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Research Article

The impact of cooking methods on the texture and color characteristics of beef, pork, and chicken

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Abstract This study investigated the effects of roasting and boiling on the texture and color of beef (brisket, loin, and shank), pork (Boston butt, hind leg, and loin), and chicken (breast, loin, and drumstick) through texture profile analysis, cutting, and color tests. Results showed that cooking methods affect meat texture and color differently based on meat type and method. Hardness, springiness, cohesiveness, and chewiness generally increased during cooking. After cooking, chicken had significantly lower hardness, chewiness, and cutting strengths than beef and pork. While beef and pork had similar texture characteristics, roasted beef showed lower hardness and chewiness than boiled beef and pork. The cutting strength of roasted beef was higher than pork, though there was no significant difference in cutting energy between cooked beef and pork. Roasted pork showed lower cutting energy than other cuts. In terms of color, the L* value (lightness) increased after cooking, while the a* value (redness) decreased, with the b* value (yellowness) showing either a decrease or no change. Chicken had the highest L* values, followed by pork and beef, while a* values were highest in beef, followed by pork and chicken.

Keywords meat texture, meat quality, thermal processing effects, cutting strength, texture profile analysis

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1. Introduction

Meat is a significant global food resource, providing various nutrients such as proteins, vitamins, and minerals, and plays an important role in the diet. Among these, beef, pork, and chicken are the most consumed meats by humans (Ardakani et al., 2024). In the sensory characteristics of meat, texture and appearance are crucial factors (Yarmand et al., 2013). The texture of meat depends on the animal's breed, muscle type, and cooking method. Meat is typically heated before consumption to inactivate pathogenic microorganisms, enhance flavor, and improve preservation. Therefore, understanding the physical changes in meat during cooking is essential (de Huidobro et al., 2005; Huff and Parrish, 1993; Yarmand and Homayouni, 2010).

Components influencing muscle strength include myofibrillar proteins (myosin and actin) and connective tissue proteins (mainly elastin and collagen), as well as the moisture content within the fibers (OFFER, 1988). The structure of meat can be simplified into a myofibrillar structure composed of a network of connective tissues and interlinked parallel fibers. During heating, various meat proteins denature, leading to cell membrane damage, fiber contraction, aggregation, gel formation of myofibrils and meat proteins, and the contraction and dissolution of connective tissues (Kong et al., 2007; Tornberg, 2005). The changes in connective tissues under heat cause a tenderizing effect, while myofibrillar proteins harden during cooking, resulting in tougher meat.

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The tenderness of meat is primarily influenced by the characteristics of its connective tissue, which is largely composed of collagen. The amount, solubility, and structure of collagen in meat are crucial factors that determine its overall texture. When connective tissue shrinks during cooking, it creates pressure on the surrounding extracellular fluid, leading to the expulsion of water and a subsequent increase in tissue rigidity. This shrinkage is directly correlated with a loss of tenderness and an increase in cook loss, which is a significant contributor to the overall eating quality of meat (Palka and Daun, 1999).

The Warner-Bratzler shear test and the texture profile analysis (TPA) are currently the most widely used instrumental texture measurement methods (de Ávila et al., 2014). TPA and cutting strength are crucial indicators for assessing meat quality, significantly impacting meat processing and consumption. TPA evaluates the sensory characteristics of meat by simulating the chewing process, measuring attributes like hardness, springiness, chewiness, and cohesiveness. Hardness reflects tenderness, springiness indicates the meat's recovery ability, and chewiness correlates with consumer acceptance. TPA provides valuable insights into texture changes under different processing conditions, aiding in the optimization of meat processing techniques. Cutting strength refers to the force required to cut meat under specific conditions, closely related to the fiber structure, fat distribution, and moisture content of the meat. Measuring cutting strength helps assess tenderness and palatability, directly influencing consumer purchasing decisions and eating experiences. The compression parameters obtained with TPA have been used by many authors to evaluate meat products (Bruna et al., 2000; Houben and van't Hooft, 2005; Hoz et al., 2004).

Meat quality, particularly texture and color, plays a crucial role in consumer satisfaction and serves as key indicators in the meat processing industry. Beef, chicken, and pork are the most consumed meats; however, there is currently a lack of research comparing the texture and color of these meats under identical conditions. This study aims to systematically compare the effects of roasting and boiling on the texture and color of beef (brisket, loin, and shank), pork (Boston butt, hind leg, and loin), and chicken (breast, loin, and drumstick), providing insights into optimizing meat processing techniques and improving sensory quality. By analyzing the texture measurement results, we will assess the degree of deformation in the meat tissue. Additionally, by incorporating color measurement results, we will observe changes in meat color. The findings of this study are expected to contribute to the evaluation of meat quality, improvement of meat processing and cooking techniques, and the development of methods to enhance consumer satisfaction.

2. Materials and methods

2.1. Materials

Beef samples selected for this study include shank, loin, and brisket from Korean native cattle, slaughtered at the Agricultural Cooperative Voice Livestock Trading Market in Eumseong, Korea. The shank is graded 1+, with a carcass weight of 510 kg, sourced from a 28-month-old steer. The loin is graded 1, with a carcass weight of 424 kg, from a 31-month-old cow. The brisket is graded 1++, with a carcass weight of 486 kg, from a 34-month-old steer. Pork samples consist of Boston butt, loin, and hind leg from Korean pigs, slaughtered at Sajo Industries in Cheonan, Korea. Chicken samples were purchased from Harin Co., Ltd. (Iksan, Korea), including breast, drumstick, and loin cuts. Prior to measurement, visible subcutaneous fat and connective tissues were removed.

2.2. Cooking methods

The meat was cut into 2 cm and roasted in a preheated oven at 175℃ (DHO2-23, Softmill, Gwangju, Korea), with one side roasted for 15 min before flipping to roast the other side for an additional 15 min. For boiling, the meat was cut into 2 cm and cooked in boiling water at 100℃ for 10 min. In both methods, cooking was performed until the central temperature of the meat reached 85±5℃ and the experiments were conducted after the samples were cooled to room temperature.

