PROCESSING AND PRODUCTS

Combined effects of sous-vide cooking conditions on meat and sensory quality characteristics of chicken breast meat

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ABSTRACT This study investigated the combined effects of cooking temperature and time on the meat and eating quality characteristics of the sous-vide chicken breast. For the control group, chicken breast samples were cooked in a convection oven until the internal temperature reached 71°C. Each sample for sous-vide cooking was vacuum packaged and then cooked under continuous thermocontrolled conditions in a water bath at 6 combinations of cooking temperature (60 and 70°C) and time (1, 2, and 3 h). Sous-vide cooked chicken meat at 60°C for 1 h (SV60-1h) showed lower cooking loss (6.58 vs. 26.5%, $P < 0.05$), Warner-Bratzler shear force (21.7 vs. 29.1 N, $P < 0.05$), and hardness (9.40 vs. 17.3 N, $P < 0.05$) than meat cooked by conventional oven. Similar to the objective tenderness parameters, cooked chicken meat from the SV60 treatments for all cooking times showed higher scores in all the tenderness attributes than the control group ($P < 0.05$). However, a higher flavor intensity was observed in the SV70-3h and control groups than in the SV60 treatments ($P < 0.05$). Owing to a lesser developed flavor in chicken meat from the SV60-1h treatment, the SV60-2h and 3h treatments were assigned a higher acceptability rating for overall impression ($P < 0.05$). Therefore, cooking temperature and time of sous-vide significantly influenced the physicochemical and palatability characteristics of chicken breast. In this study, the optimum conditions for the sous-vide chicken breast are to continuously cook at 60°C for 2 to 3 h to improve sensory quality characteristics without reducing the water-holding capacity.

Key words: sous-vide, cooking condition, meat quality, sensory quality, chicken breast

INTRODUCTION

The worldwide consumption of poultry meat has been steadily increasing over the past several decades (Petracci and Cavani, 2012), although the consumer preference for meat types, including beef, pork, and chicken, varies among countries, locations, and individuals (Font-i-Furnols and Guerrero, 2014). This trend indicates that many consumers strongly believe that poultry meat help to achieve or improve their healthy diet, as poultry meat contains a higher protein level and lower fat content (Resurreccion, 2004). In this sense, the food industry has been continuously striving to develop new poultry meat products, especially ready-

to-eat products that satisfy consumer preferences and convenience (Resurression, 2004).

Sous-vide cooking is one of the methods to produce ready-to-eat products. There is growing interest in applying the sous-vide cooking method to various foods to improve consumer preference in the food industry, including food service, catering service, and restaurants (Ayub and Ahmad, 2019; Ruiz-Carrascal et al., 2019). In this cooking method, the raw food is vacuum-sealed in a heat-stable and food-grade plastic pouch and then cooked in a water bath under precisely controlled temperature and time (Baldwin, 2012). In comparison to the conventional cooking method, sous-vide cooking can create more uniform meat quality traits and improve the organoleptic characteristics in a variety of meat types, especially tougher meat cuts (Baldwin, 2012; Roldan et al., 2014).

Many consumers in Korea prefer chicken legs than chicken breast when buying or consuming chicken products, as cooked breast meat tends to exhibit a tougher and more crumbly texture than cooked chicken legs (Hong et al., 2015). These characteristics of chicken

breast can be improved using the sous-vide cooking method. To improve the sensory quality of chicken breast, it is necessary to estimate the precise combination of cooking temperature and time of sous-vide, as this combination is a pivotal factor that influences the quality characteristics of sous-vide–cooked chicken (Roldan et al., 2014). However, the optimal cooking conditions for the eating quality of sous-vide–cooked chicken breast have not yet been elucidated clearly. Therefore, this study evaluated the effects of combined cooking conditions on the product and sensory quality characteristics of the sous-vide chicken breast to improve the utilization of chicken breast and satisfy consumer preferences.

