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ARTICLE

Impact of Sous-vide Cooking on Quality Attributes of High-Fat and Low-Fat Cuts of Beef, Pork, and Chicken

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Abstract Low-fat cuts have gained popularity due to rising consumer interest in health-conscious diets. However, their tough texture and low juiciness necessitate quality improvement through optimized cooking methods. Sous-vide, a cooking method that can enhance tenderness and juiciness, can be a viable solution to address these challenges. This study aimed to compare quality characteristics of high-fat and low-fat cuts of beef (sirloin, BHF; top round, BLF), pork (belly, PHF; ham, PLF), and chicken (thigh, CHF; breast, CLF) before and after sous-vide cooking. All samples were vacuum-sealed and cooked at 70℃ for 40 min. Proximate composition, pH, water-holding capacity (WHC), cooking loss, shear force, and color characteristics were analyzed. Results showed that low-fat cuts of raw beef and pork had higher moisture contents than high-fat cuts ($p<0.05$), although their moisture contents showed no significant differences from those of chicken cuts. BLF exhibited lower pH but higher WHC, cooking loss, and shear force than BHF ($p<0.05$), while PLF showed higher pH and WHC but lower cooking loss than PHF ($p<0.05$), although they showed no significant differences in shear force ($p>0.05$). For chicken, CLF had lower pH and cooking loss but higher shear force than CHF ($p<0.05$). Results of this study demonstrate that sous-vide cooking can improve the quality of PLF and CLF by reducing cooking loss and shear force. However, further research is needed to optimize sous-vide conditions for BLF to address its high cooking loss and shear force.

Keywords quality characteristics, sous-vide, high-fat, low-fat, livestock species

Introduction

Fat is an essential nutrient and an important energy source for the human body. Consumers generally prefer meat with a higher fat content, which provides a tender texture and a rich flavor, both of which are known to affect meat quality (Ahmad et al., 2018). In contrast, non-preferred meat tends to have a lower fat content, resulting in a tougher texture. When classifying preferred and non-preferred cuts from livestock species, preferred cuts of pork include belly and shoulder loin, while non-preferred cuts include loin, picnic shoulder, and ham (Moon, 2013a). For beef, preferred cuts include loin, tenderloin, and ribs, while non-preferred cuts include chuck and top round (Jeon, 2012). For chicken, thigh is preferred, in contrast to breast, which is not preferred.

According to the 2023 Korea National Health and Nutrition Examination Survey (KDCA, 2024), the prevalence of obesity and hypercholesterolemia has increased over the past decade. One of the main reasons is an increase of energy intake from fat, which increased from 21.8% in 2014 to 26.3% in 2023. Obesity and hypercholesterolemia are major risk factors for various chronic diseases, such as diabetes, certain cancers, hypertension, and cardiovascular diseases, which has become a significant public health concern (Shatwan and Almoraie, 2022). In response, consumer interest in health and wellness has intensified, leading to a growing preference for low-fat food products. However, low-fat meat cuts are often characterized by dryness, toughness, and reduced juiciness, necessitating optimization of cooking methods to enhance their sensory quality.

Sous-vide is a cooking method in which ingredients are vacuum-sealed in packaging and then heated evenly at low temperatures in a water bath or steam oven. This method is applied to various ingredients such as fruits, vegetables, and meats (Kathuria et al., 2022). Sous-vide minimizes nutrient degradation and ensures minimal moisture loss. This helps preserve food moisture and maintain intrinsic flavors, ensuring consistent taste and quality (Zavadlav et al., 2020). In particular, low-fat cuts tend to have a dry and tough texture when they are prepared with conventional cooking methods. In contrast, sous-vide cooking at low temperatures can mitigate protein denaturation in meat and enhance osmosis through vacuum sealing, resulting in enhanced tenderness (Ruiz-Carrascal et al., 2019).

