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ARTICLE

# Correlations of Sensory Quality Characteristics with Intramuscular Fat Content and Bundle Characteristics in Bovine *Longissimus Thoracis* Muscle

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**Abstract** The aim of this study was to investigate the relation of sensory quality traits of cooked beef to fresh meat quality and histochemical characteristics, especially muscle bundle traits, in the *longissimus thoracis* muscle of Hanwoo steers. Cooking loss negatively correlated with softness, initial tenderness, chewiness, rate of breakdown (RB), and amount of perceptible residue (AR) after chewing ($p<0.05$), and drip loss showed negative correlation with RB and AR ($p<0.05$). All the attributes of tenderness exhibited negative correlation with the Warner-Bratzler shear force value ($p<0.05$). Marbling score and the intramuscular fat (IMF) content showed positive correlation with all the organoleptic characteristics, including tenderness attributes, juiciness, and flavor ($p<0.05$). Regarding histochemical characteristics, muscle fiber size did not have a significant correlation with all the sensory quality traits, although the area percentage of type I fiber was related with softness, initial tenderness, and chewiness ($p<0.05$). On the contrary, the characteristics of muscle bundle were related to all the sensory tenderness attributes ($p<0.05$), and the sensory tenderness increased with smaller muscle bundle size ($p<0.05$). These results suggest that the IMF content and bundle characteristics can be used as indicators for explaining the variations in sensory tenderness in well-marbled beef.

**Keywords** sensory quality, meat quality, intramuscular fat content, muscle bundle, Hanwoo beef

## Introduction

Beef palatability factors (tenderness, juiciness, and flavor) are considered the most important characteristics that determines consumer satisfaction (Grunert et al., 2004). Sensory quality traits of cooked meat, specifically tenderness, juiciness, and overall acceptability, are influenced by the intramuscular fat (IMF) content (Hocquette et al., 2010; Lee et al., 2018a; Wood et al., 2008). Bovine muscles contain a greater amount of IMF showed tenderer and more juicy compared to bovine muscles contain a low amount of IMF (Hocquette et al., 2010). Thus, most consumers in the US, Japan, and Korea tend to prefer well-marbled beef; thus eating satisfaction is well-associated with the amount of IMF (Cho et al., 2010; Hunt et al., 2014; Hwang et al., 2010), and the minimum content of IMF to achieve acceptable consumer satisfaction of beef in the US is greater than 3%–4% (Savell et al., 1986). In contrast, the European consumers generally prefer the leaner meat due to health concerns (Ngapo et al., 2007). Thus, the consumer acceptability range is wide, primarily due to personal likes/dislikes, culture, religion and family or personal customs. These factors have an impact on eating experiences and purchasing decisions. Owing to these reasons, researches on the effect of IMF percentage on the eating quality traits of cooked beef have generated conflicting results (Hocquette et al., 2010). However, studies have shown that muscle fiber characteristics can impact consumer eating experience by influencing the meat quality characteristics (Choi and Kim, 2009; Rehfeldt et al., 2008).

Muscle fiber characteristics, especially metabolic and morphological properties, could influence the meat quality characteristics and palatability in different species, since the skeletal muscle is primarily composed of muscle fibers (Choi and Kim, 2009; Choi and Oh, 2016). Muscle fibers are classified into various types depending on their contractile and metabolic properties: slow-twitch oxidative (type I), fast-twitch oxido-glycolytic (type IIA) and fast-twitch glycolytic (IIX and IIB) fibers (Schiaffino and Reggiani, 1996). Muscle fibers are grouped together into muscle bundle surrounded by connective tissue, which ensures the muscular contractility in living animals (Schleip et al., 2006). Similar to the fiber number in most terrestrial vertebrates, bundle characteristics of skeletal muscle are also fully developed before or soon after birth with the exception of bundle size (Schleip et al., 2006). With increases in muscle fiber size postnatally, muscle bundle size will also increase. Albrecht et al. (2006) reported no significant difference in the number of fiber per bundle in various cattle breeds aged 2–24 months. In carcasses, muscle bundle characteristics are associated with texture and firmness quality traits evaluated on the exposed muscle cut surface, and thus can influence the sensory quality traits of cooked meat, especially tenderness (Chandraratne et al., 2006; Borgogno et al., 2016). However, the relationship between the muscle bundle, including total bundle number per each muscle, fiber number per each bundle, and bundle size, and organoleptic characteristics of cooked beef remains undefined. The objective of the present study was to determine the correlation of sensory quality traits of cooked beef with fresh meat quality, IMF content and histochemical characteristics of Hanwoo beef.

