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ARTICLE

Meat Tenderness Characteristics of Ten Major Muscles from Hanwoo Steers according to Quality Grades of Carcasses

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Abstract

The objective of this study was to determine the influence of quality grade (QG) on meat tenderness characteristics of ten major muscles from Hanwoo steers. A total of 25 Hanwoo carcasses (5 carcasses × 5 QGs) were selected. Intramuscular fat content, collagen content, sarcomere length, and Warner-Bratzler shear force (WBSF) of *Longissimus thoracis* (LT), *Longissimus lumborum* (LL), *Psoas major* (PM), *Semisponals* (SS), *Triceps brachii* (TB), *Semimembranosus* (SM), *Gluteus medius* (GM), *Rectus Abdominis* (RA), *Superficialis flexor* (SF), and *Internal and external intercostal* (IC) were determined. IC had the highest fat content, followed by LT, RA, LL, PM, GM, SS, SF, TB, and SM. High-fat muscles such as LT, LL, IC, RA, and PM had significantly ($p<0.05$) different fat contents among QGs. Collagen contents were significantly ($p<0.05$) different among QGs. With decreasing QG, increasing collagen content was found in muscles. There were significant ($p<0.05$) differences in sarcomere length among QGs of several muscles. However, no significant ($p>0.05$) difference in sarcomere length was found among QGs for LL, PM, or RA muscle. PM had the lowest WBSF, followed by LL, LT, RA, IC, GM, SM, SF, SS, and TB. WBSF of QG 1^{++} was lower than that of QG 1 for SS, TB, and SM. All muscles of QG 1 showed lower WBSF than QG 3 except TB or IC. Results of this study suggested that differences in WBSF among these 10 muscles by QG were due to differences in collagen content and sarcomere length.

Keywords beef tenderness, Hanwoo muscles, quality grade, intramuscualr fat, shear force

Introduction

Meat tenderness is the most important eating quality trait because it strongly influences consumer's perception of acceptability. Tenderness is mainly affected by amount and solubility of connective tissue, composition and contractile state of muscle fibers, and proteolysis extent of rigor muscle (Joo *et al*., 2013). Intramuscular fat (IMF) content can also indirectly affect meat tenderness. In fact, high marbled and tender meat at reasonable prices has been always important to consumers. Marbling has been implicated as a contribution factor to beef palatability in the last few decades because increased marbling level has positive effect on beef tenderness, juiciness, flavor, and overall palatability (Emerson *et al*., 2013; O'Quinn *et al*., 2012; Savell *et al*., 1987; Smith *et al*., 1985). For these reasons, demand for marbled and tender beef continues to grow due to income increases in Korea with shift in choice preferences. However, very few studies have investigated the relationship between marbling and tenderness in relation to quality grade

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(QG) of Hanwoo carcasses.

In Korea, highly marbled beef is preferred by consumers. Hanwoo producers continue to develop effective production and feeding systems to increase marbling level of loin muscles. Consequently, QG of beef carcass has increased from 3 QGs (QG 1, QG 2, and QG 3) to 5 QGs by addition of QG 1^{+} and QG 1^{++} which are very highly marbled carcass (Joo *et al*., 2017). Hanwoo beef with QG 1^{++} or 1^{+} is now considered as a premium class of beef in Korea. Of Hanwoo cattle slaughtered in 2015, 10.0%, 26.4%, and 31.4% had QG 1^{++}, QG 1^{+}, and QG 1, respectively (KAPE, 2017). Meanwhile, some consumers have complaints that different ratio of marbling for many muscles from the hind part or the forepart of carcass is not same as loin cuts have 5 QGs. Such complaints are based on the fact that there are no differences in tenderness or intramuscular fat content among many muscles except loin muscle with price difference. In this regards, it is important to determine marbling level and tenderness of major muscles obtained from 10 primal cuts of Hanwoo carcass. In addition, the relationship between marbling level and tenderness of these 10 major muscles needs to be determined so that utilization of individual cuts from Hanwoo carcass could be improved. Therefore, the objective of this study was to determine fat content and tenderness traits of 10 major muscles from Hanwoo carcass.

