrangement with 3 independent replications.

Sample Preparation

Chicken breasts (*M. pectoralis major*, 132.96 ± 9.42 g) of commercial broilers, which passed 48 h after slaughter, were purchased from a local market. Sodium chloride (food-grade, 99.9%, Hanju, Ulsan, Korea) was also purchased from a local market. All chemicals used were analytical grade.

Each 4.5 g and 9.0 g of sodium chloride was dissolved in 100 mL of distilled water to prepare 2 different levels of salt brine (4.5% and 9.0%, w/v). The prepared salt brines were stored in a 4°C refrigerator until use.

The weight of each chicken breast (n = 48) was recorded and randomly assigned into four groups (12 breasts per treatment); 1.5% NaCl and conventionally cooked group, 1.5% NaCl and sous-vide cooked group, 0.75% NaCl and conventionally cooked group, and 0.75% NaCl and sous-vide cooked group. For each treatment, the salt brines (equivalent to 20% (v/w) pump above each recorded breast weight) were injected into each chicken breast, and the salted chicken breasts were individually vacuum packaged in a nylon/polyethylene (PA/PE) package and stored in a 4°C refrigerator for 24 h. After the overnight storage, each treatment group was thermally processed under two conditions; conventional and sous-vide cooking. Conventional cooking was performed in an 80°C water bath equipped with a circulator until the internal temperature reached 71°C. The time for conventional cooking was approximately 15 min. Sous-vide cooking was done in a 60°C water bath for 2 h, which was suggested as an optimal condition for chicken breast (Park et al., 2020). The internal temperature of chicken breasts, where the geometric center in the upper part of cooked chicken breasts had a thickness of over 1 cm, was monitored by inserting a constant iron thermocouple of a digital thermometer equipped with a data logger (Tes-1384, Tes Electrical Electronic Co., Taipei, Taiwan). After heating, cooked chicken breast hams were cooled using running water for 30 min and removed from the package. The chicken breasts were weighed for cooking loss measurement and randomly assigned for further analysis. The samples used for shelf stability analysis were individually vacuum packaged in a PA/PE bag and stored in a 4°C refrigerator for 4 weeks. Lipid oxidation and total plate count were analyzed weekly.

Physicochemical and Sensory Analysis

pH Measurement The pH value of cooked chicken breasts was determined in triplicate using an insert-type pH meter (HI99163, Hanna instruments, RI).

Proximate Composition and Sodium Content The moisture (oven air-drying method), lipid (Soxhlet extraction), and ash (muffle furnace) content of the cooked chicken breast hams were analyzed using the AOAC method (AOAC, 2000). The protein content was analyzed using the high-temperature combustion process according to the Dumas combustion method (Leco, St. Joseph, MI). The analyses were conducted in triplicate.

The sodium content of chicken breast hams was analyzed in duplicate (Song et al., 2020a). The sample (0.5 g) was decomposed by adding 4 mL of 70% (v/v) nitric acid and heated at 180°C for 30 min using a high-pressure heater (Ultrawave Microwave Synthesis Systems, Milestone Inc., Tokyo, Japan). The sample was diluted with distilled deionized demineralized water to 50 mL of final volume and filtered with a 0.45 μm hydrophilic teflon filter. The filtrate was expressed as g/100g by quantifying the sodium content using an inductively coupled plasma spectrophotometer (ICP-OES, Perkin Elmer, Waltham, MA).

Instrumental Color Instrumental color characteristics of cooked chicken breasts were measured using a colorimeter (CR-400, Minolta, Osaka, Japan) equipped with an 8 mm diameter aperture with a 2° standard observer. According to the manufacturer's manual, calibration was done using a white tile (CIE L*: +93.01, CIE a*: −0.25, CIE b*: +3.50) under a D_{65} illumination source. After cooking was done, the chicken breast samples were removed from the vacuum package and placed at room temperature for 1 h for cooling and blooming. The color measurement was performed once at the cooked samples. CIE L*, a*, and b* values were recorded from six random locations on a skin-side surface. The obtained data of CIE L*, a*, and b* values were used for calculating color parameters such as hue angle, chroma, and delta E using the following equations, respectively (AMSA, 2012). In delta E, total color change between raw and cooked samples was considered.

$$\text{Hue angle} = \text{arctangent}\ (b*/a*)$$

$$\text{Chroma} = \sqrt{a*^2 + b*^2}$$

$$\text{Delta E} = \sqrt{(\Delta L*)^2 + (\Delta a*)^2 + (\Delta b*)^2}$$

Where, $\Delta L^* = L^*_{cooked} - L^*_{raw}$; $\Delta a^* = a^*_{cooked} - a^*_{raw}$; $\Delta b^* = b^*_{cooked} - b^*_{raw.}$

Cooking Yield The cooking yield of cooked chicken breasts was determined using a percentage of cooked sample weight against raw sample weight. Before weighing the cooked sample, the moisture on the sample surface was blotted using paper towels.