## Materials and Methods

### Animals and muscle samples

Eighty-four Hanwoo steers (aged 26–30 months; mean carcass weight of 458.4±71.1 kg) were obtained from a commercial slaughter house in three batches (20, 32, and 32 animals per day). At 45 min postmortem, muscle pH was measured ($pH_{45\ min}$) from the left carcass side using spear-type portable pH meter and probe (IQ-150 pH meter and PH77-Ssprobe, IQ Scientific Instruments Inc., San Diego, CA). Approximately 20 g samples were removed from the *longissimus thoracis* muscle at the carcass grading site (13$^{th}$ thoracic vertebrae), and were cut into muscle pieces (0.5 cm×0.5 cm×1.0 cm) for the measurement of fiber and bundle characteristics. Muscle samples then were stored at –80°C until further analyses. In addition, after 24 h of chilling at 4°C, a cross-section of the *longissimus thoracis* muscle was removed between the 10$^{th}$ to 13$^{th}$ thoracic vertebrae (10 to 13 cm thickness) from the left side of each carcass. Muscle samples were used to determine meat and sensory quality characteristics. Meat quality characteristics studied were muscle $pH_{24\ h}$, objective color measurement, water-holding capacity (WHC), and Warner-Bratzler shear force (WBS). Meat quality measurements were performed along with sampling for sensory quality characteristics of cooked meat. A trained sensory panel was used to evaluate various eating quality attributes, and each sample was cut into steak-shaped chops (1.5 cm thick, approximately 100–120 g), frozen and stored at –20℃ until further analysis. Overall fat content was determined by the Soxhlet method using a solvent extraction system (AOAC, 2012). Marbling score was assigned according to the beef marbling standard (BMS) (1, devoid; 9, very abundant) as provided by the Korean Institute of Animal Products Quality Evaluation (KAPE, 2017). Loin-eye area at the 13th thoracic vertebrae from left side of each carcass was provided by the KAPE (2017).

### Sensory quality evaluation

Each trained panelists were evaluated a total of 84 samples twice (84 samples×2 replicates). The assessments were performed in separated booths during 33 sessions (5–6 samples per session). Twelve sensory panelists (six women and six men; aged 24–43 years) were trained to assess the meat samples for over 1 year. While training the sensory panelists, muscle samples from different locations and marbling scores of Hanwoo beef were used to obtain consistent and precise results. The sensory panelists were trained according to the previous procedure of Meilgaard et al. (1991) and the American Meat Science Association guidelines (AMSA, 1995). All training and testing were conducted in the Muscle Biology Laboratory at the Kyoungpook National University. A total of 168 samples randomly coded with a three-digit number and selected. Steak-size cuts were roasted in a convection oven (MJ324; LG Electronics, Korea); the temperature was set to 180°C. Steak was turned every 3 min until the core temperature reached 71°C, which was measured using a thermometer (Testo 108; Testo Se & Co., Germany) placed in the geometric center of every sample. Cooked steaks then were sliced into 1.3 $cm^3$ cubes, and then kept in a closed polyethylene bag and maintained in a water bath at 54°C until presented to the sensory panelists (Fortin et al., 2005). Unsalted crackers and sufficient water were supplied to trained panelists to rinse and cleanse the plate at the start of a session and between beef samples. Cooked steaks were assessed for 9 traits including softness (S), initial tenderness (IT), chewiness (C), rate of breakdown (RB), amount of perceptible residue (AR), juiciness (J), flavor intensity (FI), off flavor intensity (OFI), and mouth coating (MC) (AMSA, 1995; Meilgaard et al., 1991).