Materials and Methods

Sample preparation

A total of 25 Hanwoo steer carcasses were selected at commercial plants and 10 major muscles were sampled from 10 primal cuts. A total of 25 carcasses (5 carcasses × 5 five QGs) were used. QGs (1^{++}, 1^{+}, 1, 2, and 3) was primarily determined by the degree of marbling using Korean Beef Marbling Standard (BMS). The following 10 muscles were used in this study: *Longissimus thoracis* (LT), *Longissimus lumborum* (LL), *Psoas major* (PM), *Semisponals* (SS), *Triceps brachii* (TB), *Semimembranosus* (SM), *Gluteus medius* (GM), *Rectus Abdominis* (RA), *Superficialis flexor* (SF), and *Internal and external intercostal* (IC). At 24 h of chilling after slaughter, ten muscles were removed to investigate intramuscular fat content, collagen content, sarcomere length, and shear force of these muscles.

Intramuscular fat content

Fat content was determined using modified method of Folch *et al*. (1957). Briefly, lipid was extracted from 3 g of homogenized meat sample using 30 ml of Folch solution I (chloroform : methanol = 2 : 1, v/v). The homogenate was filtered with Whatman no.1 filter paper. Filtered solution was mixed with 0.88% of NaCl by stirring. The solution was then allowed to separate into two layers. After washing the wall of a measuring cylinder with 10 ml of Folch solution II (chloroform : methanol : H_2O = 3: 47:50), the final volume of the lower layer was recorded. The upper layer (methanol and water layer) was removed using an aspirator. Then 10 mL of the lower layer (chloroform containing lipid extracts) was added into a dish to dry at 50°C. The weight of the dish was measured before and after drying. Fat content was computed based on weight difference of the dish.

Collagen content

Collagen content was determined using method of AOAC (2000). Total collagen content was determined in duplicates for approximated 4 g of minced meat sample. After adding 30 mL of H_2SO_4 to the sample, hydrolysis was subsequently performed at 105°C for 16 h. After hydrolysis, water was added to the sample to reach a total volume of 500 mL. Filtered solution (5 mL) was then passed through a Whatman no.1 filter paper and diluted to 100 mL. After adding 1 mL of oxidant solution (50 mM of chloramine-T hydrate, 156 mM citric acid, 375 mM NaOH, 661 mM sodium acetate trihydrate, 29% v/v 1-propanol, pH 6.0) to 2 mL of the diluted solution, samples were vortexed and left at room temperature for 20 min before adding 1 mL of color regent (246 mM of 4-dimethylaminobenzaldehyde, 35% v/v perchloric acid, and 65% v/v 2-propanol). Samples were then vortexed, covered with foil, and then placed in a water bath at 60°C for 15 min. Samples were cooled in running water for 3 min before measuring its absorbance at wavelength of 558 nm. Hydroxyproline content was calculated from a standard curve obtained with the following: 1.2, 2.4, 3.6, and 4.8 μg hydroxyproline per ml of H_2O. Results were calculated using the following equation: Total collagen content = Hydroxyproline × 8. Results were expressed as mg/g of meat.

Sarcomere length

Sarcomere length was determined using the method of Cross *et al*. (1981). Briefly, samples were placed in vials containing solution A (0.1 M KCl, 0.39 M boric acid, and 5 mM ethylenediaminetetra acetic acid in 2.5% glutaraldehyde) for 2 h. Samples were then transferred to fresh

vials containing solution B (0.25 M KCl, 0.29 M boric acid, and 5 mM ethylenediaminetetra acetic acid in 2.5% glutaraldehyde) for 17 to 19 h. On the following day, individual fibers were torn into pieces and placed onto microscope slides with a drop of solution B. Each slide was then placed horizontally in the path of a vertically oriented laser beam to give an array of diffraction bands on a screen. These bands were perpendicular to the long axis of fibers as described by Cross *et al*. (1981). Sarcomere length (μm) was calculated using the following formula: Sarcomere length = ({632.8 × 103 × D × SQRT [(T/D)2 + 1]} / T) × 100, where D was the distance (mm) from the specimen-holding device to the screen (D = 98 mm) and T was the separation (mm) between zero and the first maximum band. Average sarcomere length was obtained from 10 measurements for each meat sample.

Warner-Bratzler shear force

Warner-Bratzler shear force (WBSF, kg/cm^2) was measured using an Instron Universal Testing Machine (Model 3343, Instron, USA) with V-shaped shear blade. Approximately 50 g meat was placed in a plastic bag and broiled in a water bath at temperature of 90°C for 30 min. Meat was then surface dried and sectioned as close as practicable to a 0.5 cm × 4.0 cm (approximately 2.0 cm^2) cross section area across fibers to measure cutting force. Six sections were obtained for each meat sample. Samples were placed at right angles to the blade. Crosshead speed was set at 100 mm/min and full scale load was 50 kg.