2.3. Texture profile analysis (TPA)

TPA objectively evaluates the texture of food by simulating mechanical chewing processes. Differences in texture parameters may arise from various factors, including fat content, muscle fiber types and proportions, and collagen content (Sun et al., 2017). To investigate the effects of cooking methods on the texture characteristics of pork, beef, and chicken, TPA was conducted based on Warner-Bratzler shear force (WBSF) tests. Springiness, cohesiveness, and chewiness were calculated using equations (1), (2), and (3). Raw and cooked meat samples were cut into dimensions of 1 cm × 1 cm × 1 cm, aligned with the direction of the muscle fibers to ensure consistent results and minimize variability, and measured using a physical testing machine (Z0.5 TS, ZwickRoell Co., Ltd., Ulm, Germany). The pre-test speed was set at 80 mm/min, with a testing speed of 80 mm/min and a trigger (preload) force of 0.1 N. The samples were compressed to 50% in the direction vertical to the muscle fibers and held for 3 sec. Using a 100 mm diameter probe, hardness, springiness, chewiness, and cohesiveness were measured six times for each sample.

$$\text{Springiness (\%)} = D_2 / D_1 \times 100 \quad (1)$$

D_1: Distance of first occurred maximum stress

D_2: Distance of second occurred maximum stress

$$\text{Cohesiveness (\%)} = A_2 / A_1 \quad (2)$$

A_1: Area of first occurred maximum stress

A_2: Area of second occurred maximum stress

$$\text{Chewiness (\%)} = \text{Springiness} \times \text{Cohesiveness} \times \text{Hardness} \quad (3)$$

2.4. Measurement of cutting strength, cutting energy, and degree of texturization of cutting strength and cutting energy

To evaluate the cutting strength, cutting energy, and the degree of organization of cutting strength and cutting energy, the test was conducted based on the Werner-Bratzler cutting test, which is the most widely used to evaluate the tenderness of meat (Destefanis et al., 2008). The cutting strength and cutting energy of the samples were measured for both parallel and vertical sections. Cutting strength is defined as the force required to cut meat, while cutting energy is the total energy needed for the cutting process. The cutting strength and energy required to cut meat vary depending on the direction of the muscle fibers, with the vertical direction having higher values than the parallel direction. The degree of texturization was calculated by measuring the vertical and parallel directions with adjacent meat. Using this value, the degree of texturization of cutting strength and cutting energy was calculated. Measurements were conducted using a physical testing machine (Z0.5 TS, ZwickRoell Co., Ltd.) with a Zwick Roell Warner-Bratzler shear device. The pre-test speed was set at 80 mm/min, with a testing speed of 80 mm/min and a trigger (preload) force of 0.1 N. The cutting strength and cutting energy were calculated using equations (4) and (5). The degree of texturization, which indicates the degree of fiber formation in meat, was calculated by substituting the values of the parallel and vertical cutting strength and cutting energy into equation (6) and the cutting energy into equation (7). The cutting strength and cutting energy of each sample and each degree of texturization were measured six times repeatedly.

$$\text{Cutting strength (g/cm}^2\text{)} = \text{Maximum stress / Cross-sectional area} \quad (4)$$

$$\text{Cutting energy (mJ/cm}^2\text{)} = \text{Energy at area of occurred by cutting / Cross-sectional area} \quad (5)$$

$$\text{Texturization degree of cutting strength} = CS_V / CS_P \quad (6)$$

CS_V: Cutting strength of vertical direction

CS_P: Cutting strength of parallel direction

$$\text{Texturization degree of cutting energy} = CE_V / CE_P \quad (7)$$

CE_V: Cutting energy of vertical direction

CE_P: Cutting energy of parallel direction

2.5. Color measurement

To ensure the representativeness of the measurements, color testing was conducted on homogenized samples. Before measurement, the meat was ground in a grinder (SFM-S0120WS, SHINIL, Cheonan, Korea) for at least 5 min. Color values L*, a*, and b* were measured using a benchtop spectrophotometer (CM-5, Konica Minolta Inc., Tokyo, Japan) with a wavelength resolution of 10 nm, conducting three measurements for each sample.

2.6. Statistical analysis

Statistical analysis of the results was conducted using IBM SPSS Statistics (version 27, IBM Corp., Armonk, NY, USA) employing one-way ANOVA. For items showing significant differences, Tukey's post-hoc test was performed at the $p< 0.05$ level. Additionally, Pearson correlation analysis was conducted to explore the relationships between variables.

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3. Results and discussion

3.1. Texture profile

3.1.1. Beef

The texture experiment results for beef before and after cooking are presented in Table 1. There were no significant differences in the hardness of raw beef among different cuts. Except for the shank, the hardness of other beef cuts significantly increased after cooking. This may be attributed to protein denaturation and moisture loss during cooking, which causes muscle fibers to become firmer (Sun et al., 2017). The shank, having a higher collagen content, is thought to soften during heat treatment, resulting in lower hardness compared to other cuts (Jeremiah et al., 2003). The springiness of beef was significantly higher when boiled compared to raw meat. Although there were no significant