Although various studies on sous-vide cooking have been conducted, research comparing its effects on low-fat and high-fat cuts across different livestock species and identifying their specific characteristics is limited. Therefore, this study aimed to provide fundamental information on quality changes of high-fat and low-fat cuts of beef, pork, and chicken when subjected to sous-vide cooking.

Materials and Methods

Raw materials

High-fat cuts (sirloin, BHF) and low-fat cuts (top round, BLF) of beef, high-fat cuts (belly, PHF) and low-fat cuts (ham, PLF) of pork, and high-fat cuts (thigh, CHF) and low-fat cuts (breast, CLF) of chicken used in this study were purchased from a butcher shop located in Cheongju, Korea. All samples were transported under refrigerated conditions (4±1℃) and used on the day of purchase. Chicken samples were manually deboned to separate thighs and breasts. All samples were trimmed to remove external fat and connective tissues, then cut into uniform pieces with a thickness of 2 cm and a weight of 17.77±4.43 g.

Sous-vide cooking procedure

Prepared beef, pork, and chicken cuts were individually vacuum-packaged in nylon/polyethylene (PA/PE) pouches using a vacuum packaging machine (SBV-600L, Sambo Tech, Gimpo, Korea). Sous-vide cooking was performed in a constant-temperature water bath (BS2-30, Jeiotech, Daejeon, Korea) at 70℃ for 40 min. After cooking, all samples were cooled at 4±1℃ for 10 min to stabilize before further analysis.

Proximate composition analysis

The proximate composition analysis was conducted to measure the moisture, crude protein, crude fat, and crude ash content

(%) in both cooked and uncooked samples, following the methods outlined by AOAC (2007). Moisture content was determined using the oven drying method at 105℃. Crude protein content was measured using a nitrogen/protein analyzer (rapid MAX N exceed, Elementar, Langenselbold, Germany) utilizing Dumas method. Crude fat content was measured using the method of Folch et al. (1957). A 0.5 g sample was homogenized in 25 mL of Folch solution (chloroform:methanol, 2:1, v/v) and stored at 4℃ for 24 h. The mixture was filtered through Whatman No. 2 paper, rinsed with 5 mL of Folch solution, and mixed with 10 mL of distilled water. After centrifugation at 983×g for 20 min at room temperature, the upper aqueous layer was removed, and the chloroform layer was evaporated overnight under a fume hood before weighing. Crude ash content was determined using the incineration method at 550℃ for 10 h. All measurements were performed at least in triplicate.

pH measurement

The pH in both cooked and uncooked samples was measured by adding 45 mL of distilled water to 5 g of each sample. All samples were homogenized for 30 s using a homogenizer (Stomacher 400 Circulator, Seward, Manchester, UK). The pH was measured with a calibrated pH meter (Orion Star™ A211, Thermo Fisher Scientific, Cheshire, UK) using phosphate buffer solutions at pH 4.0 and 7.0. Measurements were performed at least in triplicate.

Water-holding capacity

Water-holding capacity was measured by modifying the centrifugation method of Laakkonen (Laakkonen et al., 1970). A 0.5 g sample was placed in a tube and heated in a water bath (BS2-30, Jeiotech) at a constant temperature of 80℃ for 20 min. The sample was then cooled at room temperature for 10 min, followed by centrifugation at 437×g for 10 min at 10℃. Measurements were performed at least in triplicate. The weight was recorded and calculated using the following formula:

$$\text{Water holding capacity (\%)} = \frac{\text{Total moisture} - \text{Free moisture}}{\text{Total moisture}} \times 100 \quad (1)$$

$$\text{Free moisture (\%)} = \frac{\text{Weight before centrifugation} - \text{Weight after centrifugation}}{\text{Weight of sample} \times \text{Fat coefficient}} \times 100 \quad (2)$$

$$\text{Fat coefficient} = 1 - \frac{\text{Fat (\%)}}{100} \quad (3)$$

Cooking loss

Cooking loss was determined as the percentage (%) weight ratio of the sample before and after heating. Samples of uniform size were sous-vide cooked in a water bath at a constant temperature of 70℃ for 40 min, ensuring no contact between samples. After cooking, the samples were cooled at room temperature for 10 min. The weight was recorded and calculated using the following formula:

$$\text{Cooking loss (\%)} = \frac{\text{Weight before cooking (g)} - \text{Weight after cooking (g)}}{\text{Weight before cooking (g)}} \times 100 \quad (4)$$