MATERIALS AND METHODS

Muscle Samples and Treatments

A total of 70 pectoralis major muscles from a total of 70 broiler carcasses were used in the present study. Each carcass was randomly assigned to one of 7 groups, including the control and 6 sous-vide treatments (7 groups $\times$ 10 replicates). At 24-h postmortem, samples of the right and left pectoralis major muscles were dissected from the carcasses. Breast samples from the left side were used for measuring the meat quality traits, cooking loss, and objective texture parameters, while samples from the right side were removed and then immediately frozen and stored at $-20°C$ for the sensory evaluation. Fresh meat quality traits at 24-h postmortem were measured, and no significant differences in muscle pH and lightness were observed among the groups ($P > 0.05$; data not shown). All chicken breasts used in this study belonged to the normal quality condition, based on a previous report (Barbut et al., 2005).

For the control group, chicken breast samples were cooked in a convection oven (MJ324; LG Electronics, Seoul, Korea) set at 180°C, turning every 3 min, and to an international temperature of 71°C. For sous-vide treatments, each muscle sample was vacuum packaged individually in a nylon-polyethylene bag using a vacuum packaging machine (Leepack; Hanguk Electronic, Incheon, Korea) and then cooked in a continuously thermocontrolled water bath (WSB-30; Daihan Scientific, Gangwon-do, Korea) under different temperature and time combinations. Six combinations of cooking temperature (60°C and 70°C) and time (1, 2, and 3 h) were used for the sous-vide treatments.

Quality Measurements of Cooked Chicken Breast

All cooked samples were immediately cooled in an ice-slurry until equilibration. The pH of each cooked meat sample was measured on the left side of the chicken breast using a portable pH and temperature-measuring instrument with a penetration probe (Testo 206-pH2; Testo AG, Lenzkirch, Germany). The color values, including lightness ($L*$), redness ($a*$), and yellowness ($b*$), were measured across the cut surface using a Minolta chromameter (CR-400; Minolta Camera Co, Osaka, Japan) according to the recommendations of Commission Internationale de l'Eclairage (1978). The chromameter parameters, including illuminant type, standard observer angle, aperture size, and calibration, were consistent with those reported previously (Lee et al., 2018).

Cooking Loss and Objective Texture Parameters

After the cooking process, cooking loss and objective texture parameters, including the Warner-Bratzler shear force (**WBS**) and texture profile analysis (**TPA**), were measured based on a previous publication (Honikel, 1998). For cooking loss measurement, each sample was weighed before and after cooking to calculate the percentage of cooking loss (Honikel, 1998). For analysis of WBS, 6 to 10 cores (1.27-cm diameter) were removed parallel to the muscle fiber orientation, and the WBS values were acquired using an Intron Universal Testing Machine (Model 1011; Instron Corp., Canton, MA) with the Warner-Bratzler blade operating at a crosshead speed of 200 mm/min (American Meat Science Association, 2015). The TPA was performed using a TMS-Touch texture analyzer (Food Technology Corp., Sterling, VA). The cooked breast was compressed to 75% of its original height at a speed of 100 mm/min. Texture parameters for hardness, adhesiveness, springiness, gumminess, and chewiness were assessed using the method of Bourne (1978).

Sensory Quailty Evaluation

For the sensory quality analysis, a total of 70 chicken breast samples were evaluated during 14 sessions (5 samples for 1 session). All panel training sessions and sensory evaluations were performed at the Kyungpook Naiiversity, and the human ethics approval was granted by the Bioethics Committee of Kyungpook National University (protocol number 2019-0027). Eleven trained panelists (6 women and 5 men; aged from 24 to 45 yr) were trained to conduct the sensory analysis, in accordance with the published procedure (Meilgaard et al., 1991; American Meat Science Association, 2015). The panel evaluated cooked chicken breast samples from control and sous-vide treatments for 10 attributes, and a description of these attributes is presented in Table 1.

Statistical Analysis

To analyze the effect of sous-vide treatments on meat quality, cooking loss, objective texture parameters, and sensory quality, the general linear model in SAS software (SAS Institute, Cary, NC) was performed to elucidate any associations. Significant differences in the least-squares means of investigated parameters between the treatments were compared by the probability difference which was set at $P < 0.05$. All data were presented as least-squares means with standard errors.

Table 1. List of definition for sensory quality attributes.