Table 1. Texture profile of beef, pork, and chicken before and after cooking

	Parts of meat	Hardness (N)	Springiness (%)	Cohesiveness (%)	Chewiness (g)
Beef	Raw brisket	4.75±0.42[1)d2)]	42.62±3.05[bcd]	26.52±1.16[b]	55.58±5.61[d]
	Boiled brisket	32.61±3.42[abc]	55.17±4.23[a]	36.74±3.20[a]	671.88±94.93[a]
	Roasted brisket	34.47±4.91[ab]	48.66±4.28[ab]	37.85±1.49[a]	648.31±100.49[ab]
	Raw loin	11.09±1.85[d]	38.05±1.52[cd]	19.72±0.93[c]	84.74±11.43[d]
	Boiled loin	37.78±6.20[a]	46.70±4.62[ab]	31.00±4.75[b]	552.23±119.08[ab]
	Roasted loin	27.83±5.77[bc]	37.20±4.97[cd]	26.70±1.32[b]	286.66±91.54[c]
	Raw shank	10.14±2.12[d]	34.57±3.88[d]	17.77±3.54[c]	62.36±10.21[d]
	Boiled shank	25.37±5.34[c]	48.50±4.93[ab]	41.73±0.92[a]	521.61±102.48[b]
	Roasted shank	11.11±3.46[d]	45.63±7.49[bc]	37.56±4.49[a]	189.62±52.68[cd]
Pork	Raw Boston butt	2.89±0.56[c]	41.32±4.32[b]	31.20±2.53[bc]	37.46±4.27[c]
	Boiled Boston butt	25.77±3.85[a]	55.82±8.62[a]	27.99±3.16[cd]	407.62±53.99[b]
	Roasted Boston butt	27.03±6.24[a]	49.71±4.83[ab]	25.87±1.02[cd]	348.95±50.88[b]
	Raw hind leg	10.62±3.41[bc]	45.90±2.94[b]	27.95±4.30[cd]	133.20±18.04[c]
	Boiled hind leg	33.06±5.14[a]	48.31±2.86[ab]	40.44±4.18[a]	653.11±81.76[a]
	Roasted hind leg	32.13±7.82[a]	57.01±2.79[a]	39.75±1.66[a]	735.70±150.76[a]
	Raw loin	13.68±2.61[b]	44.84±3.26[b]	24.73±2.89[d]	152.15±15.85[c]
	Boiled loin	33.77±4.75[a]	48.07±3.67[ab]	40.33±3.10[a]	663.71±63.37[a]
	Roasted loin	34.18±6.92[a]	57.20±8.96[a]	33.72±1.76[b]	658.37±46.88[a]
Chicken	Raw breast	11.42±1.51[bc]	37.44±2.96[d]	21.51±3.10[b]	92.21±7.38[de]
	Boiled breast	18.45±2.63[a]	50.06±1.87[ab]	35.18±2.43[a]	325.12±43.18[a]
	Roasted breast	9.18±1.81[cd]	44.10±2.81[bcd]	27.98±1.76[ab]	115.15±15.43[cd]
	Raw tender	6.61±1.95[de]	48.91±6.96[abc]	22.73±3.62[b]	75.33±23.18[de]
	Boiled tender	13.16±2.50[b]	51.98±7.50[ab]	27.26±1.47[ab]	188.42±45.08[b]
	Roasted tender	11.42±2.65[bc]	43.56±2.25[bcd]	30.61±2.66[a]	153.18±25.51[bc]
	Raw drumstick	4.27±1.85[e]	39.25±2.12[cd]	22.07±1.96[b]	39.49±14.51[e]
	Boiled drumstick	6.24±2.05[de]	54.43±7.85[a]	27.79±8.57[ab]	93.68±38.33[de]
	Roasted drumstick	5.67±1.42[de]	49.59±4.94[ab]	27.03±5.60[ab]	78.29±27.37[de]

[1)]All values are mean±SD (n=6).
[2)]Different superscript letters ([a-e]) in the same column indicate significant differences ($p<0.05$) by Turkey's multiple range test.

differences in springiness between raw and roasted loin and brisket, the springiness of the shank significantly increased after roasting. Roasting can cause moisture loss, and since the loin and brisket have higher fat content, they lose less moisture, leading to smaller changes in springiness. In contrast, the lower fat content in the shank resulted in more significant changes in springiness (Jiao et al., 2020). In terms of cohesiveness, cooked beef was significantly higher than raw beef, with no significant differences between boiling and roasting. This finding is consistent with the results reported by Brady and Penfield (1981). For chewiness, cooked beef showed a notable increase compared to raw beef. Boiled beef had higher chewiness than roasted beef, though the difference in brisket was not significant. Yang et al. (2012) also compared the texture of sirloin prepared by grilling and boiling, finding that boiling enhanced chewiness more effectively than grilling. Correlation analysis revealed positive relationships among hardness, springiness, cohesiveness, and chewiness. Hardness was highly correlated with other values except for parallel cutting strength ($p<0.01$, Table 2). Chewiness was negatively correlated with b* value ($r=-0.441$, $p<0.05$, Table 2) and showed high correlations with other values except for vertical cutting energy ($p<0.01$, Table 2). This suggests that TPA measurements can express the textural quality of beef.

3.1.2. Pork

The texture experiment results for pork before and after cooking are presented in Table 1. The hardness of pork significantly increased after cooking. The Boston butt cut exhibited lower hardness compared to other cuts due to its higher fat content; however, this difference was not significant after cooking (Kim et al., 2008). While there was a trend toward increased springiness after cooking, there were no significant differences in springiness between the cooking methods. This finding is consistent with the research results of Djekic et al. (2021). In terms of cohesiveness, all cuts except for the Boston butt showed an increase after cooking, whereas the Boston butt did not exhibit significant changes. This may be related to the Boston butt’s fat content or its relatively high soluble fiber content (Bee et al., 1999). For chewiness, there were no significant differences among raw meats, but cooked Boston butt had lower chewiness due to its low cohesiveness. Correlation analysis revealed that hardness and chewiness were highly correlated with other results, except for the b* value ($p<0.01$, Table 3).

Table 2. Pearson correlation coefficients for the relationships between properties of beef

	H[1)]	S	CO	CH	CS-V	CS-P	DT-CS	CE-V	CE-P	DT-CE	L*	a*	b*
H	1	0.437**[2)]	0.463**	0.916**	-0.447**	-0.254	-0.556**	0.401**	0.597**	-0.602**	0.811**	-0.845**	-0.601**
S		1	0.630**	0.677**	-0.711**	-0.620**	-0.461**	-0.126	0.107	-0.557**	0.639**	-0.534**	-0.143
CO			1	0.693**	-0.614**	-0.355**	-0.645**	0.120	0.377**	-0.719**	0.711**	-0.657**	-0.248
CH				1	-0.629**	-0.478**	-0.567**	0.192	0.433**	-0.674**	0.928**	-0.835**	-0.441*
CS-V					1	0.863**	0.637**	0.401**	0.058	0.668**	-0.689**	0.548**	0.069
CS-P						1	0.179	0.698**	0.429**	0.391**	-0.533**	0.185	-0.306
DT-CS							1	-0.256	-0.533**	0.747**	-0.440*	0.717**	0.570**
CE-V								1	0.903**	-0.135	0.178	-0.533**	-0.739**
CE-P									1	-0.533**	0.509**	-0.787**	-0.704**
DT-CE										1	-0.815**	0.762**	0.190
L*											1	-0.858**	-0.337
a*												1	0.714**
b*													1

[1)]H, hardness; S, springiness; CO, cohesiveness; CH, chewiness; CS-V, cutting strength of vertical; CS-P, cutting strength of parallel; DT-CS, degree of texturization of cutting strength; CE-V, cutting energy of vertical; CE-P, cutting energy of parallel; DT-CE, degree of texturization of cutting energy.
[2)]*, and ** indicate that the correlations are significant at the $p<0.05$ and $p<0.01$ levels, respectively.