Shear force

The shear force of the cooked samples was measured using a texture analyzer (TA1, AMETEK, Middleboro, MA, USA) equipped with a V-blade. Sous-vide cooked samples were cut into dimensions of 1 cm×2 cm×1 cm (width×length×height) and sliced perpendicularly to the muscle fiber direction at a speed of 10 mm/min. Measurements were performed at least in triplicate. Shear force was recorded as the maximum stress.

Color measurement

Color measurements for both cooked and uncooked samples were performed using a spectro colorimeter (M-26d, Konica Minolta, Osaka, Japan) based on standardized color space defined by the International Commission on Illumination (CIE). Parameters measured included CIE L*, CIE a*, and CIE b*. A D65 illuminant was used during measurements. This instrument was calibrated with a standard white plate (CIE L*=99.41, CIE a*=–0.13, CIE b*=–0.11). Measurements were performed at least in triplicate by randomly selecting different positions on a cross-sectional area of meat.

Statistical analysis

All experiments were conducted in triplicate and all statistical analyses were performed using SPSS software, version 28.0 (IBM, Armonk, NY, USA). An independent t-test was applied to compare differences between groups, and differences were considered statistically significant when the p-value was less than 0.05. Prior to conducting the t-test, normality of the data was assessed using the Shapiro-Wilk test, and Levene's test was used to confirm equality of variances between groups.

Results and Discussion

Proximate composition analysis between high-fat and low-fat cuts of beef, pork, and chicken before and after sous-vide cooking

Results of proximate composition analysis of high-fat and low-fat cuts of beef, pork, and chicken for both cooked and uncooked samples are presented in Table 1. For moisture content, all cuts except PHF showed a decreasing trend when cooked. Across all species, low-fat cuts exhibited significantly higher moisture contents than high-fat cuts for both cooked and uncooked samples ($p<0.05$). This might have resulted from differences in fat content. Regarding crude fat content, low-fat cuts of all species showed an increasing trend with cooking, while crude fat contents of high-fat cuts except for BHF decreased when cooked ($p<0.05$). Jiang et al. (2022) have reported that sous-vide cooking, characterized by low-temperature, long-time processing, can lead to greater fat exudation than conventional cooking methods. Conversely, the relative increase in crude fat content observed in low-fat cuts is likely due to their lower initial fat contents, which can make them more susceptible to moisture loss during cooking. For crude protein content, all cuts exhibited an increasing trend when cooked, showing no significant difference between high-fat and low-fat cuts across all species in either condition ($p>0.05$). Crude ash contents showed no significant differences in most cuts except for PHF and CHF, regardless of whether they were cooked or uncooked ($p>0.05$). Variations in nutrient compositions are generally influenced by the evaporation of moisture during thermal processing, which can alter concentrations of components.

pH measurement and water-holding capacity between high-fat and low-fat cuts of beef, pork, and chicken before and after sous-vide cooking

Results of pH for high-fat and low-fat cuts of beef, pork, and chicken for both cooked and uncooked samples are presented in Fig. 1. Cooking significantly increased the pH across all cuts ($p<0.05$). This increase might be attributed to protein

Table 1. Proximate compositions between high-fat and low-fat cuts from beef, pork, and chicken before and after sous-vide cooking