### Meat quality measurements

At 45 min and 24 h postmortem, muscle pH was measured in the *longissimus thoracis* muscle. At 24 h postmortem, color values of fresh beef were evaluated after blooming time (exposing to air for 30 min at 4°C) using a Minolta chromameter (CR-400, Minolta Camera Co., Osaka, Japan). Objective color values are expressed according to the Commission Internationale de l'Eclairage (CIE, 1978) lightness (L*), redness (a*), and yellowness (b*).

Drip loss, filter-paper fluid uptake (FFU), and cooking loss were evaluated for WHC according to the earlier procedures (Kauffman et al., 1986; Honikel 1998). The cooked beef samples for WBS analysis prepared using a method similar to that of the cooking loss method. Beef samples (about 80 g of initial weight) were freshly cut at 24 h postmortem in a 4°C cold room and weighed. Each sample was kept in a closed polyethylene bag and placed in a temperature-controlled water bath at 80°C until the core temperature reached 71°C. Beef samples were then transferred to an ice water bath and chilled for 15 min. A minimum of ten cores were sliced parallel to the longitudinal direction of the muscle fibers per sample (1.27 cm diameter). Cores were then sheared perpendicular to the muscle fiber orientation using an Instron Universal Testing Instrument (Model 1011, Instron Corp., Norwood, USA) with a Warner–Bratzler shear device (cross-head speed 200 mm/min) (AMSA, 1995).

### Histochemical analysis

Muscle sections (10 μm) were obtained from each muscle sample using a cryostat (CM1860, Leica, Nussloch, Germany) at –25°C. All histochemical images for measuring the muscle fiber and determining bundle characteristics were taken using an image analysis system consisting of an optical microscope (DM500, Leica Microsystems, Wetzlar, Germany) fitted with a high-resolution digital camera (ICC50, Leica Microsystems, Milton Keynes, England) connected to a LAS EZ software (Leica Microsystems, Heerbrugg, Switzerland) for a standard workstation computer. Image-Pro Plus software (Media Cybernetics, Rockville, USA) were used for the image analysis. The histochemical images for the fiber and bundle characteristics were taken at 100× and 40× magnifications, respectively. For muscle fiber characteristics, a staining method examining myofibrillar ATPase activity was used. The myofibrillar ATPase activity was detected following pre-incubation with acid (pH 4.3) (Lind and Kernell, 1991). Muscle fibers were classified as type I, IIA, or IIX fiber (Brooke and Kaiser, 1970). The mean of muscle fiber cross-sectional area (CSA), mean CSA of each fiber type, and total fiber number were calculated. The area percentage of muscle fiber was obtained as the ratio of total area of each fiber type to the total measured fiber area multiplied with 100. To evaluate the characteristics of muscle bundle, each muscle section was performed with Aniline Blue and Orange G (Albrecht et al., 2006; Krichesky, 1931). The mean size of muscle bundle, mean numbers of fiber per each bundle, and total number of muscle bundle were calculated like those of muscle fiber. More than 30 bundles per sample were used.

### Statistical analysis

Data for sensory quality characteristics were analyzed using the SAS software (SAS, 2014) to calculate simple means. All data were checked for normality using a Shapiro-Wilk test, and data for sensory quality traits were found not to be normally distributed. Thus, the Spearman correlation coefficients were calculated using the PROC CORR procedure of SAS software (SAS, 2014) to determine the correlation between sensory quality, meat quality and histochemical characteristics. The principal component analysis (PCA) was performed by PRINCOMP procedure (SAS, 2014) based on the correlation matrix.