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Table 3. **Pearson correlation coefficients for the relationships between properties of pork**

	H[1)]	S	CO	CH	CS-V	CS-P	DT-CS	CE-V	CE-P	DT-CE	L*	a*	b*
H	1	0.370**[2)]	0.441**	0.918**	-0.779**	-0.846**	0.420**	0.635**	0.565**	0.429**	0.844**	-0.933**	0.075
S		1	0.266	0.536**	-0.431**	-0.487**	0.299*	0.426**	0.321*	0.404**	0.518**	-0.554**	0.341
CO			1	0.698**	-0.150	-0.351**	0.522**	0.593**	0.644**	0.053	0.646**	-0.481*	0.212
CH				1	-0.661**	-0.791**	0.546**	0.701**	0.653**	0.372**	0.916**	-0.888**	0.255
CS-V					1	0.912**	-0.067	-0.252	-0.181	-0.301*	-0.735**	0.804**	0.046
CS-P						1	-0.455**	-0.429**	-0.395**	-0.281*	-0.859**	0.893**	-0.117
DT-CS							1	0.527**	0.591**	0.026	0.510**	-0.417*	0.484*
CE-V								1	0.949**	0.439**	0.532**	-0.728**	0.037
CE-P									1	0.150	0.519**	-0.618**	0.071
DT-CE										1	0.244	-0.524**	-0.078
L*											1	-0.871**	0.352
a*												1	-0.059
b*													1

[1)]H, hardness; S, springiness; CO, cohesiveness; CH, chewiness; CS-V, cutting strength of vertical; CS-P, cutting strength of parallel; DT-CS, degree of texturization of cutting strength; CE-V, cutting energy of vertical; CE-P, cutting energy of parallel; DT-CE, degree of texturization of cutting energy.
[2)]*, and ** indicate that the correlations are significant at the $p<0.05$ and $p<0.01$ levels, respectively.

3.1.3. Chicken

The texture experiment results for chicken before and after cooking are presented in Table 1. Chicken exhibited lower firmness compared to other meats, which can be attributed to the properties of muscle fiber proteins and high collagen solubility (Listrat et al., 2016; Voutila, 2009). Unlike other parts the hardness, cohesiveness, and chewiness of drumsticks did not show a significant increase after heat treatment. This finding is consistent with the study by Young et al. (1991), which showed that hardness, springiness, and cohesiveness decreased as fat content increased. Boiled chicken exhibited slightly increased hardness and springiness compared to raw or grilled chicken, which contrasts with the findings of Jiao et al. (2020) but is consistent with those of Choi et al. (2016). Cohesiveness did not show significant increases after cooking but exhibited a rising trend. Chewiness also trended upward during cooking, although it was not significant for the drumstick cut. This may be due to the drumstick's higher fat content, resulting in lower hardness and chewiness (Bordoni and Danesi, 2017). Among various cooking methods, boiling had the greatest impact on increasing chewiness, especially for chicken breast, which achieved the highest chewiness value of 325.12±43.18. Correlation analysis indicated that the TPA results for chicken showed low correlation with cutting test values. In contrast, cohesiveness and chewiness displayed high correlation with color values ($p<0.01$, Table 4).

3.2. Degree of texture of cutting strength and cutting energy

3.2.1. Beef

Table 5 illustrates the changes in cutting strength and cutting energy for various beef cuts after cooking. Raw meat was cut in the vertical direction, making the measurement method for Warner-Bratzler shear strength like that of vertical cutting strength. The vertical cutting strength of raw meat was highest in the shank, followed by brisket and loin, aligning with shear strength measurements in previous studies and showing a strong correlation with total collagen and insoluble collagen content (Torrescano et al., 2003). Compared to shear test results from Lu et al. (2022), the cutting strength values showed no increasing trend after cooking. This finding is consistent with the study by Hearne et al. (1978), which suggests that cooking increases collagen solubility and that the hardening of myofibrillar proteins may reduce the cutting value. However, brisket exhibited a tendency for both cutting energy and cutting strength to increase after cooking. The

Table 4. Pearson correlation coefficients for the relationships between properties of chicken

	H[1)]	S	CO	CH	CS-V	CS-P	DT-CS	CE-V	CE-P	DT-CE	L*	a*	b*
H	1	-0.007	0.381**[2)]	0.902**	-0.251	-0.290*	0.044	0.161	-0.010	0.503**	0.460*	-0.476*	-0.447*
S		1	0.243	0.272*	-0.343*	-0.253	-0.242	-0.080	-0.028	-0.175	0.437*	-0.523**	-0.518**
CO			1	0.653**	-0.077	-0.137	0.110	0.266	0.200	0.336*	0.667**	-0.488**	-0.552**
CH				1	-0.226	-0.246	0.007	0.189	0.056	0.452**	0.631**	-0.570**	-0.587**
CS-V					1	0.901**	0.373**	0.472**	0.625**	0.112	0.071	0.241	0.171
CS-P						1	-0.037	0.181	0.398**	-0.150	-0.045	0.306	0.273
DT-CS							1	0.765**	0.632**	0.653**	0.347	-0.121	-0.241
CE-V								1	0.931**	0.732**	0.679**	-0.373	-0.456*
CE-P									1	0.455**	0.646**	-0.337	-0.419*
DT-CE										1	0.470*	-0.304	-0.331
L*											1	-0.896**	-0.927**
a*												1	0.976**
b*													1

[1)]H, hardness; S, springiness; CO, cohesiveness; CH, chewiness; CS-V, cutting strength of vertical; CS-P, cutting strength of parallel; DT-CS, degree of texturization of cutting strength; CE-V, cutting energy of vertical; CE-P, cutting energy of parallel; DT-CE, degree of texturization of cutting energy.
[2)]*, and ** indicate that the correlations are significant at the p<0.05 and p<0.01 levels, respectively.

degree of texturization derived from cutting strength and cutting energy indicated that raw meat had a higher degree of texturization than cooked meat. This is due to the higher vertical cutting strength of raw meat compared to cooked meat. The cutting strength values of raw meat in the vertical direction were higher than cooked meat, while the cutting energy values were significantly lower than those of cooked meat. This is because the cutting strength value represents the peak pressure generated during cutting, while cutting energy reflects the total energy required to cut. Although raw meat is generally soft, a high cutting strength is recorded due to the need to sever the muscle fibers. Notably, beef hardness was negatively correlated with vertical cutting strength (r=-0.447, p<0.01, Table 2). This is because cooking increases the hardness of the meat but reduces its vertical cutting strength. At the same time, hardness showed a positive correlation with vertical cutting energy (r=0.401, p<0.01, Table 2) and parallel cutting energy (r=0.597, p<0.01, Table 2). The TPA measurement results exhibited a negative correlation with the degree of texturization in cutting strength (r=-0.647 to -0.461, p<0.01, Table 2) and cutting energy (r=-0.719 to -0.557, p<0.01, Table 2). After cooking, TPA measurement results trended to increase, corresponding to the decrease in degree of texturization.