Traits (%)		Beef		Pork		Chicken	
		BHF (sirloin)	BLF (top round)	PHF (belly)	PLF (ham)	CHF (thigh)	CLF (breast)
Moisture	Un	51.53±1.05^{Ab}	73.29±0.44^{Aa}	54.42±0.32^{b}	74.90±2.36^{Aa}	71.48±4.26	75.30±0.01^{A}
	Ck	46.64±1.38^{Bb}	68.01±0.25^{Ba}	58.72±1.10^{b}	68.90±1.62^{Ba}	60.41±3.32	73.87±0.23^{B}
Crude fat	Un	27.59±0.11^{Ba}	2.76±0.11^{Bb}	24.02±0.17^{Aa}	4.10±0.83^{b}	18.96±0.03^{Aa}	0.66±0.10^{Bb}
	Ck	29.48±0.28^{Aa}	6.39±0.09^{Ab}	16.05±0.96^{Ba}	6.11±0.07^{b}	12.73±0.21^{Ba}	1.02±0.08^{Ab}
Crude protein	Un	21.14±1.20	22.97±0.46	21.01±0.51	20.06±1.43	16.78±3.34	22.49±0.21^{B}
	Ck	24.21±0.38	24.39±0.39	24.17±1.86	23.97±1.48	25.56±3.15	23.85±0.13^{A}
Crude ash	Un	0.17±0.01^{b}	0.98±0.12^{a}	1.01±0.07^{A}	0.95±0.09	2.25±0.23^{Aa}	1.55±0.14^{b}
	Ck	0.36±0.26	1.09±0.04	0.60±0.07^{B}	1.02±0.22	1.28±0.22^{B}	1.26±0.08

All values are mean±SD.
^{A,B} Means in the same column with different letters indicate significant differences within each trait (p<0.05).
^{a,b} Means in the same row with different letters indicate significant differences within each species (p<0.05).
BHF, beef high-fat cut; BLF, beef low-fat cut; PHF, pork high-fat cut; PLF, pork low-fat cut; CHF, chicken high-fat cut; CLF, chicken low-fat cut; Un, uncooked; Ck, cooked.