Shear Force Cooked samples for shear force measurement were prepared according to the method of Kim et al. (2012). Briefly, six strips of rectangular parallel-piped shape (length × width × height, 4.0 × 1.0 × 1.0 cm^3) were taken from the upper part of cooked chicken breasts that had a thickness of over 1 cm. Each strip was sheared using a Warner−Bratzler device (V-blade) on a texture analyzer (CT3, Brookfield Engineering Laboratories, INC. Middleboro, MA). Test speeds were set at 2 mm/s, and the peak shear force (kg) of six strips per breast was recorded and averaged (Kim et al. 2018).

Sodium Dodecyl Sulphate Polyacrylamide gel Electrophoresis (SDS-PAGE) SDS-PAGE was performed to determine the effect of sous-vide cooking on the protein pattern of cooked chicken breast ham, according to the method of Laemmli (1970). The protein fraction was extracted and diluted to have a protein concentration of 4 mg/mL. The sample was mixed with buffer (5 × Laemmli buffer, Elpis, Deajeon, Korea) at a ratio of 4:1 and heated for 5 min in a heating block. Fifteen microliters of the protein sample were loaded into 4% stacking gel and 12% separating gel at 100 V for 90 min. After electrophoresis, the gel was stained using a staining solution (0.25% (w/v) Coomassie blue R-250, 50% (v/v) methanol, 40% (v/v) distilled water, 10% (v/v) acetic acid) and then de-stained. A standard protein marker (Dokdo-mark EBM-1032, Elpis, Deajeon, Korea) was used.

Sensory Evaluation Sensory evaluation of cooked chicken breast hams was performed according to the procedure and method of quantitative descriptive analysis (QDA) described by Michalczuk et al. (2018) with minor modification. The cooked chicken breast hams were cut into strips (approximately 4 × 1 × 1 cm^3), and the samples were placed in plastic containers and placed in a 45°C incubator until served to sensory panels. Seven trained panels, three men and four women between 22 and 36 y of age had at least 3 times of pre-sessions to acquaint them with sample characteristics and lexicon for sensory evaluation. In training sessions, the samples were randomly provided, and the panels reviewed and discussed the mentioned attributes of the samples (Franke et al., 2017). A continuous nonstructured 10-cm length scale was used with the left and right ends for the lowest intensity, and the highest intensity, respectively, and detailed information on lexicon and boundary determinants used were as follows; whiteness (no need to define, dark gray—light cream), chicken flavor (aroma characteristic for roasted chicken breast, weak intensity—strong intensity), chicken taste (taste characteristic for cooked chicken breast, weak intensity—strong intensity), saltiness (salt perception during chewing, weak intensity—strong intensity), juiciness (the impression of meat juice during chewing, dry—juicy), tenderness (degree of tenderness, the resistance of the sample during mastication, tough—tender).

Shelf Stability

Lipid Oxidation Lipid oxidation of cooked chicken breast ham was weekly determined for 4 wk according to the 2-thiobarbituric reactive substances (**TBARS**) method of Buege and Aust (1978) as described by Kim et al. (2016). TBARS value was expressed as milligram of malondialdehyde per kilogram of meat (mg MDA/kg meat).

Microbial Properties (Total Plate Count and Salmonella spp.) For total plate count, a sample (10 g) was blended with 9 volumes of phosphate-buffered saline solution (PBS, pH 7.4), cultured in plate count agar medium, and incubated at 37°C for 24 h. For *Salmonella* spp., a sample was blended with 90 mL of buffered peptone water (Oxoid Ltd., Basingstoke, United Kingdom) and incubated at 37°C for 24 h. One hundred microliters of the cultured solution were mixed with 10 mL of Rappaport-Vassiliadis (**RV**) enrichment broth (Oxoid Ltd., Basingstoke, United Kingdom) and incubated at 42°C for 24 h. Then, one hundred microliters of the cultured medium were cultured in Xylose Lysine Desoxycholate Agar medium (XLD, Oxoid Ltd., Basingstoke, United Kingdom) at 37°C for 24 h. The number of microorganisms was expressed as log CFU/g.

Statistical Analysis

The experimental design of this study was a 2 (salt level) × 2 (cooking method) factorial with 3 independent replicates. Initially, 2-way ANOVA procedure of the SPSS 18.0 software (SPSS Inc., Chicago, IL) was performed for general quality attributes (pH, proximate composition, sodium content, instrumental color, cooking yield, shear force, and sensory properties), including the effects of salt level, cooking method, and their interaction. As a result, except for shear force, the significant interaction was found. Thus, the data of general quality attributes were statistically analyzed using the general linear model (B) procedure of the SPSS software, in which treatment was fixed as the main effect. For data of lipid oxidation and microbial properties, the GLM procedure with treatment effect, storage effect, and their interaction were considered. Duncan's multiple range test was used to compare the mean values ($P < 0.05$).

RESULTS AND DISCUSSION

Chemical Composition

The chemical composition of reduced-salt and sous-vide cooked chicken breast hams is shown in Table 1. The pH value of cooked chicken breast hams was unaffected by salt reduction and sous-vide cooking ($P > 0.05$). Similarly, Jeong (2017) previously noted that salt levels (0−3%) did not influence the pH value of cooked chicken breasts. Park et al. (2020) reported that the sous-vide cooked chicken breast at 60°C for 2 h resulted in an equivalent pH value to the oven-cooked chicken breast (71°C of core temperature). Our result was in agreement with the previous observations on the pH changes due to salt reduction and sous-vide cooking.