3.2.2. Pork

According to Table 5, there is a significant decrease in cutting strength for pork after cooking. Laville et al. (2007) noted that the reduction in cutting strength may be related to the accumulation of adipocytes within the muscle. The vertical cutting strength of raw meat was highest in pork belly, followed by hind leg and loin, with similar order for parallel cutting strength, though no significant differences were observed. There were no significant differences in cutting energy among the raw meat samples. Roasted pork belly did not show a significant increase in cutting energy after cooking, possibly due to the high fat content being rendered during roasting, which, while making the tissue firmer, also led to softening (Bkiskey et al., 1960). In contrast, boiling caused fat to leach out, reducing the fat content in the tissue and resulting in higher cutting energy compared to roasting (Jeon et al., 2015). The texture of pork did not show a significant increase or did not exhibit significant changes. The degree of texturization in the cutting strength of the hind leg pork significantly increased after cooking, reaching 1.98±0.10 after boiling, the highest among the samples. The degree of texturization derived from cutting energy showed boiled pork belly ranking first at 1.94±0.17. This is because the cutting strength in both the vertical and

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Table 5. Cutting strength and cutting energy with degree of texturization (DT) of beef, pork, and chicken before and after cooking

	Parts of meat	Cutting strength (g/cm^2)		DT of CS	Cutting energy (mJ/cm^2)		DT of CE
		Vertical	Parallel		Vertical	Parallel	
Beef	Raw brisket	7,404.16±1,137.09[1)]^{bc}[2)]	3,454.00±510.12^{bc}	2.14±0.09^{b}	106.77±16.44^{de}	46.86±7.71^{fg}	2.28±0.11^{a}
	Boiled brisket	3,773.46±164.15^{ef}	2,881.44±155.98^{cd}	1.31±0.02^{e}	164.94±22.48^{bc}	116.30±13.14^{b}	1.42±0.06^{g}
	Roasted brisket	8,743.51±300.00^{ab}	5,243.24±498.72^{a}	1.68±0.11^{cd}	267.73±19.85^{a}	144.33±12.78^{a}	1.86±0.06^{cd}
	Raw loin	4,589.31±571.15^{e}	2,499.78±355.57^{de}	1.84±0.14^{c}	78.60±14.35^{e}	39.61±5.26^{g}	1.97±0.13^{bc}
	Boiled loin	2,712.12±485.43^{f}	1,613.52±69.60^{f}	1.67±0.22^{cd}	124.76±16.63^{d}	78.10±9.33^{de}	1.60±0.11^{ef}
	Roasted loin	2,893.40±585.37^{f}	1,840.51±62.46^{ef}	1.57±0.28^{cde}	134.59±3.81^{cd}	100.57±9.65^{bc}	1.35±0.1^{g}
	Raw shank	9,286.32±2,094.35^{a}	3,783.26±731.86^{b}	2.44±0.15^{a}	125.59±16.53^{d}	61.03±7.73^{ef}	2.06±0.10^{b}
	Boiled shank	6,294.18±624.50^{cd}	3,695.21±639.62^{bc}	1.72±0.16^{c}	185.43±21.71^{b}	104.94±8.58^{bc}	1.76±0.07^{de}
	Roasted shank	4,822.98±234.64^{de}	3,392.38±287.94^{bc}	1.43±0.06^{de}	134.46±7.92^{cd}	93.17±8.27^{cd}	1.45±0.05^{fg}
Pork	Raw Boston butt	6,518.93±248.56^{a}	4,169.43±543.57^{a}	1.58±0.16^{b}	70.67±5.68^{d}	49.93±4.20^{c}	1.42±0.05^{d}
	Boiled Boston butt	4,103.79±227.50^{c}	2,897.49±193.94^{c}	1.42±0.03^{bc}	176.74±20.82^{b}	90.72±3.03^{b}	1.94±0.17^{a}
	Roasted Boston butt	2,054.50±76.65^{f}	1,429.41±145.98^{e}	1.45±0.11^{bc}	86.31±9.55^{d}	55.32±9.58^{c}	1.58±0.13^{bcd}
	Raw loin	4,247.38±219.24^{c}	3,283.64±150.50^{bc}	1.29±0.03^{c}	65.42±1.88^{d}	45.28±4.33^{c}	1.45±0.10^{cd}
	Boiled loin	2,937.30±178.67^{e}	2,128.83±196.33^{d}	1.38±0.07^{bc}	133.79±8.43^{c}	77.15±6.11^{b}	1.74±0.06^{ab}
	Roasted loin	3,074.67±267.92^{de}	1,568.91±144.66^{de}	1.96±0.13^{a}	144.63±12.92^{c}	87.78±3.89^{b}	1.65±0.08^{bc}
	Raw hind leg	5,735.88±462.64^{b}	3,837.49±689.03^{ab}	1.52±0.18^{b}	84.27±9.73^{d}	51.61±8.94^{c}	1.66±0.20^{bc}
	Boiled hind leg	4,037.33±895.46^{c}	2,041.26±423.86^{de}	1.98±0.10^{a}	209.50±11.02^{a}	137.15±20.34^{a}	1.55±0.15^{bcd}
	Roasted hind leg	3,697.34±265.85^{cd}	1,915.49±103.06^{de}	1.93±0.07^{a}	154.63±14.30^{c}	92.00±10.47^{b}	1.68±0.04^{b}
Chicken	Raw breast	1,378.69±187.92^{d}	904.77±65.84^{ef}	1.52±0.13^{c}	34.26±3.94^{de}	20.11±10^{ef}	1.70±0.14^{c}
	Boiled breast	1,894.76±537.81^{cd}	1,014.34±84.08^{de}	1.85±0.39^{c}	73.07±18.02^{b}	34.72±3.10^{bcd}	2.08±0.35^{ab}
	Roasted breast	2,967.63±353.33^{b}	1,060.76±275.40^{de}	2.89±0.44^{a}	136.93±7.99^{a}	61.31±8.55^{a}	2.26±0.22^{a}
	Raw tender	1,217.96±198.50^{d}	641.31±80.09^{f}	1.89±0.14^{bc}	28.15±5.38^{e}	18.63±1.70^{f}	1.50±0.19^{c}
	Boiled tender	2,712.12±485.43^{bc}	1,613.52±69.60^{b}	1.67±0.22^{bc}	75.96±12.19^{b}	42.96±4.51^{b}	1.76±0.16^{bc}
	Roasted tender	2,904.36±466.94^{b}	1,452.83±133.61^{bc}	1.99±0.16^{b}	63.01±4.91^{bc}	35.99±7.52^{bcd}	1.79±0.25^{bc}
	Raw drumstick	4,941.86±921.10^{a}	2,681.01±207.32^{a}	1.84±0.25^{bc}	62.49±6.66^{bc}	40.84±4.05^{bc}	1.53±0.05^{c}
	Boiled drumstick	1,529.37±190.74^{d}	1,012.11±112.51^{de}	1.51±0.08^{c}	48.09±3.05^{cd}	32.97±4.71^{cd}	1.47±0.12^{c}
	Roasted drumstick	1,699.65±103.69^{d}	1,182.64±125.22^{cd}	1.44±0.07^{c}	42.70±3.48^{de}	28.67±2.51^{de}	1.49±0.02^{c}