Attribute	Definition
Tenderness attributes	
Softness	Force required to compress the sample between the molar teeth (hard = 1 to soft = 9)
Initial tenderness	Force required to chew 3 times after initial compression (tough = 1 to tender = 9)
Chewiness	Energy required at the 9th chew to swallow at a constant rate (very chewy = 1 to very tender = 9)
Rate of breakdown	Number of chews required for the sample to disintegrate during the mastication process before swallowing (very slow = 1 to very fast = 9)
Amount of perceptible residue	Amount of connective tissue remaining upon complete disintegration of meat sample (abundant = 1 to none = 9)
Juiciness	Amount of moisture released after the 5th chew (not juicy = 1 to extremely juicy = 9)
Flavor intensity	Intensity of beef flavor after the 8th chew (very weak = 1 to very strong = 9)
Off-flavor intensity	Intensity of any flavor or after-taste perceived as inappropriate to cooked beef (very strong = 1 to very weak = 9)
Overall tenderness and overall acceptability	Dislike extremely = 1 to like extremely = 9

RESULTS

Quality Characteristics of Sous-Vide Chicken Breast

A comparison of the meat quality traits between the control and sous-vide treatments is shown in Table 2. Sous-vide samples cooked at 60°C (SV60) showed a lower pH value than the control group ($P < 0.05$), except for samples cooked at 60°C for 2 h (SV60-2h). There was no significant difference in cooked pH within the SV60 or SV70 treatments ($P > 0.05$). In measurements of cooked meat color, lightness value was not significantly different between the control and treatment groups, and no difference was also observed between sous-vide treatment times at each temperature ($P > 0.05$). On the contrary, the SV70-3h chicken breast was lighter in color than the chicken breast cooked at SV60-1h (81.2 vs. 84.1, $P < 0.05$). Redness was higher in the SV60 chicken breast than in the control and SV70 breast meat ($P < 0.05$), and no significant difference was detected between the control and SV70 groups ($P > 0.05$). A higher redness was detected in samples from the SV60-1h treatment than in samples from the SV60-3h treatment (4.22 vs. 3.47, $P < 0.05$). There was no difference in yellowness between the sous-vide treatments, except for SV60-2h, and this treatment showed a lower value than the SV60-3h or SV70-1h treatments (12.3 vs. 13.1 and 13.8, $P < 0.05$).

Cooking Loss and Objective Texture Properties of Sous-Vide Chicken Breast

There was a marked difference ($P < 0.05$) in cooking loss between the control and sous-vide groups (Table 3). The control group showed a higher cooking loss than all sous-vide treatments (26.5%, $P < 0.05$), except for samples from the SV70-3h treatment (25.3%, $P > 0.05$). Within the SV60 treatments, chicken breast cooked for 1 h exhibited a lower loss than those cooked for 2 and 3 h (6.58 vs. 11.7 and 13.2%, $P < 0.05$). Moreover, the SV60 treatments showed lower loss than the SV70 treatments at all treatment times, and cooking loss significantly increased as treatment temperature increased in the SV70 treatments ($P < 0.05$).

For the objective texture parameters, the WBS value was higher in cooked meat from the control group than that in cooked meat from the SV60-1h and -2h treatments (29.1 vs. 21.7 and 23.3 N, $P < 0.05$), although similar values were observed among the control, SV60-3h, and SV70 treatments ($P > 0.05$). The control group exhibited the highest TPA-hardness value (17.3 N, $P < 0.05$) compared with the sous-vide treatments, and higher values were detected in the SV70 treatments than in the SV60 treatments ($P < 0.05$). On the contrary, the adhesiveness value was higher for the SV60-1h treatment than that for the control group (1.69 vs. 0.74 N mm, $P < 0.05$), although no difference was observed in chewiness between the control and SV60

Table 2. Effects of temperature and time on product quality traits of sous-vide–cooked chicken breast meat.