Statistical analysis

Data from three replications were analyzed by analysis of variance (ANOVA) using statistical analysis systems (SAS, 2002). ANOVA was adopted to design a mathematical model using SAS 9.2 (SAS Institute Inc., USA). Duncan's multiple range test was used to determine significance among means. Statistical significance was considered when *P* value was less than 0.05.

Results and Discussion

Results of fat contents in 10 muscles of Hanwoo carcasses with five QGs are shown in Fig. 1. As expected, there were significant (p<0.05) differences in average fat content among these 10 major muscles. IC had the highest fat content, followed by LT, RA, LL, PM, GM, SS, SF, TB, and SM. Such order of fat content among these 10 muscles was similar to that reported in our previous studies (Jung *et al*., 2015; Hwang and Joo, 2016). In a previous study, RA, IC, LT, LL, and PM were classified as high-fat muscles while TB, SS, SF, GM, and SM were categorized as low-fat muscles (Hwang and Joo, 2016).

In this study, significant (p<0.05) differences in IMF content among QGs were observed for all 10 muscles. Especially, high-fat muscles showed considerable differences among QGs. LT and LL showed significant (p<

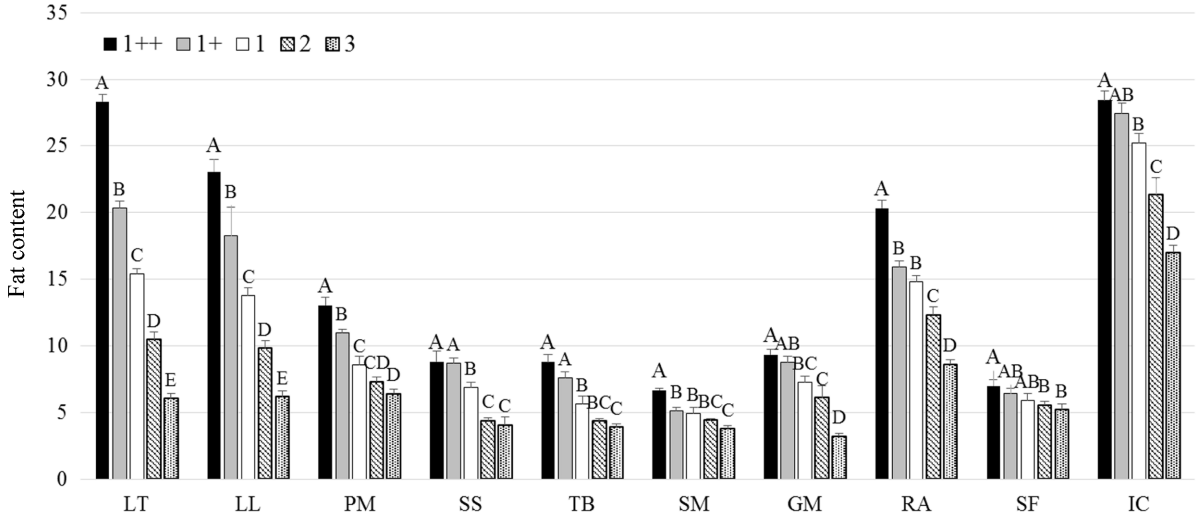

Fig 1. Fat content (%) of ten major muscles from Hanwoo steers according to quality grade of carcass. LT, *Longissimus thoracis*; LL, *Longissimus lumborum*; PM, *Psoas major*; SS, *Semisponals*; TB, *Triceps brachii*; SM, *Semimembranosus*; GM, *Gluteus medius*; RA, *Rectus Abdominis*; SF, *Superficialis flexor*; IC, *Internal and external intercostal*. $^{A-E}$Means±SE with different superscripts in the same row are significantly different (p<0.05).