[1)]All values are mean±SD (n=6).
[2)]Different superscript letters ($^{a-e}$) in the same column indicate significant differences ($p<0.05$) by Turkey's multiple range test.

parallel direction decreased after cooking, and the ratio of the cutting strength decrease in the parallel direction is higher than that in the vertical direction. Vertical except for cohesiveness, cutting measurements showed a positive correlation with TPA measurements. The difference in the correlation between pork and beef was that, for beef, TPA measurements exhibited negative correlations with the degree of texturization based on cutting strength and energy (Table 2). In contrast, pork displayed positive correlations, except for the correlation between cohesiveness and the degree of texturization based on cutting energy (Table 3). This difference is attributed to the tendency of beef to show a decrease in the degree of texturization after cooking, whereas pork tended to exhibit an increase.

3.2.3. Chicken

The cutting strength and cutting energy of chicken are lower than those of other meats due to its white meat characteristics (Xiong, 1994). Both breast and loin showed an upward trend in cutting strength and energy after cooking. When the vertical cutting strength of boiled and roasted breasts was compared, the vertical cutting strength of breast increased from 1,378.69±187.92 g/cm^2 before cooking (Table 5) to 2,967.63±353.33 g/cm^2 after roasting, while the vertical cutting strength of boiled chicken breast increased to 1,894.76 ±537.81 g/cm^2. This finding is consistent with the study by Chumngoen et al. (2018), which reported higher shear force for roasted breasts. The drumstick exhibited significantly higher cutting strength and cutting energy compared to other raw chicken parts before cooking. However, cutting strength decreased significantly after cooking, while cutting energy decreased significantly after roasting and decreased insignificantly after boiling. According to Weng et al. (2022), this can be attributed to the high oxidative fiber content in the drumstick muscles, which increased the shear value compared to other parts. Among the degree of texturization derived from cutting strength, only roasted breast meat showed a significant increase at 2.89±0.44, while other parts did not exhibit significant differences. This is because the parallel cutting strength exhibited little change, while the vertical cutting strength increased significantly.

The cutting energy of the breast significantly increased after cooking, primarily due to a greater increase in vertical cutting energy compared to that in the parallel direction. Unlike beef and pork, there is a low correlation between cutting experiment results and TPA results; however, the degree of texturization from cutting energy shows positive correlations with hardness, cohesiveness, and chewiness (r= 0.503, r=0.336, r=0.452, Table 4).

3.3. Color

Table 6 shows the color measurement results for beef, pork, and chicken. According to the color analysis results in Table 6, there is no significant difference in the L* and a* values of raw beef. After cooking, the L* value increases while the a* value decreases in beef. This is consistent with the findings of Oz et al. (2017), but the b* value shows no significant difference or a downward trend after cooking, which is inconsistent with their study. Cornforth et al. (1986) point out that the color of cooked meat is influenced by the levels of nitric oxide, myoglobin, niacin, globin, and hemoglobin. Correlation analysis indicates that the TPA measurements of cooked beef are positively correlated with the L* value and negatively correlated with the a* value ($p<0.01$, Table 2). There is a strong negative correlation in beef between the L* and a* values ($r=-0.858$, $p<0.01$, Table 2), while a* and b* values are strongly positively correlated ($r=0.714$, $p<0.01$, Table 2).

When examining the color changes in pork, the L* value increases after cooking, while the a* value decreases. This is consistent with the findings of Yang et al. (2009). The a* values of raw pork are ranked as Boston butt, hind leg, and loin, which correlates with the levels of myoglobin found in Bkiskey’s et al. (1960) research. The b* value of Boston butt before cooking is 17.81±0.63, which decreases to 15.57±0.47 after cooking; while the b* value of loin before cooking is 17.27±0.32, which increases to 20.12±0.06 after cooking. These results suggest that the degree of Maillard reaction occurring during cooking may have an effect (Park, 2008). The L* value shows high correlation with other measurement indicators, except for the degree of texturization induced by cutting energy and b* value ($p<0.01$, Table 3). The a* value is also correlated with other measurement indicators, except for the b* value ($p<0.05$, Table 3). The b* value is only correlated with the degree of texturization of cutting strength ($r=0.484$, $p<0.05$, Table 3).

The L* and a* values of chicken significantly decrease after cooking, which is consistent with the findings of Fletcher et al. (2000) and Qiao et al. (2002). The b* value also significantly decreases after cooking. The L* value is higher in breast and loin than in drimstick, while the a* value is higher in drumstick than in breast and loin. Nusairat et al. (2022) point out that this is because chicken breast and loin mainly consist of white fibers with low myoglobin content, while drumstick is made up of dark red fibers with high myoglobin content. The color values show correlation with TPA analysis results ($p<0.01$, Table 4). There is a significant negative correlation between the a* and b* values ($r=-0.896$, $p<0.01$, Table 4); a significant negative correlation between the b* and L* values ($r=-0.927$, $p<0.01$, Table 4); and a significant positive correlation between the b* and a* values ($r=0.976$, $p<0.01$, Table 4).