Significant differences in moisture, protein and ash contents between cooked chicken breast hams were found, but all treatments (0.68−0.78 g/100 g) presented similar fat content ($P > 0.05$). At each salt level, sous-vide cooking significantly increased the moisture content of cooked chicken breast hams compared to conventional cooking. Numerous previous studies have reported that sous-vide cooking could increase the moisture content of chicken breast, causing a reduction in cooking loss (Jeong et al., 2018; Park et al., 2020; Haghighi et al., 2021). Underlying mechanisms for reducing cooking loss in sous-vide cooked meat will be discussed in the cooking loss section. The lowest protein content was observed for 1.5% NaCl and sous-vide cooked chicken breast ham ($P < 0.05$). This result was likely due to a relative decrease in the protein content as the moisture content increased.

The ash content of reduced-salt (0.75% NaCl) chicken breast hams (1.83−1.89 g/100 g) was significantly lower compared to 1.5% NaCl chicken breast hams (2.65−2.72 g/100 g). As expected, sodium content also presented similar trend, and 0.75% NaCl chicken breast hams (0.39−0.40 g/100 g) had approximately 47% of decreased sodium content compared to 1.5% NaCl chicken breast hams (0.75−0.76 g/100 g) ($P < 0.05$). The decreased ash and sodium contents could be attributed to a 50% reduction of NaCl in the formula of 0.75% NaCl chicken breast hams. Consequently, our results also confirmed that sous-vide cooking could positively affect on moisture improvement in cooked chicken breast hams, including reduced-salt level.

Color Characteristics

Color characteristics of reduced-salt and sous-vide cooked chicken breast ham are shown in Table 2. Color parameters such as CIE L* (lightness), CIE a* (redness), CIE b* (yellowness), hue angle (discoloration), chroma (color saturation), and delta E (total color difference) were evaluated, a significant difference between treatments was observed for only lightness. The lowest lightness was found at 1.5% NaCl and sous-vide cooked chicken breast ham ($P < 0.05$), but there was no significant difference in lightness between other treatments. This result could be attributed to the decreased lighter scattering on the surface due to the improvement in water-holding capacity.

Previous studies have generally reported that sous-vide cooking could inhibit the thermal denaturation of myoglobin due to relatively lower heating temperature, which could, in turn, allow the sous-vide cooked meat to have intense reddish color (Jeong et al., 2018). This phenomenon has also been reported in sous-vide cooked chicken breasts (Park et al., 2020; Haghighi et al., 2021). Park et al. (2020) reported that sous-vide cooking at 60°C for 2 h increased the redness of the chicken breast. Haghighi et al. (2021) noted that increases in temperature (60−100°C) and time (60−150 min) led to a

Table 1. Chemical composition of reduced-salt and sous-vide cooked chicken breast ham.

	Regular-salt (1.5% NaCl)		Reduced-salt (0.75% NaCl)		
Trait	Conventional cooking[1]	Sous-vide cooking	Conventional cooking	Sous-vide cooking	Significance of P value
pH (cooked)	5.82 ± 0.10	5.89 ± 0.04	5.91 ± 0.12	5.83 ± 0.10	0.201
Proximate composition (g/100 g)					
Moisture	73.17 ± 0.08[b]	74.40 ± 0.23[a]	72.74 ± 0.18[b]	74.31 ± 0.48[a]	<0.001
Protein	23.36 ± 0.15[b]	21.99 ± 0.46[c]	24.32 ± 0.60[a]	23.09 ± 0.22[b]	0.001
Fat	0.69 ± 0.07	0.68 ± 0.14	0.70 ± 0.16	0.78 ± 0.12	0.563
Ash	2.72 ± 0.07[a]	2.65 ± 0.14[a]	1.89 ± 0.01[b]	1.83 ± 0.02[b]	<0.001
Sodium (mg/100 g)	760 ± 2.0[a]	750 ± 4.0[a]	400 ± 3.0[b]	390 ± 10.0[b]	<0.001

[1]Conventional cooking was done at 80°C until the core temperature reached 71°C, whereas sous-vide cooking was conducted at 60°C for 2 h.
[a–c]Means sharing the same letters within a row are not significantly different ($P \geq 0.05$).

Table 2. Color characteristics of reduced-salt and sous-vide cooked chicken breast ham.