## Results

### Correlation between sensory and meat quality characteristics

Table 1 presents the mean, standard deviation, and overall range (maximum and minimum) for all the sensory quality traits. The variables tested, especially five attributes of tenderness, showed broad ranges. The correlation between sensory and meat quality characteristics are presented in Table 2. Muscle pH at 45 min and 24 h postmortem did not have a significant correlation with any of the sensory quality traits ($p>0.05$). Lightness of meat was positively correlated with the five tenderness-related attributes ($p<0.05$), including scores of S ($r=0.35$), IT ($r=0.32$), C ($r=0.29$), RB ($r=0.37$), and AR ($r=0.33$). Redness and yellowness were positively correlated with RB score ($r=0.23$ and 0.27, respectively). However, it did not correlate significantly with J, FI, and MC ($p>0.05$). Further, drip loss exhibited a negative correlation with the RB ($r=-0.29$) and AR ($r=-0.22$). Cooking loss was negatively correlated with all the eating quality characteristics ($p<0.05$), except the C and FI ($p>0.05$). The WBS showed a negative correlation with scores for tenderness attributes ($p<0.05$), whereas the marbling score was positively related with all the sensory quality characteristics including tenderness, juiciness, and flavor ($p<0.05$). In particular, the content of IMF correlated with MC ($r=0.62$) and the tenderness attributes including S ($r=0.40$), IT ($r=0.41$), C ($r=0.46$), RB ($r=0.33$), and AR ($r=0.50$).

**Table 1.** **Sensory quality traits of the *longissimus thoracis* muscle (10th to 13th thoracic vertebrae) of the Hanwoo steer**

| | Mean | SD | Minimum | Maximum |
|---|---|---|---|---|
| Tenderness attribute | | | | |
| Softness[1)] | 5.56 | 1.24 | 2.63 | 7.75 |
| Initial tenderness[2)] | 5.40 | 1.33 | 2.00 | 7.80 |
| Chewiness[3)] | 5.15 | 1.39 | 2.00 | 7.63 |
| Rate of breakdown[4)] | 5.03 | 1.11 | 2.13 | 7.13 |
| Amount of perceptible residue[5)] | 5.38 | 0.87 | 3.25 | 7.70 |
| Juiciness[6)] | 5.31 | 0.88 | 3.25 | 7.25 |
| Flavor intensity[7)] | 5.72 | 0.53 | 4.50 | 6.75 |
| Off flavor intensity[8)] | 6.23 | 0.42 | 5.25 | 7.25 |
| Mouth coating[9)] | 5.19 | 1.11 | 2.50 | 7.80 |

1) Scale: 1, very hard; 9, very soft.
2) Scale: 1, very tough; 9, very tender.
3) Scale: 1, very chewy; 9, very tender.
4) Scale: 1, very slow; 9, very fast.
5) Scale: 1, very abundant; 9, none.
6) Scale: 1, not juicy; 9, extremely juicy.
7) Scale: 1, very weak; 9, very strong.
8) Scale: 1, very strong; 9, very weak.
9) Scale: 1, none; 9, very high.

**Table 2.** **Correlation coefficient (r) between sensory quality characteristics of cooked beef and meat quality characteristics in the *longissimus thoracis* muscle of Hanwoo steer**