3.4. Integrated assessment

Table 7 shows the effects of roasting and boiling on beef,

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Table 6. Color values (L*, a*, and b*) of beef, pork, and chicken before and after cooking

Species	Parts	L*	a*	b*
Beef	Raw shank	40.55±0.53[1)d2)]	15.32±1.14[a]	17.95±0.60[a]
	Boiled shank	48.32±0.59[bc]	7.03±0.22[c]	14.45±0.16[d]
	Roasted shank	46.19±0.24[c]	8.77±0.06[b]	16.32±0.19[bc]
	Raw loin	40.29±1.15[d]	14.89±0.27[a]	17.81±0.67[a]
	Boiled loin	55.43±0.29[a]	4.31±0.06[e]	14.50±0.19[d]
	Roasted loin	55.95±0.37[a]	6.83±0.17[c]	17.11±0.13[ab]
	Raw brisket	39.01±0.44[d]	15.26±0.29[a]	15.76±0.22[c]
	Boiled brisket	48.79±0.75[b]	4.91±0.14[de]	14.10±0.30[de]
	Roasted brisket	46.27±0.60[c]	6.29±0.23[cd]	13.22±0.08[e]
Pork	Raw Boston butt	50.18±0.35[f]	13.44±0.19[a]	17.81±0.63[ab]
	Boiled Boston butt	57.02±0.40[d]	2.38±0.15[e]	16.01±0.13[bc]
	Roasted Boston butt	64.29±0.44[c]	2.97±0.16[de]	15.57±0.47[c]
	Raw loin	53.35±0.80[e]	9.83±0.46[c]	17.27±0.32[abc]
	Boiled loin	74.59±0.31[a]	1.36±0.11[f]	16.9±1.41[abc]
	Roasted loin	75.52±0.07[a]	1.14±0.00[f]	18.12±0.06[a]
	Raw hind leg	50.08±0.11[f]	11.46±0.38[b]	16.18±0.10[abc]
	Boiled hind leg	66.86±0.38[b]	2.64±0.10[e]	16.85±0.46[abc]
	Roasted hind leg	65.76±0.20[b]	3.53±0.12[d]	17.11±0.34[abc]
Chicken	Raw breast	59.40±0.34[g]	6.46±1.06[b]	21.69±0.60[a]
	Boiled breast	82.55±0.06[a]	1.31±0.07[e]	14.48±0.03[e]
	Roasted breast	82.30±0.08[ab]	2.68±0.16[d]	15.34±0.04[d]
	Raw tender	60.08±0.29[f]	5.23±0.29[c]	18.54±0.22[b]
	Boiled tender	82.78±0.11[a]	0.11±0.01[f]	13.52±0.33[e]
	Roasted tender	81.78±0.09[b]	1.24±0.18[ef]	14.04±0.06[e]
	Raw drumstick	61.04±0.07[e]	8.20±0.35[a]	22.28±0.10[a]
	Boiled drumstick	72.75±0.10[d]	2.31±0.11[de]	16.37±0.13[c]
	Roasted drumstick	73.86±0.12[c]	2.49±0.19[d]	16.12±0.09[cd]

[1)]All values are mean±SD (n=3).
[2)]Different superscript letters ([a-e]) in the same column indicate significant differences ($p<0.05$) by Turkey's multiple range test.

pork, and chicken. Both cooking methods improved the TPA results for beef, pork, and chicken. Before cooking, there were no significant differences in hardness among the three types of meat. In beef, the hardness and chewiness after boiling were significantly higher than after roasting, while there were no significant differences in hardness and chewiness between the cooking methods for other cuts. The differences in hardness and chewiness of chicken before and after cooking were not significant. Springiness and cohesiveness increased after cooking, with no significant differences between boiling and roasting.

The vertical cutting strength showed a decreasing trend after cooking. Although roasting did not significantly reduce the vertical cutting strength of beef, boiling resulted in a significant decrease. The vertical cutting strength of pork significantly decreased during both roasting and boiling.

Table 7. The texture and color results for raw, roasted and boiled beef, pork and chicken