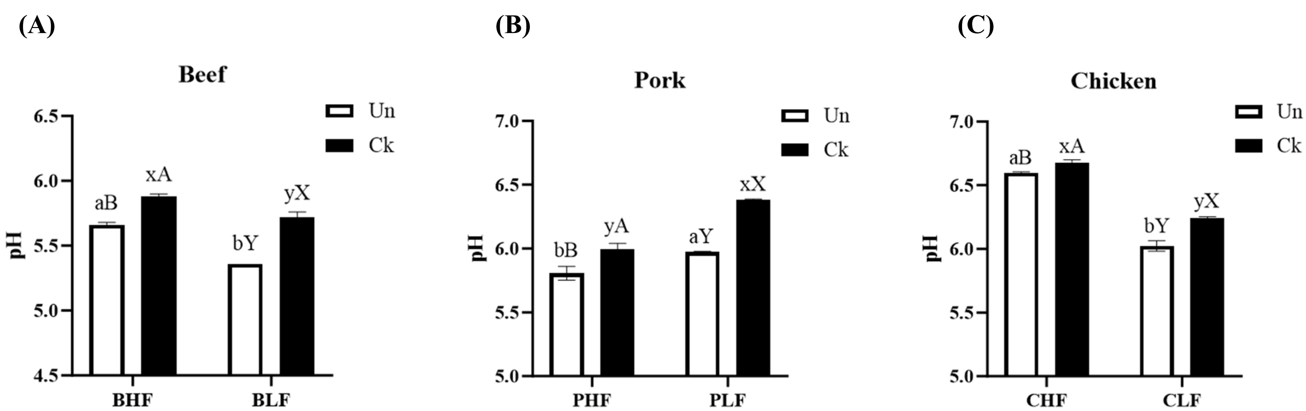

Fig. 1. pH measurement between high-fat and low-fat cuts from beef, pork, and chicken before and after sous-vide cooking. (A) Beef, (B) pork, (C) chicken. ^{A,B} Means with different letters indicate significant differences in the high-fat cuts (p<0.05). ^{a,b} Means with different letters indicate significant differences in the uncooked condition (p<0.05). ^{X,Y} Means with different letters indicate significant differences in the low-fat cuts (p<0.05). ^{x,y} Means with different letters indicate significant differences in the cooked condition (p<0.05). BHF, beef high-fat cut; BLF, beef low-fat cut; PHF, pork high-fat cut; PLF, pork low-fat cut; CHF, chicken high-fat cut; CLF, chicken low-fat cut; Un, uncooked; Ck, cooked.

denaturation caused by heat, which can lead to loss of acidic groups (Becker et al., 2016) and exposure of basic amino groups (Hwang et al., 2019). Previous studies have demonstrated that the pH of beef is increased by 0.03 to 0.33 depending on the internal temperature (Moon, 2013b). In this study, low-fat cuts of beef and chicken had significantly lower pH values than high-fat cuts when cooked, whereas PLF showed a higher pH than PHF of pork (p<0.05). pH is a critical factor influencing microbial growth and survival. Most microbes thrive under neutral pH conditions, but microbial growth rates decrease as the pH deviates further from neutrality (Rebezov et al., 2022). These results suggest that low-fat cuts of beef and chicken may have relatively higher microbial safety compared to high-fat cuts. But, PLF, with a pH closer to neutrality, may be more susceptible to microbial growth than PHF. However, the sous-vide method, by providing uniform heat treatment throughout the interior of meat, effectively reduces microbial populations and eliminates major pathogens such as *Salmonella* and

Escherichia coli (Głuchowski et al., 2019; Gu et al., 2024).

Water-holding capacities (WHCs) of high-fat and low-fat cuts of beef, pork, and chicken for both cooked and uncooked samples are presented in Fig. 2. WHC significantly increased with cooking across all cuts ($p<0.05$). Lean muscle contains approximately 75% water, which exists as *bound water*, *immobilized water*, and *free water*. In this study, WHC was measured after loss of free water and immobilized water during cooking. Low-fat cuts of beef and pork exhibited higher WHC than high-fat cuts for both cooked and uncooked samples. However, WHC showed no significant differences between chicken cuts regardless of cooking status ($p>0.05$). Among all cuts, CHF demonstrated the highest WHC when cooked, which was presumed to be due to its higher pH value. As the pH of meat moves further away from its isoelectric point, electrostatic repulsion between proteins increases, leading to greater myofibrillar lattice spacing and an improved capacity to retain water (Huff-Lonergan and Lonergan, 2005).

Cooking loss and shear force of sous-vide cooked high-fat and low-fat cuts of beef, pork, and chicken

Cooking loss results of high-fat and low-fat cuts from beef, pork, and chicken are presented in Fig. 3. Cooking loss was significantly lower in high-fat cuts for beef, whereas it was significantly lower in low-fat cuts for pork and chicken ($p<0.05$).

Results of shear force of high-fat and low-fat cuts of beef, pork, and chicken are presented in Fig. 4. Across all species, low-fat cuts exhibited higher shear force than high-fat cuts, with significant differences observed in beef and chicken ($p<0.05$). Previous studies have demonstrated that as moisture loss increases during cooking, denaturation of myofibrils and connective tissues intensifies, resulting in firmer textures and higher shear force values (Nethery et al., 2022). Similarly, in this study, BLF showed higher cooking loss and shear force than BHF, supporting a positive correlation between cooking loss and shear force. Conversely, PLF and CLF exhibited lower cooking loss values than high-fat cuts but showed higher shear force values. Shear force is influenced by factors such as collagen content and muscle fiber length. Lower collagen content and longer muscle fibers are associated with improved tenderness (Bhat et al., 2018). For pork and chicken, a higher proportion of white muscle fibers with shorter muscle fiber lengths compared to beef might have limited the impact of