| | $pH_{45\ min}$ | $pH_{24\ h}$ | L* | a* | b* | Drip loss | FFU | Cooking loss | WBS | Marbling score | IMF content |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Tenderness attribute | | | | | | | | | | | |
| Softness[1)] | –0.15 | –0.04 | 0.35** | 0.13 | 0.20 | –0.18 | –0.08 | –0.33** | –0.56*** | 0.53*** | 0.40*** |
| Initial tenderness[2)] | –0.16 | –0.01 | 0.32** | 0.12 | 0.18 | –0.20 | –0.06 | –0.23* | –0.54*** | 0.54*** | 0.41*** |
| Chewiness[3)] | –0.14 | –0.02 | 0.29** | 0.08 | 0.12 | –0.19 | –0.03 | –0.21 | –0.52*** | 0.53*** | 0.46*** |
| Rate of breakdown[4)] | –0.13 | –0.01 | 0.37** | 0.23* | 0.27* | –0.29** | –0.23* | –0.24* | –0.47*** | 0.40*** | 0.33** |
| Amount of perceptible residue[5)] | –0.04 | –0.06 | 0.33** | 0.18 | 0.12 | –0.22* | –0.15 | –0.25* | –0.43*** | 0.51*** | 0.50*** |
| Juiciness[6)] | 0.11 | 0.08 | 0.12 | –0.02 | –0.01 | 0.09 | 0.06 | –0.29** | –0.41*** | 0.53*** | 0.53*** |
| Flavor intensity[7)] | 0.16 | 0.04 | –0.04 | –0.04 | –0.05 | 0.21 | 0.21 | –0.16 | –0.28** | 0.30** | 0.27* |
| Off flavor intensity[8)] | –0.09 | 0.01 | 0.15 | 0.13 | 0.12 | –0.01 | –0.03 | –0.40*** | –0.27* | 0.44*** | 0.24* |
| Mouth coating[9)] | 0.08 | 0.09 | 0.19 | –0.05 | –0.02 | 0.11 | 0.13 | –0.30** | –0.49*** | 0.68*** | 0.62*** |

1) Scale: 1, very hard; 9, very soft.
2) Scale: 1, very tough; 9, very tender.
3) Scale: 1, very chewy; 9, very tender.
4) Scale: 1, very slow; 9, very fast.
5) Scale: 1, very abundant; 9, none.
6) Scale: 1, not juicy; 9, extremely juicy.
7) Scale: 1, very weak; 9, very strong.
8) Scale: 1, very strong; 9, very weak.
9) Scale: 1, none; 9, very high.
* $p<0.05$; ** $p<0.01$; *** $p<0.001$.
FFU, filter-paper fluid uptake; WBS, Warner-Bratzler shear force; IMF, intramuscular fat.

## Relationship between sensory quality and histochemical characteristics

There was no correlation between muscle fiber area and sensory quality of cooked beef (p>0.05; Table 3); however, the total fiber number positively correlated with the scores of AR (r=0.27) and MC (r=0.38). In the composition of fiber type, the area percentage of type I fiber showed positive correlation with S (r=0.23), IT (r=0.24), C (r=0.24) and J (r=0.23) scores, whereas the percentage of type IIX fiber negatively correlated with the score for softness (r=–0.22). However, no significant correlation was observed between type IIA percentage and sensory quality traits (p>0.05). Table 4 presents the relationships between the sensory quality traits and muscle bundle characteristics. Bundle size and fiber number per bundle exhibited similar correlation tendencies. They correlated negatively with the scores of S (r=–0.43 and –0.38, respectively), IT (r=–0.41 and –0.36, respectively), C (r=–0.44 and –0.38, respectively), RB (r=–0.44 and –0.39, respectively), and AR (r=–0.30 and –0.27, respectively). Total bundle number positively correlated with all the tenderness attributes (p<0.05). On the contrary, no significant correlation was observed between the characteristics of muscle bundle and all the traits (p>0.05), except for the tenderness attributes (p<0.05).

## PCA of the experiments

The PCA was performed to understand the correlation between the variables, including sensory quality traits of cooked beef, meat quality and histochemical characteristics (Fig. 1). The first three of these PCs accounted for 55.6% of the variance observed in the 34 variables (PC1=30.8%, PC2=14.5% and PC3=10.3%). All sensory quality traits were distinguishable by the