Temperature (Tem)		60°C			70°C				Level of significance		
Time	Control	1 h	2 h	3 h	1 h	2 h	3 h	SEM	Tem	Time	Tem × time
Meat pH	6.06[a]	5.89[b]	6.01[a,b]	5.89[b]	5.97[a,b]	6.07[a]	6.06[a]	0.05	*	NS	NS
Meat color											
Lightness (L^*)	83.7[a,b]	81.2[b]	82.1[b]	83.0[a,b]	83.5[a,b]	84.1[a]	84.1[a]	0.45	***	NS	NS
Redness (a^*)	2.13[c]	4.22[a]	4.36[a]	3.47[b]	2.31[c]	1.90[c]	2.17[c]	0.25	***	NS	NS
Yellowness (b^*)	11.7[b]	13.0[a,b]	12.3[b]	13.1[a]	13.8[a]	13.8[a]	13.5[a]	0.34	**	NS	NS

[a-c]Different superscripts in the same row represent significant differences ($P < 0.05$).
Levels of significance: NS, not significant; *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$.

Table 3. Effects of temperature and time on cooking loss and objective texture properties of sous-vide–cooked chicken breast meat.

Temperature (Tem)		60°C			70°C				Level of significance		
Time	Control	1 h	2 h	3 h	1 h	2 h	3 h	SEM	Tem	Time	Tem × time
Cooking loss (%)	26.5[a]	6.58[e]	11.7[d]	13.2[d]	17.3[c]	22.4[b]	25.3[a]	0.63	***	***	NS
WBS (N)	29.1[a]	21.7[b]	23.3[b]	26.0[a]	25.3[a,b]	25.8[a]	28.5[a]	0.68	***	***	NS
Texture profile analysis											
Hardness (N)	17.3[a]	9.40[d]	9.64[d]	9.78[d]	11.0[c]	11.3[c]	12.3[b]	0.36	***	*	NS
Adhesiveness (N mm)	0.74[c]	1.69[a,b]	0.97[c]	0.91[c]	1.45[b]	1.90[a]	1.48[b]	0.15	***	*	***
Cohesiveness	0.12	0.14	0.17	0.42	0.16	0.15	0.14	0.09	NS	NS	NS
Springiness (mm)	4.02	4.28	4.19	4.71	4.29	4.60	4.65	0.31	NS	NS	NS
Gumminess (N)	1.93	1.30	1.69	1.88	1.60	1.72	1.76	0.17	NS	NS	NS
Chewiness (N mm)	8.05[a,b]	5.20[b]	4.64[b]	5.87[b]	6.30[b]	6.91[a,b]	8.38[a]	0.61	***	*	NS

[a-e]Different superscripts in the same row represent significant differences ($P < 0.05$).

Abbreviation: WBS, Warner-Bratzler shear force.

Levels of significance: NS, not significant; *$P < 0.05$; ***$P < 0.001$.

groups ($P > 0.05$). In addition, there were no differences in cohesiveness, springiness, and gumminess between the control and treatments ($P > 0.05$).

Sensory Quality Characteristics of Sous-Vide Chicken Breast

The effects of various sous-vide treatments on the palatability characteristics, as assessed by trained panelists, are presented in Table 4. Cooked chicken breast from the SV60 treatments showed greater scores in all the tenderness attributes than cooked meat from the control group ($P < 0.05$), and no differences were detected in these attributes between sous-vide cooking times in the SV60 treatments ($P > 0.05$). The SV70-1h treatment scored higher for softness (5.92 vs. 4.69, $P < 0.05$), initial tenderness (5.95 vs. 4.44, $P < 0.05$), and chewiness (5.99 vs. 4.50, $P < 0.05$), while the

SV70 meat cooked for 2 and 3 h presented similar scores to the control group ($P > 0.05$). In addition, no significant differences were observed in the scores for the rate of breakdown (5.95 vs. 6.55, $P > 0.05$) and amount of perceptible residue (5.79 vs. 6.24, $P > 0.05$) between the SV70-1h and SV60-3h treatments.

The SV60-1h group showed the highest score in juiciness among the groups (6.62, $P < 0.05$), and no difference was observed in the juiciness scores between the SV60-3h and SV70-1h treatments (5.18 vs. 5.11, $P > 0.05$). For the intensities of flavor and off-flavor, the control meat exhibited higher ratings than the SV60 treatments ($P < 0.05$) and did not differ from the SV70-3h treatment ($P > 0.05$). The SV60-1h treatment was assigned lower off-flavor intensity in relation to the SV60-2h and -3h treatments (5.32 vs. 6.54 and 6.62, $P < 0.05$). Lower overall tenderness and acceptability were observed in the control group than in all the sous-vide treatments ($P < 0.05$). In addition, the

Table 4. Effects of temperature and time on sensory quality characteristics of sous-vide–cooked chicken breast meat.