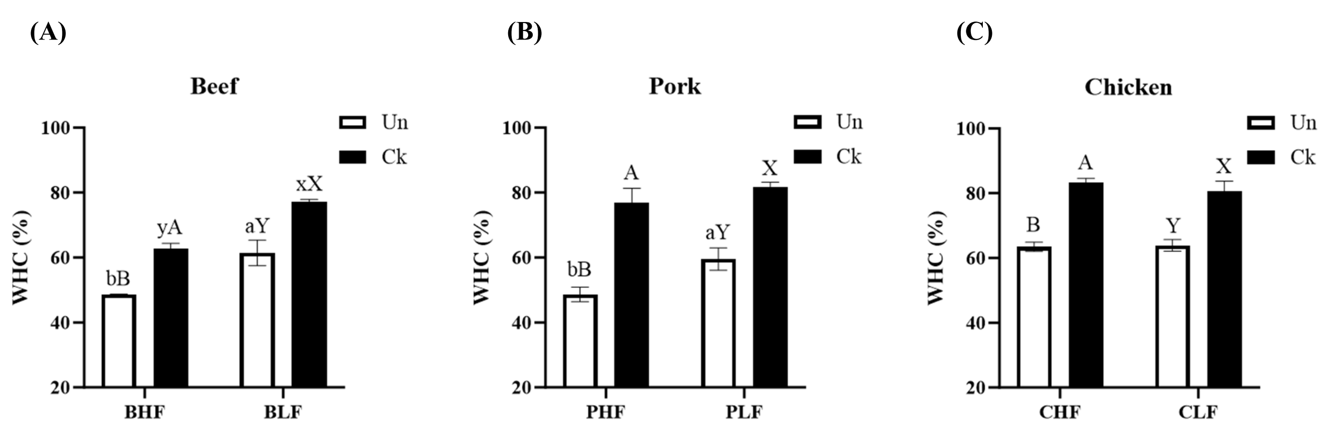

Fig. 2. WHC between high-fat and low-fat cuts from beef, pork, and chicken before and after sous-vide cooking. (A) Beef, (B) pork, (C) chicken. ^{A,B} Means with different letters indicate significant differences in the high-fat cuts ($p<0.05$). ^{a,b} Means with different letters indicate significant differences in the uncooked condition ($p<0.05$). ^{X,Y} Means with different letters indicate significant differences in the low-fat cuts ($p<0.05$). ^{x,y} Means with different letters indicate significant differences in the cooked condition ($p<0.05$). WHC, water-holding capacity. BHF, beef high-fat cut; BLF, beef low-fat cut; PHF, pork high-fat cut; PLF, pork low-fat cut; CHF, chicken high-fat cut; CLF, chicken low-fat cut; Un, uncooked; Ck, cooked.