0.05) differences in fat content among five QGs. IC, RA, and PM also showed significantly (p<0.05) different fat contents among QGs. However, fat content of QG 2 was not significantly (p>0.05) different from that of QG 3 for PM muscles. RA and IC muscles of QG 1^{+} showed no significant (p>0.05) difference in fat content from those of QG 1. In contrast, differences in fat content among QGs were not remarkable for low-fat muscles, although all five muscles showed significantly (p<0.05) difference in fat content between QG 1^{++} and QG 2 or QG 3. These results suggest that fat contents in low-fat muscles are less affected by QG compared to those in high-fat muscles.

Results of collagen contents of ten major muscles from Hanwoo steers with different QGs are summarized in Table 1. SF had the highest collagen content while LL had the lowest collagen content. A wide range of collagen contents were found among muscles, similar to results of Rhee *et al*. (2003) showing that PM has the lowest collagen concentration, followed by GM and LD, while BF, ST, and SS have the highest collagen concentrations. In this study, collagen contents were significantly (p<0.05) different among QGs, although no significant (p>0.05) difference in collagen content was found between QG 1^{++} and QG 1^{+}. Collagen contents of QG 2 muscles were not significantly (p>0.05) different from those of QG 3 either except for GM muscle. With decreasing QG (i.e., decreasing intramuscular fat content), collagen contents were increased in all muscles.

Overall, our results on differences in collagen contents among different QG muscles from Hanwoo carcass were in agreement with those of previous reports (Lee *et al*., 2009; Moon *et al*., 2006). It has been reported that total collagen contents of strip loins in 1^{++}, 1^{+} and 1 QG groups are significantly (p<0.05) lower than those in QG 3 group (Lee *et al*., 2009). However, they reported that other muscles such as chuck, top round, brisket, and loin showed no significant (p>0.05) difference in total collagen content among QGs. Moon *et al*. (2006) have also reported that total collagen content for LT with QG 3 is significantly (p <0.05) higher than that for LT with QG 1 and QG 2. For ST, SM, PM, and *serratus ventralis* (SV), total collagen content of QG 1 has been found to be the lowest of all QGs (Moon *et al*., 2006). The present study also clearly showed that collagen content in every single muscle of Hanwoo carcass was affected by QG mainly determined by IMF content in LD muscle.

Differences in sarcomere length among these 10 muscles of QGs are summarized in Table 2. Sarcomere length ranged from 3.03 μm in QG 1^{++} PM to 1.67 μm in QG 3 SM. PM had the longest sarcomere length while SM had the shortest sarcomere length. There were significant (p< 0.05) differences in sarcomere length between PM and IC. However, LT, LL, SS, TB, GM, RA, and SF muscle showed no significant (p>0.05) differences in sarcomere length. For several muscles, there were significant (p< 0.05) differences in sarcomere length among QGs. For LT muscle, sarcomere lengths of QG 1^{++} and 1^{+} were significantly (p<0.05) different from those of QG 2 and QG 3. However, LL, PM, and RA showed no significant (p>0.05) difference in sarcomere length among QGs. Lee *et al*. (2009) have reported sarcomeres of high QG muscles are longer than those of low QG muscles. They also reported that sarcomere length of QG 1^{++} brisket was significantly (p<0.05) longer than for that of QG 3 brisket. In addition,

Table 1. Collagen content (%) of ten major muscles from Hanwoo steers according to quality grade of carcass

Grade	Hanwoo major muscles[1)]									
	LT	LL	PM	SS	TB	SM	GM	RA	SF	IC
1^{++}	0.90± 0.03^{Cc}	0.77± 0.02^{Dc}	0.80± 1.04^{Dc}	1.04± 0.05^{Bd}	1.07± 0.02^{Bc}	1.03± 0.02^{Bb}	0.89± 0.02^{Cd}	1.03± 0.01^{Bc}	1.28± 0.03^{Ac}	1.09± 0.03^{Bc}
1^{+}	0.95± 0.03^{Ec}	0.79± 0.02^{Fc}	0.82± 0.02^{Fc}	1.15± 0.05^{BCcd}	1.12± 0.01^{CDbc}	1.04± 0.01^{Db}	0.92± 0.02^{Ecd}	1.07± 0.02^{CDc}	1.39± 0.03^{Ab}	1.22± 0.05^{Bbc}
1	1.07± 0.04^{Eb}	0.90± 0.03^{Fb}	0.91± 0.02^{Fb}	1.24± 0.03^{Cbc}	1.20± 0.01^{CDb}	1.12± 0.02^{DEb}	0.98± 0.02^{Fc}	1.16± 0.01^{CDb}	1.44± 0.02^{Ab}	1.34± 0.06^{Bab}
2	1.19± 0.02^{EFa}	1.11± 0.03^{Fa}	1.12± 0.03^{Fa}	1.36± 0.04^{BCab}	1.42± 0.04^{Ba}	1.24± 0.03^{DEa}	1.29± 0.03^{CDEa}	1.34± 0.04^{BCDa}	1.58± 0.02^{Aa}	1.38± 0.05^{BCa}
3	1.26± 0.02^{DEa}	1.09± 0.04^{Fa}	1.18± 0.02^{EFa}	1.46± 0.04^{Ba}	1.43± 0.04^{Ba}	1.32± 0.06^{CDa}	1.17± 0.03^{EFb}	1.38± 0.02^{BCa}	1.66± 0.04^{Aa}	1.47± 0.03^{Ba}