Trait	Regular-salt (1.5% NaCl)		Reduced-salt (0.75% NaCl)		Significance of P value
	Conventional cooking[1]	Sous-vide cooking	Conventional cooking	Sous-vide cooking	
CIE L* (lightness)	80.76 ± 0.89[a]	78.42 ± 1.07[b]	82.13 ± 0.63[a]	81.37 ± 1.81[a]	0.024
CIE a* (redness)	2.52 ± 1.84	2.99 ± 0.74	3.05 ± 0.16	3.40 ± 0.31	0.804
CIE b* (yellowness)	11.60 ± 2.22	10.66 ± 0.49	11.85 ± 1.23	11.99 ± 0.91	0.513
Hue angle	77.42 ± 3.07	74.44 ± 2.96	75.52 ± 0.73	74.18 ± 0.58	0.649
Chroma	11.89 ± 2.13	11.08 ± 0.67	12.24 ± 1.23	12.47 ± 0.95	0.348
Delta E	30.00 ± 2.77	28.99 ± 4.12	31.24 ± 5.73	28.55 ± 4.70	0.085

[1]Conventional cooking was done at 80°C until the core temperature reached 71°C, whereas sous-vide cooking was conducted at 60°C for 2 h.
[a,b]Means sharing the same letters within a row are not significantly different ($P \geq 0.05$).

decrease in the redness of sous-vide cooked chicken breasts.

Contrary to the previous observation, our result shows no increase in the redness of sous-vide cooked chicken breast hams. According to Park et al. (2020), the high proportion of deoxymyoglobin under vacuum conditions, which is a more stable form of myoglobin compared to oxy and metmyoglobin, could be related to the increased redness of sous-vide cooked chicken breast. However, it has been well known that the adding sodium chloride is one of the factors accelerating the oxidation of biological molecules in meat products (Ladikos and Lougovois, 1990). Chen et al. (1992) have found that an increase in sodium chloride concentration (0−1.5%) could accelerate myoglobin oxidation, causing metmyoglobin formation. Unlike the unsalted condition of previous studies, thus, the sodium chloride salting process performed in this study might be one of the reasons affecting the color change in sous-vide cooked chicken breast. Thus, the result of this study shows that the salt level could affect the color change of sous-vide cooked chicken breast ham.

Cooking Loss

The cooking loss of reduced-salt and sous-vide cooked chicken breast ham is shown in Figure 1. A reduction in salt level resulted in a noticeable increase in cooking loss, but sous-vide cooking noticeably reduced the cooking loss of reduced-salt (0.75% NaCl) chicken breast ham ($P < 0.05$). Noticeably, 0.75% NaCl and sous-vide cooked chicken breast ham showed comparable cooking loss with 1.5% NaCl and conventionally cooked chicken breast ham ($P > 0.05$). Similarly, Park et al. (2020) reported that sous-vide cooking at 60°C for 2 h caused 11.7% cooking loss in chicken breast. Haghighi et al. (2021) also noted similar results, in which the sous-vide cooking at 60°C for 2 h resulted in 12.42% of the cooking loss. In this study, the cooking loss of

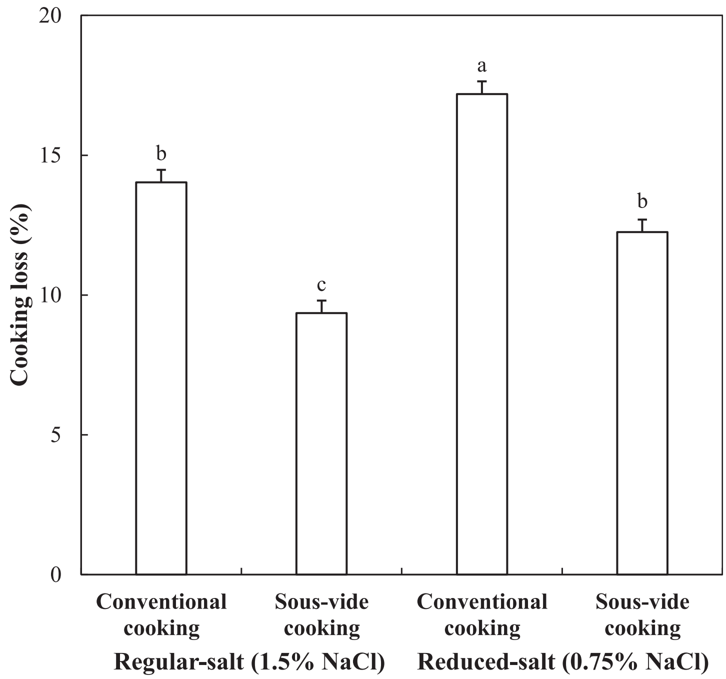

Figure 1. Cooking loss of reduced-salt and sous-vide cooked chicken breast ham. Error bar means standard deviation. Conventional cooking was done at 80°C until the core temperature reached 71°C, whereas sous-vide cooking was conducted at 60°C for 2 h. a−c Means sharing the same letters are not significantly different ($P \geq 0.05$).

regular- and reduced-salt sous-vide cooked chicken breast hams were 9.35% and 12.25%, respectively, which was similar to the previous observation.

In previous studies, the improvement impact of sous-vide cooking on the water-holding capacity of meat products has been understood as follows; 1) a decrease in water evaporation by the barrier action of vacuum package, 2) a reduction of thermal denaturation of muscle protein due to relatively low temperatures (Puolanne & Halonen, 2010; Ayub and Ahmad, 2019; Haghighi et al., 2021), and 3) the prevention of thermal shrinkage of connective tissues consisting of perimysium (Tornberg, 2005; Jeong et al., 2018).