Temperature (Tem)		60°C			70°C				Level of significance		
Time	Control	1 h	2 h	3 h	1 h	2 h	3 h	SEM	Tem	Time	Tem × time
Tenderness attributes											
Softness[1]	4.69[c]	7.14[a]	6.97[a]	6.58[a]	5.92[b]	5.37[b,c]	5.24[c]	0.21	***	**	NS
Initial tenderness[2]	4.44[c]	7.11[a]	7.16[a]	6.70[a]	5.95[b]	5.40[b,c]	5.19[c]	0.22	***	*	NS
Chewiness[3]	4.50[c]	7.16[a]	7.12[a]	6.72[a]	5.99[b]	5.41[b,c]	5.21[c]	0.24	***	*	NS
Rate of breakdown[4]	4.16[d]	6.73[a]	6.90[a]	6.55[a,b]	5.95[b]	5.15[c]	5.39[b,c]	0.22	***	NS	NS
Amount of perceptible residue[5]	4.14[d]	6.64[a]	6.53[a]	6.24[a,b]	5.79[b]	6.42[a,b]	5.16[c]	0.19	***	*	NS
Juiciness[6]	2.86[d]	6.62[a]	5.70[b]	5.18[b]	5.11[b]	4.25[c]	3.57[d]	0.25	***	***	NS
Flavor intensity[7]	6.56[a]	4.91[c]	5.48[b]	5.28[b,c]	5.96[a,b]	5.64[b]	6.32[a]	0.20	***	NS	*
Off-flavor intensity[8]	7.94[a]	5.32[c]	6.54[b]	6.62[b]	6.20[b]	7.24[a,b]	7.10[a,b]	0.26	***	***	NS
Overall tenderness[9]	4.33[c]	7.07[a]	7.00[a]	6.59[a]	5.83[b]	5.41[b]	5.18[b]	0.25	***	NS	NS
Overall acceptability[9]	4.05[c]	5.74[b]	6.66[a]	6.39[a]	6.01[a,b]	5.66[b]	5.33[b]	0.23	***	NS	**

[a-d]Different superscripts in the same row represent significant differences ($P < 0.05$).

Levels of significance: NS, not significant; *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$.

[1]Scale: 1 = very hard, 9 = very soft.
[2]Scale: 1 = very tough, 9 = very tender.
[3]Scale: 1 = very chewy, 9 = very tender.
[4]Scale: 1 = very slow, 9 = very fast.
[5]Scale: 1 = very abundant, 9 = none.
[6]Scale: 1 = not juicy, 9 = extremely juicy.
[7]Scale: 1 = very weak, 9 = very strong.
[8]Scale: 1 = very strong, 9 = very weak.
[9]Scale: 1 = dislike extremely, 9 = like extremely.

SV60-1h treatment showed lower overall acceptability than the SV60-2h and -3h treatments (5.74 vs. 6.66 and 6.39, $P < 0.05$) and exhibited a similar score to the SV70 at all treatment times ($P > 0.05$).