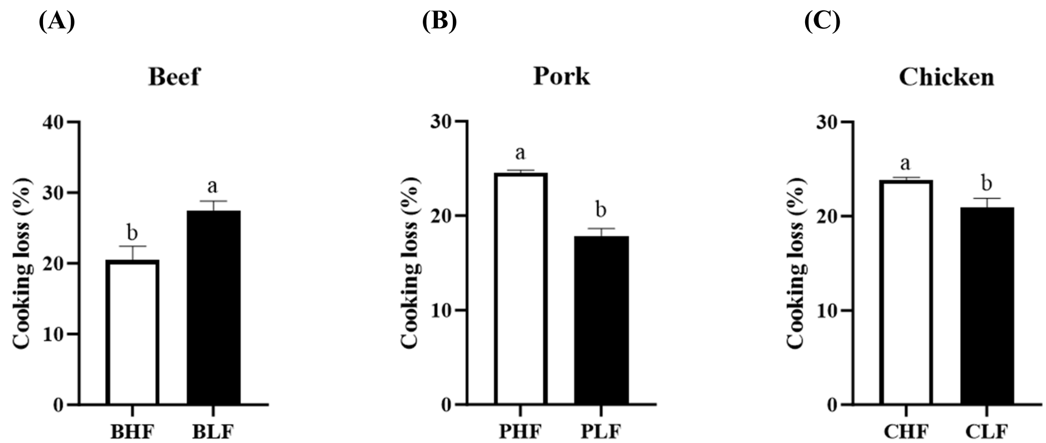

Fig. 3. Cooking loss between high-fat and low-fat cuts from beef, pork, and chicken after sous-vide cooking. (A) Beef, (B) pork, (C) chicken. [a,b] Means with different letters indicate significant differences after sous-vide cooking (p<0.05). BHF, beef high-fat cut; BLF, beef low-fat cut; PHF, pork high-fat cut; PLF, pork low-fat cut; CHF, chicken high-fat cut; CLF, chicken low-fat cut.

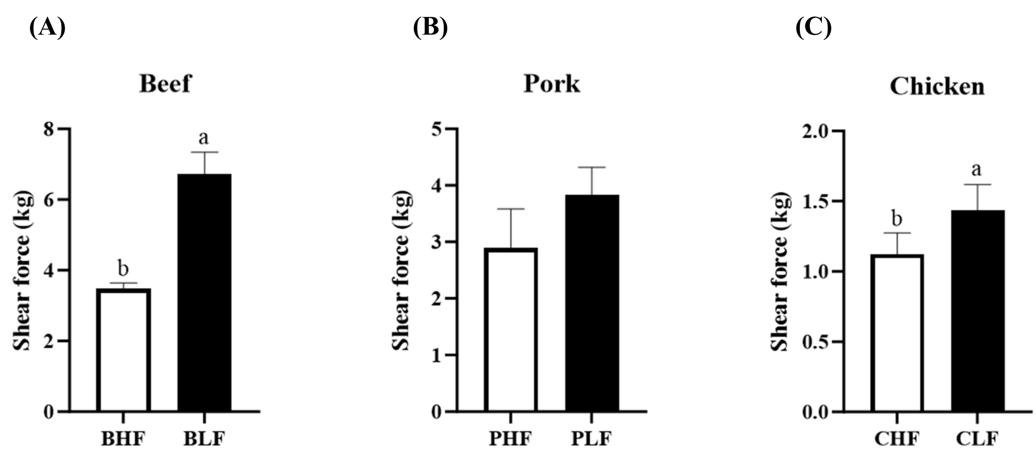

Fig. 4. Shear force between high-fat and low-fat cuts from beef, pork, and chicken after sous-vide cooking. (A) Beef, (B) pork, (C) chicken. [a,b] Means with different letters indicate significant differences after sous-vide cooking (p<0.05). BHF, beef high-fat cut; BLF, beef low-fat cut; PHF, pork high-fat cut; PLF, pork low-fat cut; CHF, chicken high-fat cut; CLF, chicken low-fat cut.

cooking loss on shear force.

Color measurement of high-fat and low-fat cuts of beef, pork, and chicken before and after sous-vide cooking

Results of color measurement of high-fat and low-fat cuts of beef, pork, and chicken for both cooked and uncooked samples are presented in Table 2. Meat color is determined by factors such as intramuscular fat, moisture, and myoglobin content (Lawrie, 2006), which are influenced by the chemical state of myoglobin and physical properties of meat (Jeong et al., 2009). Sous-vide cooking characterized by low-temperature processing prevents complete denaturation of myoglobin, thereby preserving the red color of the meat (Shin et al., 2023). For CIE L*, it showed a significant increase for PLF and CLF after cooking (p<0.05). This might be attributed to higher WHC in these samples, as residual surface moisture can increase light scattering, resulting in higher CIE L* values (Sánchez del Pulgar et al., 2012). The significant increase in CIE L* observed for PLF and CLF might be attributed to their lower moisture loss during cooking, which can enhance surface light