In the development of low-salt meat products, the improvement of water-holding capacity is the most critical strategy because the decline of water-holding capacity could negatively impact cooking yield, texture, and sensory acceptance (Inguglia et al., 2017). To improve the water-holding capacity of low-salt meat products, thus, consumer-friendly processing techniques known to be harmless, such as high pressure, ultrasound, and hot-processing, have been multiply considered in the meat processing industry (Inguglia et al., 2017; Song et al., 2020b). In addition, our result indicates that sous-vide cooking could be a promising technique for improving the water-holding capacity of low-salt meat products.

Shear Force

The shear force of reduced-salt and sous-vide cooked chicken breast ham is shown in Figure 2. A salt reduction and sous-vide cooking significantly decreased shear force of chicken breast ham, and the lowest shear force was observed for 0.75% NaCl and sous-vide cooked chicken breast ham ($P < 0.05$). Similarly, Jeong et al. (2018) have suggested that decreased shear force of sous-vide cooked pork ham could be associated with the high moisture content, which was also in agreement with our results.

In general, cooking temperature and time cause considerable change in shear force of cooked meat, which is associated with the thermal denaturation of muscle proteins and the activation of endogenous proteases (Baldwin, 2012). In particular, the longitudinal shrinkage of myofibrillar proteins increases shear force at around 40−60°C (Baldwin, 2012). Nevertheless, the gelatinization of collagen in the connective tissue around 53−63°C at a slow heating rate has been known to decrease shear force (Purslow, 2018). The temperature range of sous-vide cooking is typically recognized as 55−80°C (Park et al., 2020), in which an increase in cooking temperature can increase the shear force of cooked meat (Chumngoen et al., 2016). Therefore, low temperature cooking around 50 to 60°C can minimize the increase in the shear force of cooked meat since the denaturation of myofibrils and the shrinkage of collagen can occur partially (Christensen et al., 2000). Moreover, 65 °C of cooking temperature can reduce shear force of cooked meat, which could be related to the improvement of collagen solubility (Zhang and Wang, 2012). According to Gao et al. 2003, a slow heating rate at low temperature could require more time to dissociate the structure of muscle proteins and to interact with the protein molecules,

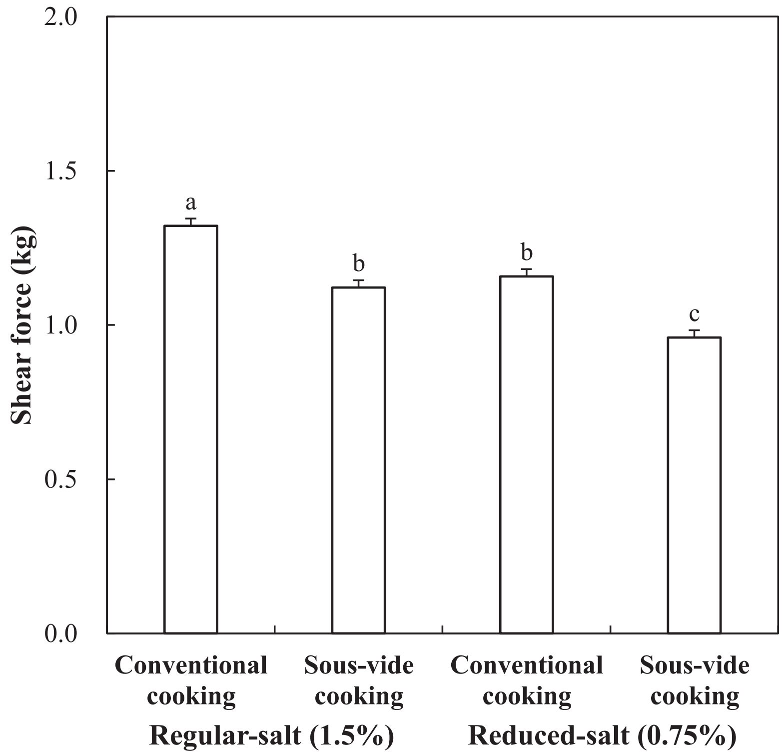

Figure 2. Shear force of reduced-salt and sous-vide cooked chicken breast ham. Error bar means standard deviation. Conventional cooking was done at 80°C until the core temperature reached 71°C, whereas sous-vide cooking was conducted at 60°C for 2 h. a−c Means sharing the same letters are not significantly different ($P \geq 0.05$).