DISCUSSION

Sous-vide can be applied to almost all types of food and involves cooking for a longer time at 55 to 80°C, unlike the traditional methods for a shorter cooking time at higher temperature, such as grilling and frying (Ayub and Ahmad, 2019). Meat cooked by sous-vide exhibits the marked differences in its physicochemical characteristics compared with meat cooked by conventional methods (King and Whyte, 2006; Ayub and Ahmad, 2019). Especially, sous-vide cooked meat is lighter and redder in color than meat cooked by conventional cooking (King and Whyte, 2006). This color difference between the cooking methods can be explained by the changes in the myoglobin pigment during cooking (Hunt et al., 1999; King and Whyte, 2006). Hunt et al. (1999) reported that cooking causes denaturation of the protein portion in myoglobin, and this denaturation begins between 55°C and 65°C, such that most of the myoglobin is denatured and brown at 70°C to 80°C. However, sensitivity to heat denaturation differs among the 3 forms of myoglobin (King and Whyte, 2006). Especially, deoxymyoglobin, which is the prevalent form in vacuum packaged meat, is more resistant to heat denaturation than the oxymyoglobin and metmyoglobin (Van Laack et al., 1996; Hunt et al., 1999). Therefore, vacuum package chicken meat cooked at 60°C showed a redder cut surface than meat cooked by conventional oven and vacuum-packaged meat cooked at 70°C ($P < 0.05$), although no difference in lightness between the control and SV60 groups was observed in the present study. A higher pH was detected in meat cooked by conventional oven than sous-vide chicken cooked at 60°C for 1 h because an increase in the cooking temperature is accompanied by an increase in the meat pH (Geileskey et al., 1998).

The SV60-1h treatment displayed the lowest cooking loss among the groups, and the SV60 treatment at all cooking times showed lower loss than the control and the SV70 treatments ($P < 0.05$). These lower cooking loss of sous-vide cooked meat at a lower temperature can be explained in 2 ways. First of all, the lower temperature condition in sous-vide minimizes coagulation of heat-sensitive proteins unlike the other cooking methods, especially grilling (Dominguez-Hernandez et al., 2018). Second, vacuum packaging of sous-vide method can reduce water loss by evaporation (Dominguez-Hernandez et al., 2018). On the other hand, cooking loss is well correlated with objective tenderness parameters, as protein coagulation accompanies meat toughness (Choi et al., 2019). In the present study, the SV60-1h and -2h treatments with a lower cooking loss showed lower WBS and TPA-hardness values than meat cooked using a conventional oven with a higher cooking loss ($P < 0.05$).

As a consequence of heating, several changes including protein denaturation and fiber shrinkage occur, and these changes contribute to increasing the toughness of meat (Tornberg, 2005). Denaturation of muscle proteins begins to occur at 35°C to 40°C, and a significant shrinkage in diameter and length of fibers occurs above 60°C (Warner et al., 2017). Generally, both the cooking temperature and time affect meat tenderness, and increasing cooking temperature has a greater effect on fiber shrinkage than increasing cooking time (Dominguez-Hernandez et al., 2018). Thus, the lower cooking temperature in sous-vide condition produces tenderer meat, and sensory juiciness also increases as cooking temperature and time reduce (Dominguez-Hernandez et al., 2018). In this study, the sous-vide chicken meat cooked at 60°C was tenderer and juicier than the control meat, and meat cooked at 60°C for 1 h was juicier than meat cooked for 2 and 3 h ($P < 0.05$). Moreover, the SV60-3h treatment presented similar scores to the SV70-1h treatment for the rate of breakdown, amount of perceptible residue, and juiciness ($P > 0.05$). Unlike tenderness and juiciness, cooked meat flavor, which is mainly attributed to the volatile aromatic compounds, commonly develops at temperatures above 70°C, and so sous-vide meat cooked at a lower temperature exhibits poorer flavor than meat cooked at a higher temperature because of the extent of Maillard reaction (Calkins and Hodgen, 2007). Thus, the SV60-1h treatment exhibited lower scores for flavor and off-flavor intensities than the control and SV70 treatments, although overall tenderness was higher in the SV60 treatment than that in the SV70 treatment.

CONCLUSION

Cooking conditions significantly influenced the physicochemical and sensory quality characteristics of sous-vide chicken breast in the present study. Sous-vide meat cooked at 60°C exhibited a greater water-holding capacity and required lower initial and final force to penetrate the meat than meat cooked by conventional oven. However, owing to a lesser developed flavor in sous-vide meat cooked at 60°C for 1 h, higher overall acceptability was observed in meat cooked at 60°C for 2 and 3 h. In addition, Baldwin (2012) recommended that 20- to 25-mm-thick meat samples should be cooked in a 60°C water bath for at least 88 to 101 min to improve the food safety of sous-vide chicken breast. Taken together, the optimum conditions in this study for the sous-vide chicken breast were continuous cooking at 60°C for 2 to 3 h to improve sensory quality characteristics and minimize water loss.

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