$^{A-F}$Means (±S.E.) in the same row with different letters are significantly different (p<0.05).

$^{a-d}$Means (±S.E.) in the same column with different letters are significantly different (p<0.05).

[1)]LT, *Longissimus thoracis*; LL, *Longissimus lumborum*; PM, *Psoas major*; SS, *Semisponals*, TB, *Triceps brachii*; SM, *Semimembranosus*; GM, *Gluteus medius*; RA, *Rectus Abdominis*; SF, *Superficialis flexor*; IC, *Internal and external intercostal.*

Table 2. Sarcomere length (μm) of ten major muscles from Hanwoo steers according to quality grade of carcass

Grade	Hanwoo major muscles[1)]									
	LT	LL	PM	SS	TB	SM	GM	RA	SF	IC
1^{++}	2.09± 0.08^{BCab}	2.03± 0.07^{BCD}	3.03± 0.04^{A}	2.16± 0.11^{BCa}	2.28± 0.22^{Ba}	2.13± 0.11^{BCa}	1.89± 0.04^{CDb}	1.71± 0.15^{D}	2.07± 0.07^{BCa}	2.27± 0.04^{Bb}
1^{+}	2.17± 0.08^{BCa}	2.10± 0.08^{BC}	2.84± 0.20^{A}	1.81± 0.17^{Cb}	2.00± 0.22^{BCab}	1.80± 0.10^{Cb}	2.11± 0.08^{BCa}	2.19± 0.36^{BC}	1.87± 0.06^{BCbc}	2.43± 0.15^{ABab}
1	1.93± 0.03^{BCbc}	2.00± 0.06^{BC}	2.85± 0.11^{A}	2.09± 0.09^{BCab}	2.02± 0.13^{BCab}	1.82± 0.05^{Cb}	1.94± 0.06^{BCab}	1.89± 0.31^{BC}	2.04± 0.08^{BCab}	2.27± 0.10^{Bb}
2	1.89± 0.04^{Ec}	1.96± 0.02^{DE}	2.92± 0.03^{A}	2.01± 0.02^{Dab}	2.34± 0.06^{Ca}	1.65± 0.01^{Fb}	2.04± 0.06^{Dab}	1.52± 0.01^{G}	1.85± 0.05^{Ebc}	2.67± 0.04^{Ba}
3	1.89± 0.04^{BCDc}	1.93± 0.01^{BCD}	2.85± 0.03^{A}	1.85± 0.01^{BCDab}	1.74± 0.16^{CDb}	1.62± 0.17^{Db}	1.94± 0.03^{BCDab}	2.17± 0.27^{B}	1.77± 0.03^{CDc}	2.13± 0.12^{BCb}

$^{A-G}$Means (±S.E.) in the same row with different letters are significantly different (p<0.05).
$^{a-c}$Means (±S.E.) in the same column with different letters are significantly different (p<0.05).
[1)]LT, *Longissimus thoracis*; LL, *Longissimus lumborum*; PM, *Psoas major*, SS, *Semisponals*, TB, *Triceps brachii*, SM, *Semimembranosus*, GM, *Gluteus medius*; RA, *Rectus Abdominis*; SF, *Superficialis flexor*; IC, *Internal and external intercostal.*

briskets of QG 1^{++} and QG 2 had significantly (p<0.05) greater sarcomere lengths than strip loin and top round with the same QG (Lee *et al*., 2009). However, decreasing sarcomere length with decreasing of QG was not observed in the present study. Our results showed no consistency in sarcomere length among muscles of different QGs.