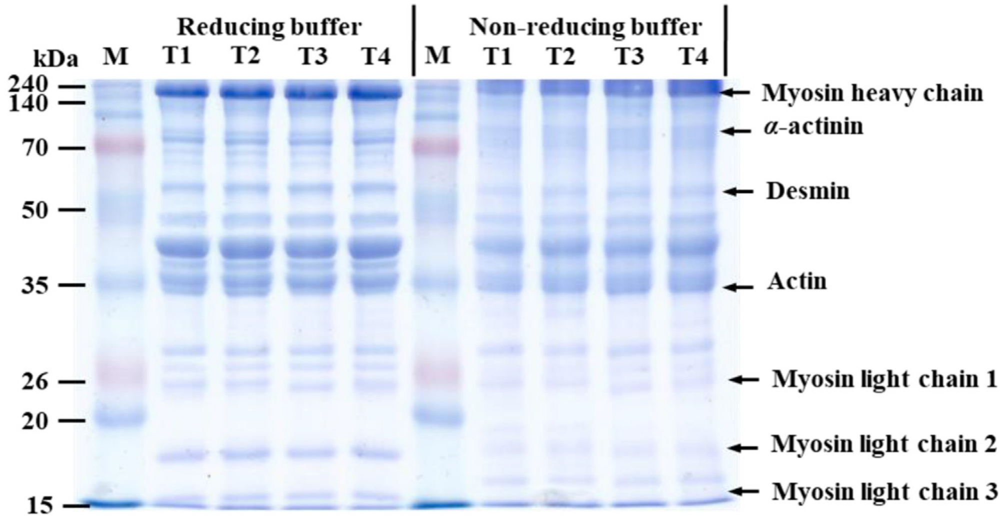

Figure 3. SDS-PAGE photograph of extractable proteins from reduced-salt and sous-vide cooked chicken breast ham. M, standard protein marker; T1, 1.5% NaCl and conventionally cooked chicken breast ham; T2, 1.5% NaCl and sous-vide cooked chicken breast ham; T3, 0.75% NaCl and conventionally cooked chicken breast ham; T4, 0.75% NaCl and sous-vide cooked chicken breast ham. Conventional cooking was done at 80°C until the core temperature reached 71°C, whereas sous-vide cooking was conducted at 60°C for 2 h.

resulting in a stable microstructure, which can contribute to the improvement in the tenderness of cooked meat. Concerning those reasons, despite a decrease in salt level, it could be expected that sous-vide cooking could decrease the shear force of reduced-salt chicken breast hams.

Myofibrillar Protein Pattern (SDS-PAGE)

Patterns of extractable proteins from reduced-salt and sous-vide cooked chicken breast ham are shown in Figure 3. Under both reducing and non-reducing conditions, all treatments presented similar band patterns and intensity of myofibrillar muscle proteins, including probably myosin heavy chain, α-actinin, desmin, actin, and myosin light chains. As a similar result, Song et al. (2020b) reported that different ionic NaCl concentrations (0.5%−2.0%) had no impact on the profile of extractable myofibrillar proteins from salted chicken breasts. Moreover, Bhat et al. (2020) found that sous-vide cooking at 60°C for 4.5 h and 10 h did not change the myofibrillar protein profile of beef muscle and suggested that sous-vide cooking at the applied heating condition could improve the texture of beef muscle without a change in myofibrillar protein profile. Furthermore, our result indicates that combined application of salt reduction and sous-vide cooking may have little to no effects on the myofibrillar protein profile of chicken breast ham.

Sensory Properties

The sensory properties of reduced-salt and sous-vide cooked chicken breast ham are visualized in Table 3. The scores of color, chicken flavor and chicken taste of cooked chicken breast hams were unaffected by salt reduction and/or sous-vide cooking ($P > 0.05$). As expected, 0.75% NaCl chicken breast hams had

Table 3. Sensory properties of reduced-salt and sous-vide cooked chicken breast ham.

	Regular-salt (1.5% NaCl)		Reduced-salt (0.75% NaCl)		
Trait[1]	Conventional cooking[2]	Sous-vide cooking	Conventional cooking	Sous-vide cooking	Significance of P value
Whiteness	6.6 ± 0.5	6.0 ± 0.3	6.9 ± 0.3	6.4 ± 0.3	0.074
Redness	5.0 ± 0.2[bc]	5.6 ± 0.3[a]	4.8 ± 0.1[c]	5.5 ± 0.5[ab]	0.033
Chicken odor	6.2 ± 0.1	6.2 ± 0.2	6.4 ± 0.6	6.0 ± 0.6	0.715
Chicken flavor	6.5 ± 0.3	6.2 ± 0.2	6.9 ± 0.3	6.1 ± 0.7	0.209
Saltiness	6.1 ± 0.5[a]	6.7 ± 0.4[a]	4.8 ± 0.1[b]	4.5 ± 0.6[b]	<0.001
Juiciness	5.0 ± 0.3[b]	6.4 ± 0.8[a]	4.9 ± 0.4[b]	6.8 ± 0.7[a]	0.009
Tenderness	5.8 ± 0.1[b]	7.0 ± 0.2[a]	5.3 ± 0.5[b]	6.9 ± 0.2[a]	<0.001
Chewiness	5.9 ± 0.3	5.8 ± 0.2	5.8 ± 0.6	5.6 ± 0.2	0.824

[1]Whiteness (no need to define, dark gray − light cream), chicken flavor (aroma characteristic for roasted chicken breast, weak intensity − strong intensity), chicken taste (taste characteristic for cooked chicken breast, weak intensity − strong intensity), saltiness (salt perception during chewing, weak intensity − strong intensity), juiciness (the impression of meat juice during chewing, dry − juicy), tenderness (degree of tenderness, the resistance of the sample during mastication, tough − tender).
[2]Conventional cooking was done at 80°C until the core temperature reached 71°C, whereas sous-vide cooking was conducted at 60°C for 2 h.
[a-c]Means sharing the same letters within a row are not significantly different ($P \geq 0.05$).