Table 2. Color between high-fat and low-fat cuts from beef, pork, and chicken before and after sous-vide cooking

Traits		Beef		Pork		Chicken	
		BHF (sirloin)	BLF (top round)	PHF (pork belly)	PLF (ham)	CHF (thigh)	CLF (breast)
CIE L*	Un	42.43±1.17	44.73±1.30^{A}	54.89±4.93^{a}	38.12±1.06^{Bb}	54.10±0.84^{B}	54.81±0.23^{B}
	Ck	38.93±2.71	39.79±2.91^{B}	58.54±3.46	60.80±0.15^{A}	70.47±1.86^{Ab}	79.77±0.86^{Aa}
CIE a*	Un	24.91±0.15^{Aa}	20.08±1.56^{Ab}	9.73±3.63	9.87±1.38^{A}	7.45±2.63^{a}	3.90±0.45^{Ab}
	Ck	7.68±0.84^{B}	8.20±0.60^{B}	6.52±1.10	6.68±0.92^{B}	3.83±0.76	2.11±0.41^{Bb}
CIE b*	Un	19.25±0.42^{A}	18.35±0.74	15.60±2.51^{a}	11.23±0.77^{Bb}	15.10±1.52^{a}	11.58±0.40^{Bb}
	Ck	14.08±1.18^{B}	15.23±1.03	18.24±1.15	19.81±1.20^{A}	16.10±0.59^{b}	18.79±1.55^{Aa}

All values are mean±SD.
[A,B] Means in the same column with different letters indicate significant differences within each trait ($p<0.05$).
[a,b] Means in the same row with different letters indicate significant differences within each species ($p<0.05$).
BHF, beef high-fat cut; BLF, beef low-fat cut; PHF, pork high-fat cut; PLF, pork low-fat cut; CHF, chicken high-fat cut; CLF, chicken low-fat cut; Un, uncooked; Ck, cooked.

scattering. For CIE a*, all cuts showed a decrease after cooking. During the cooking process, myoglobin undergoes heat-induced denaturation, leading to oxidation of iron ions from Fe^{2+} to Fe^{3+}. This transition converts myoglobin into metmyoglobin, which appears brown or gray and reduces CIE a* (Becker et al., 2016). For CIE b*, an increasing trend was observed after cooking of all cuts except for beef. This might be related to an increase in brown-colored metmyoglobin content (Botinestean et al., 2016).

Conclusion

This study analyzed quality changes in high-fat and low-fat cuts of beef, pork, and chicken before and after sous-vide cooking. Low-fat cuts exhibited higher moisture content, increased crude fat after cooking, and higher shear force compared to high-fat cuts across all species. Beef BLF showed higher cooking loss and shear force than BHF, while pork PLF and chicken CLF demonstrated improved cooking loss but retained higher shear force. CIE L* and CIE b* increased with cooking for pork and chicken, while CIE a* decreased across all species. The sous-vide condition used was effective for improving PLF and CLF quality but less so for BLF due to its high cooking loss and shear force. These findings offer fundamental insights into quality changes in high-fat and low-fat cuts subjected to sous-vide cooking.

Conflicts of Interest

The authors declare no potential conflicts of interest.

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Author Contributions

Conceptualization: Choi J. Data curation: An D, Kim T. Formal analysis: Kim M, Ku B, Kang J. Methodology: Kim M, Choi J. Software: Kim M, Kang J. Validation: Park W, Kim J, Cho J, Choi J. Investigation: Park W, Kim J, Cho J, Choi J. Writing - original draft: Kim M, An D, Kim T. Writing - review & editing: Kim M, Ku B, Kang J, An D, Kim T, Park W, Kim J, Cho J, Choi J.

Ethics Approval

This article does not require IRB/IACUC approval because there are no human and animal participants.

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