Differences in WBSF in the 10 muscle with various QGs are summarized in Table 3. For samples with QG 1, PM had the lowest WBSF, followed by LL, LT, RA, IC, GM, SM, SF, SS, and TB. In general, the average WBSF of all QG samples failed to detect any difference among SS, TB, SM, and SF low-fat muscles. However, there were significant (p<0.05) differences in WBSF among muscles with various QGs. WBSF values were increased with decreasing QG (from QG 1^{++} to QG 3). For example, WBSF of QG 1^{++} was lower than that of QG 1 for SS, TB, and SM. Muscles of QG 1 also showed lower WBSF than QG 3 except TB or IC. The lower WBSF of QG 1^{++}, QG 1^{+}, and QG 1 compared to QG 2 and QG 3 found in this study was similar to that of Lee *et al*. (2009) showing that WBSF of chuck cut with QG 1^{++}, QG 1^{+}, and QG 1 were significantly (p<0.05) lower than those of chuck with QG 3. These results suggest that differences in tenderness among muscles with various QGs might be due to differences in collagen content and sarcomere length.

In conclusion, tenderness traits such as collagen content, sarcomere length, and WBSF were highly variable among 10 muscles with various QGs from Hanwoo steers. There were significant differences in fat and collagen contents among QGs of 10 major muscles, resulted in differences in WBSF. Such differences in WBSF among 10 muscles with various quality grades were partially due to differen-

Table 3. Warner-Bratzler shear force (kg/m^2) of ten major muscles from Hanwoo steers according to quality grade of carcass

Grade	Hanwoo major muscles[1)]									
	LT	LL	PM	SS	TB	SM	GM	RA	SF	IC
1^{++}	3.32± 0.30^{BCab}	2.97± 0.36^{Cb}	2.22± 0.14^{Db}	3.88± 0.14^{ABc}	4.44± 0.28^{Ab}	3.98± 0.11^{ABc}	3.62± 0.34^{BCb}	3.50± 0.22^{BCb}	4.59± 0.11^{Ac}	2.90± 0.16^{Cb}
1^{+}	4.16± 0.52^{ABCa}	2.86± 0.43^{DEb}	2.06± 0.27^{Eb}	5.08± 0.24^{ABb}	5.25± 0.45^{Aab}	4.67± 0.20^{ABb}	3.94± 0.20^{BCDb}	5.27± 0.71^{Aa}	4.80± 0.23^{ABbc}	3.24± 0.14C^{Dab}
1	2.93± 0.28^{CDb}	2.69± 0.45^{Db}	2.00± 0.16^{Eb}	5.06± 0.12^{ABb}	5.70± 0.13^{Aa}	4.69± 0.22^{Bb}	3.45± 0.25^{Cb}	3.08± 0.07^{CDb}	4.93± 0.22^{Bbc}	3.38± 0.11C^{Dab}
2	3.86± 0.21^{BCab}	4.33± 0.43^{BCa}	2.52± 0.11^{Db}	5.47± 0.22^{Ab}	5.44± 0.25^{Aa}	5.58± 0.19^{Aa}	4.70± 0.21^{ABa}	4.40± 0.58^{BCab}	5.39± 0.25^{Aab}	3.73± 0.09^{Ca}
3	4.00± 0.06^{DEa}	4.32± 0.24^{CDa}	3.15± 0.25^{Ea}	6.74± 0.32^{Aa}	5.88± 0.38^{ABa}	5.71± 0.15^{Ba}	5.04± 0.15^{BCa}	5.72± 0.67^{Ba}	5.65± 0.18^{Ba}	3.72± 0.24^{DEa}

$^{A-E}$Means (±S.E.) in the same row with different letters are significantly different (p<0.05).
$^{a-c}$Means (±S.E.) in the same column with different letters are significantly different (p<0.05).
[1)]LT, *Longissimus thoracis*; LL, *Longissimus lumborum*; PM, *Psoas major*; SS, *Semisponals*; TB, *Triceps brachii*, SM, *Semimembranosus*; GM, *Gluteus medius*; RA, *Rectus Abdominis;* SF, *Superficialis flexor*; IC, *Internal and external intercostal.*

ces in sarcomere length. Results obtained from the present study could be used to facilitate the development of cut-specific strategies to improve meat tenderness by targeting individual Hanwoo muscle characteristics.

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