significantly lower saltiness scores than 1.5% NaCl chicken breast hams, in which no positive effect of sous-vide cooking on the saltiness was found ($P > 0.05$). Interestingly, sous-vide cooking could increase the juiciness and tenderness of 0.75% NaCl chicken breast ham, resulting in comparable scores to 1.5% NaCl chicken breast ham. Considering the improved cooking loss and shear force, thus, an increase in the scores of juiciness and tenderness in reduced-salt and sous-vide cooked chicken breast ham might be related to the improvement effect on water-holding capacity. Recently, Park et al. (2020) noted that sous-vide cooked chicken breast at 60°C for 2 h had a higher score in tenderness attributes and juiciness but lower scores in flavor compared to oven-cooked chicken breasts. Furthermore, our result indicates that sous-vide cooking could be a valuable method to improve sensory defects of chicken breast ham, regardless of salt level, even though the positive efficacies may be limited to tenderness and juiciness.

Lipid Oxidation

Lipid oxidation of reduced-salt and sous-vide cooked chicken breast ham, determined by the 2-thiobarbituric reactive substance (TBARS) method, is shown in Figure 4. At initial storage time (0 week), the highest TBARS value was found at 1.5% NaCl and conventionally cooked chicken breast ham (approx. 0.42 mg MDA/kg) ($P < 0.05$). However, salt reduction and sous-vide cooking decreased the initial formation of TBARS in cooked chicken breast ham ($P < 0.05$). In general, NaCl, which acts as a pro-oxidant, has been well documented to accelerate lipid oxidation of meat products during storage, and suggested pro-oxidation mechanisms of sodium chloride are as follows; structural damage, the release of nonheme free irons, and inactivation of endogenous antioxidant enzymes (Mariutti and Bragagnolo, 2017).

In this study, sous-vide cooked chicken breast hams had significantly lower TBARS values than conventionally cooked chicken breast hams. Thermal treatment, including cooking, can accelerate the formation of TBARS in meat and meat products, depending upon applied time and temperature (Domínguez et al., 2019). Hoac et al. (2006) found that an increase in internal heating temperature (60−80°C) could accelerate TBARS formation immediately after heat treatment, together with decreasing the activity of endogenous antioxidant enzymes such as glutathione peroxidase. Similarly, Mei et al. (1994) suggested that a cooking temperature over 60−70°C caused the inactivation of endogenous antioxidant enzymes, which could accelerate lipid oxidation of meat. In this study, therefore, the reduced TBARS formation in sous-vide cooked chicken breast hams was likely due to the relatively lower cooking temperature than conventional cooking. Similar observations presenting initially reduced TBARS formation due to sous-vide cooking have also been reported recently in chicken breasts (Haghighi et al., 2021; Yuan et al., 2022).

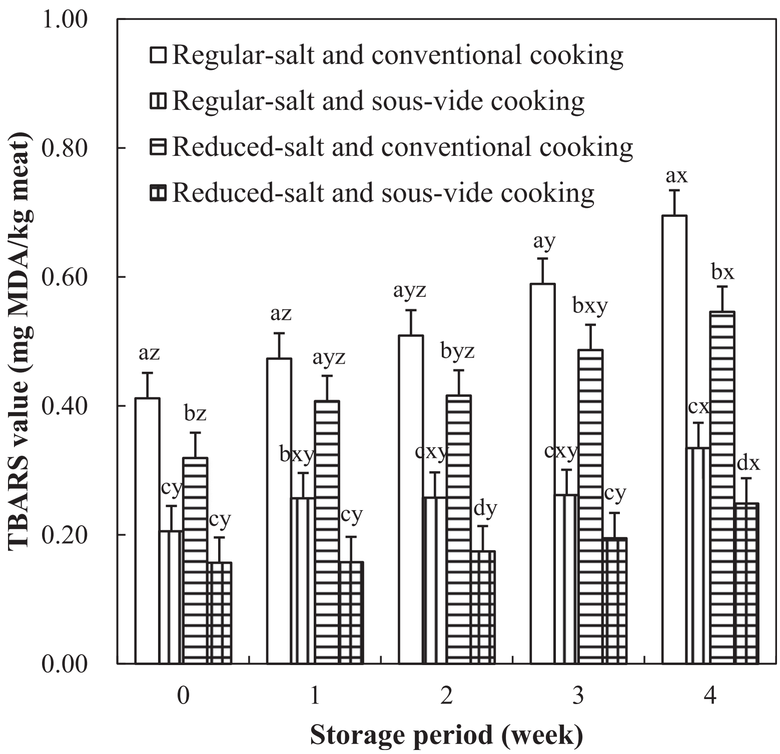

Figure 4. Changes in 2-thiobarbituric reactive substances (TBARS) value of reduced-salt and sous-vide cooked chicken breast ham. Error bar means standard deviation. Conventional cooking was done at 80°C until the core temperature reached 71°C, whereas sous-vide cooking was conducted at 60°C for 2 h. a−d Means sharing the same letters within each storage period are not significantly different ($P \geq 0.05$). x−z Means sharing the same letters within each treatment are not significantly different ($P \geq 0.05$).