	H$^{1)}$ (N)	S (%)	CO (%)	CH	CS-V (g/cm^2)	CS-P (g/cm^2)	DT-CS	CE-V (mJ/cm^2)	CE-P (mJ/cm^2)	DT-CE	L*	a*	b*
L-BF	8.66 ±3.26$^{2)c4)}$	38.41 ±4.40$^{2)e}$	21.34 ±4.39$^{2)d}$	67.56 ±15.58$^{2)d}$	7,093.27 ±2,389.72$^{2)a}$	3,245.68 ±764.81$^{2)ab}$	2.14 ±0.28$^{2)a}$	103.65 ±24.81$^{2)cd}$	49.16 ±11.27$^{2)c}$	2.11 ±0.17$^{2)a}$	39.95 ±1.09$^{3)e}$	15.16 ±0.77$^{3)a}$	17.17 ±1.20$^{3)bc}$
R-BF	24.47 ±11.08^{b}	43.83 ±7.35^{de}	34.04 ±5.97^{ab}	374.86 ±217.94^{b}	5,486.63 ±2,533.00^{ab}	3,492.04 ±1,465.34^{ab}	1.56 ±0.20^{c}	178.93 ±65.68^{a}	112.69 ±25.20^{a}	1.55 ±0.24^{cd}	49.47 ±4.88^{d}	7.29 ±1.14^{c}	15.55 ±1.79^{cde}
B-BF	31.92 ±7.11^{a}	50.13 ±5.72^{abc}	36.49 ±5.50^{a}	581.91 ±119.84^{a}	4,259.92 ±1,606.71^{bc}	2,730.06 ±951.72^{bc}	1.57 ±0.24^{c}	158.38 ±32.26^{ab}	99.78 ±19.23^{a}	1.59 ±0.16^{cd}	50.90 ±3.46^{d}	5.42 ±1.25^{d}	14.35 ±0.30^{e}
L-PK	9.06 ±5.23^{c}	44.02 ±3.90^{cde}	27.96 ±4.14^{c}	107.60 ±53.64^{cd}	5,500.73 ±1,017.40^{ab}	3,763.52 ±612.01^{a}	1.47 ±0.18^{c}	73.46 ±10.26^{def}	48.94 ±6.46^{c}	1.51 ±0.16^{d}	51.20 ±1.70^{d}	11.57 ±1.61^{b}	17.08 ±0.84^{bc}
R-PK	31.11 ±7.29^{a}	54.64 ±6.76^{a}	33.11 ±6.02^{abc}	581.01 ±197.85^{a}	2,942.17 ±727.46^{cde}	1,637.94 ±244.47^{de}	1.78 ±0.26^{bc}	128.52 ±33.12^{bc}	78.37 ±18.65^{b}	1.64 ±0.10^{bcd}	68.52 ±5.29^{b}	2.55 ±1.09^{e}	17.60 ±2.04^{b}
B-PK	30.87 ±5.71^{ab}	50.73 ±6.48^{ab}	36.25 ±6.86^{a}	574.82 ±140.09^{a}	3,692.81 ±750.61^{cd}	2,355.86 ±481.56^{cd}	1.59 ±0.29^{c}	173.34 ±34.66^{a}	101.67 ±28.88^{a}	1.74 ±0.21^{bcd}	66.16 ±7.63^{bc}	2.13 ±0.60^{e}	16.59 ±1.01^{bcd}
L-CN	7.44 ±3.49^{c}	41.86 ±6.71^{de}	22.10 ±2.84^{d}	69.01 ±28.19^{d}	2,512.84 ±1,843.82^{de}	1,409.03 ±940.53^{e}	1.75 ±0.24^{c}	41.63 ±16.22^{f}	26.53 ±10.71^{d}	1.58 ±0.16^{cd}	60.17 ±0.77^{c}	6.63 ±1.41^{cd}	20.84 ±1.78^{a}
R-CN	8.76 ±3.09^{c}	45.75 ±4.34^{bcd}	28.54 ±3.83^{bc}	115.54 ±39.60^{cd}	2,523.88 ±681.45^{de}	1,232.07 ±246.15^{e}	2.11 ±0.67^{ab}	80.88 ±42.01^{de}	41.99 ±15.72^{cd}	1.85 ±0.37^{b}	79.31 ±4.10^{a}	2.14 ±0.69^{e}	15.17 ±0.91^{cde}
B-CN	12.62 ±5.62^{c}	52.16 ±6.25^{a}	30.08 ±6.15^{bc}	202.41 ±106.49^{c}	2,045.42 ±651.12^{e}	1,213.32 ±303.34^{e}	1.68 ±0.28^{c}	65.71 ±17.54^{ef}	36.88 ±5.95^{cd}	1.77 ±0.34^{bc}	79.36 ±4.96^{a}	1.17 ±1.08^{e}	14.72 ±1.31^{de}

1)H, hardness; S, springiness; CO, cohesiveness; CH, chewiness; CS-V, cutting strength of vertical; CS-P, cutting strength of parallel; DT-CS, degree of texturization of cutting strength; CE-V, cutting energy of vertical; CE-P, cutting energy of parallel; DT-CE, degree of texturization of cutting energy; L, law; R, roasted; B, boiled; BF, beef; PK, pork; CN, chicken.
2)All values are mean±SD (n=6).
3)All values are mean±SD (n=3).
4)Different superscript letters ($^{a-e}$) in the same column indicate significant differences ($p<0.05$) by Turkey's multiple range test.

There was no significant difference in vertical cutting strength between cooked and uncooked chicken. Additionally, there were no significant differences in vertical cutting strength between boiling and roasting. The parallel cutting strength of pork significantly decreased after cooking, while there were no significant differences for beef and chicken. There were also no significant differences in parallel cutting strength between roasting and boiling. The degree of texturization of cutting strength in beef decreased from 2.14±0.28 before cooking to 1.56±0.20 during roasting and 1.57±0.24 during boiling. The degree of texturization of cutting strength in pork showed no significant differences after roasting and boiling. The degree of texturization of cutting strength in chicken increased from 1.75±0.24 after roasting to 2.11±0.67, significantly higher than the 1.68±0.28 after boiling. The vertical and parallel cutting strengths were highest in beef, followed by pork and chicken. Both vertical and parallel cutting energies significantly increased after cooking. There were no significant differences in vertical and parallel cutting energies between roasting and boiling for beef and chicken, whereas boiled pork had significantly higher vertical and parallel cutting energies than roasted pork. The degree of texturization of cutting energy in beef decreased from 2.11±0.17 before cooking to 1.55±0.24 and 1.59±0.16 after roasting and boiling, respectively. There were no significant differences in the degree of texturization of cutting energy for pork before and after cooking, while chicken increased from 1.58±0.16 before cooking to 1.85±0.37 after roasting; the value after boiling was 1.77±0.34, which was an increase but not significant.

After cooking, both the L* and a* values decreased. There were no significant differences in the b* value of pork before and after cooking, while the b* values of beef and chicken showed a decreasing trend after cooking. The L* value was highest in chicken, followed by pork and beef. Among the red a* values, beef was highest, and the a* value of pork before cooking was significantly higher than that of beef, while there were no significant differences between the a*

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values of pork and chicken after cooking. The b* value of raw chicken was 20.84±1.78, which was significantly high. There were no differences in color among cooking methods.

4. Conclusions

This study examined the effects of roasting and boiling on the texture and color of beef, pork, and chicken using texture profile analysis, cutting tests, and color tests. Results showed that cooking methods significantly influenced meat quality, with variations depending on meat type and cooking style. Chicken exhibited the lowest hardness and chewiness after cooking, with roasting preserving texture better than boiling for most cuts. Vertical cutting strength decreased for beef and pork post-cooking, while chicken remained unchanged. The degree of texturization in cutting strength increased in pork loin and hind leg but decreased in other cuts. Cutting energy increased across all species, with chicken exhibiting the lowest values in both vertical and horizontal directions. Color analysis revealed increased L* (lightness) values and decreased a* (redness) values after cooking, while b* (yellowness) showed minimal change. Chicken had the highest L* values, while beef had the highest a* values. These findings provide insights into optimizing cooking methods to enhance meat quality and consumer satisfaction, contributing to quality control standards and the development of meat alternatives.

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Conflict of interests

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Author contributions

Conceptualization: Gu BJ. Methodology: Kim J, Han Y, Lee Y, Kang C, Gu BJ. Formal analysis: Kim J, Han Y, Lee Y, Kang C, Jung H. Validation: Kim J, Han Y, Lee Y, Kang C, Gu BJ. Writing - original draft: Kim J, Zhang Y, Gu BJ. Writing - review & editing: Kim J, Zhang Y, Gu BJ.

Ethics approval

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

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