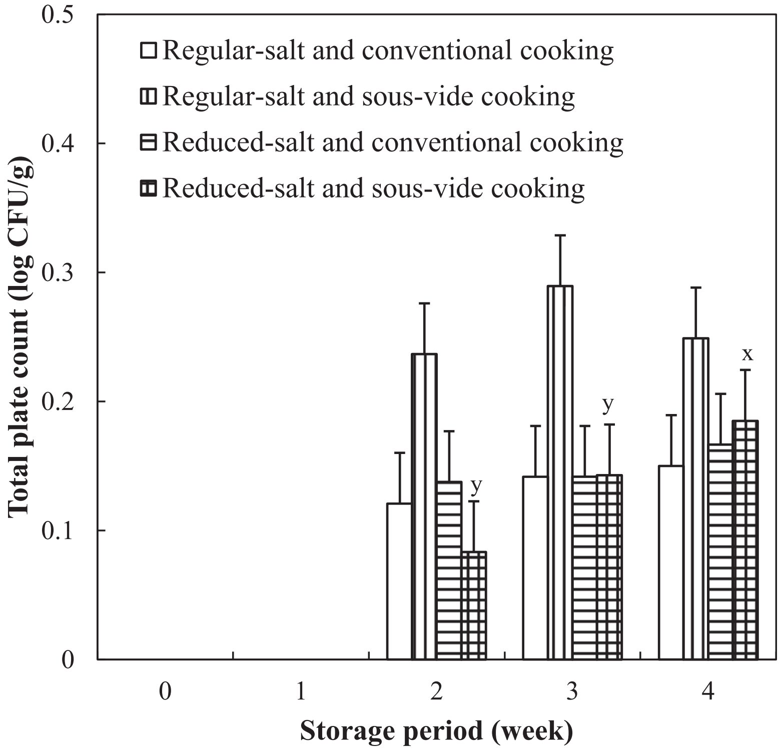

Figure 5. Changes in total plate count of reduced-salt and sous-vide cooked chicken breast ham. Error bar means standard deviation. Conventional cooking was done at 80°C until the core temperature reached 71°C, whereas sous-vide cooking was conducted at 60°C for 2 h. x, y Means sharing the same letters within each treatment are not significantly different ($P \geq 0.05$).

All treatments showed increasing trends in lipid oxidation during 4 weeks of refrigerated storage, and reduced-salt and sous-vide cooked chicken breast hams showed more stability to lipid oxidation ($P < 0.05$). Reduced salt and sous-vide cooked chicken breast ham had the lowest TBARS value at 4 weeks of refrigerated storage ($P < 0.05$). Therefore, the results of this study indicate that the application of sous-vide cooking could be beneficial for retarding lipid oxidation of low-salt meat products during storage.

Total Plate Count

The total plate count of cooked chicken breast ham during 4 weeks of refrigerated storage is shown in Figure 5. Regardless of salt level and cooking method, all cooked chicken breast hams presented below 1 log CFU/g of total plate count during 4 wk of refrigerated storage, while the total plate count of cooked chicken breast hams was detectable from 2 weeks of storage period. Regular-salt (1.5% NaCl) and sous-vide cooked chicken breast ham showed the numerically highest total plate count for 2 to 4 wk; however, there was no difference between treatments ($P > 0.05$). During the overall storage period, *Salmonella* spp. was not detected in all cooked chicken breast hams (data not shown).

The improvement in microbiological safety has been recognized as an essential subject in developing low-salt meat products since a reduction in salt content could allow the rapid growth of microorganisms during storage (Desmond, 2006). In this study, however, sous-vide cooked chicken breast hams showed little to no negative impacts on microbial properties even at reduced-salt conditions. As a similar result, Jeong et al. (2018) have reported that the total plate count of sous-vide cooked pork loin ham at 61°C for 45 min was not detectable. Karyotis et al. (2017) noted that D_{60} values of *Listeria monocytogenes* and *Salmonella* spp. in sous-vide cooked processed marinated chicken breasts were 7.28 min and 5.92 min, respectively. Thus, this study presents that sous-vide cooking at 60°C for 2 h may have no adverse impacts on microbial stability of reduced-salt chicken breast ham during 4 wk of refrigerated storage.

CONCLUSION

Our results show that the application of sous-vide cooking could be beneficial in lowering the cooking loss and shear force of chicken breast ham, regardless of salt level. Moreover, the sensorial juiciness and tenderness of reduced-salt and sous-vide cooked chicken breast ham were comparable to those of regular-salt chicken breast ham. During 4 wk of refrigerated storage, sous-vide cooking could delay lipid oxidation, without any detrimental impact on microbial stability. Therefore, this study suggests that sous-vide cooking could be a practical thermal process for improving the water-holding capacity and texture of chicken breast ham without adverse impacts on shelf stability. Further studies on the combined application of sous-vide cooking with salt replacers would be warranted to improve the sensorial acceptance of saltiness of sous-vide cooked low-salt meat products.

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DISCLOSURES

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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