**Table 3. Correlation coefficient (r) between sensory quality characteristics of cooked beef and muscle fiber characteristics in the *longissimus thoracis* muscle of Hanwoo steer**

| | Muscle fiber area | | | | Total fiber number | | | | Fiber area percentage | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | Type I | Type IIA | Type IIX | Sum | Type I | Type IIA | Type IIX | Type I | Type IIA | Type IIX |
| Tenderness attribute | | | | | | | | | | | |
| Softness[1)] | –0.03 | 0.08 | 0.03 | 0.01 | 0.18 | 0.21 | 0.13 | 0.04 | 0.23* | 0.08 | –0.19 |
| Initial tenderness[2)] | 0.01 | 0.10 | 0.04 | 0.02 | 0.19 | 0.21 | 0.13 | 0.05 | 0.24* | 0.05 | –0.17 |
| Chewiness[3)] | 0.01 | 0.09 | 0.02 | 0.02 | 0.19 | 0.20 | 0.14 | 0.05 | 0.24* | 0.04 | –0.16 |
| Rate of breakdown[4)] | –0.04 | 0.07 | 0.02 | –0.04 | 0.21 | 0.19 | 0.20 | 0.09 | 0.15 | 0.11 | –0.14 |
| Amount of perceptible residue[5)] | –0.07 | –0.02 | 0.01 | –0.04 | 0.27* | 0.27* | 0.20 | 0.12 | 0.13 | 0.08 | –0.11 |
| Juiciness[6)] | 0.05 | 0.03 | 0.07 | 0.10 | 0.10 | 0.18 | 0.08 | –0.01 | 0.23* | 0.05 | –0.13 |
| Flavor intensity[7)] | 0.06 | 0.09 | –0.02 | 0.09 | 0.01 | 0.12 | 0.05 | –0.04 | 0.20 | –0.02 | –0.04 |
| Off flavor intensity[8)] | –0.09 | 0.02 | –0.05 | –0.06 | 0.21 | 0.21 | 0.20 | 0.15 | 0.09 | 0.03 | –0.08 |
| Mouth coating[9)] | –0.06 | 0.02 | –0.07 | 0.01 | 0.24* | 0.38** | 0.16 | 0.11 | 0.21 | –0.03 | –0.07 |

1) Scale: 1, very hard; 9, very soft.
2) Scale: 1, very tough; 9, very tender.
3) Scale: 1, very chewy; 9, very tender.
4) Scale: 1, very slow; 9, very fast.
5) Scale: 1, very abundant; 9, none.
6) Scale: 1, not juicy; 9, extremely juicy.
7) Scale: 1, very weak; 9, very strong.
8) Scale: 1, very strong; 9, very weak.
9) Scale: 1, none; 9, very high.
* p<0.05; ** p<0.01.

**Table 4. Correlation coefficient (r) between the sensory quality characteristics of cooked beef and muscle bundle characteristics in the *longissimus thoracis* muscle of Hanwoo steer**

| | Muscle bundle characteristics | | |
|---|---|---|---|
| | Bundle area | Fiber number per bundle | Total bundle number |
| Tenderness attribute | | | |
| Softness[1)] | –0.43*** | –0.38** | 0.50*** |
| Initial tenderness[2)] | –0.41*** | –0.36** | 0.50*** |
| Chewiness[3)] | –0.44*** | –0.38** | 0.51*** |
| Rate of breakdown[4)] | –0.44*** | –0.39*** | 0.50*** |
| Amount of perceptible residue[5)] | –0.30** | –0.27* | 0.39*** |
| Juiciness[6)] | –0.17 | –0.15 | 0.24* |
| Flavor intensity[7)] | 0.14 | –0.13 | 0.10 |
| Off flavor intensity[8)] | –0.05 | –0.06 | 0.18 |
| Mouth coating[9)] | 0.18 | –0.13 | 0.27* |

[1)] Scale: 1, very hard; 9, very soft.
[2)] Scale: 1, very tough; 9, very tender.
[3)] Scale: 1, very chewy; 9, very tender.
[4)] Scale: 1, very slow; 9, very fast.
[5)] Scale: 1, very abundant; 9, none.
[6)] Scale: 1, not juicy; 9, extremely juicy.
[7)] Scale: 1, very weak; 9, very strong.
[8)] Scale: 1, very strong; 9, very weak.
[9)] Scale: 1, none; 9, very high.
* $p<0.05$; ** $p< 0.01$; *** $p<0.001$.

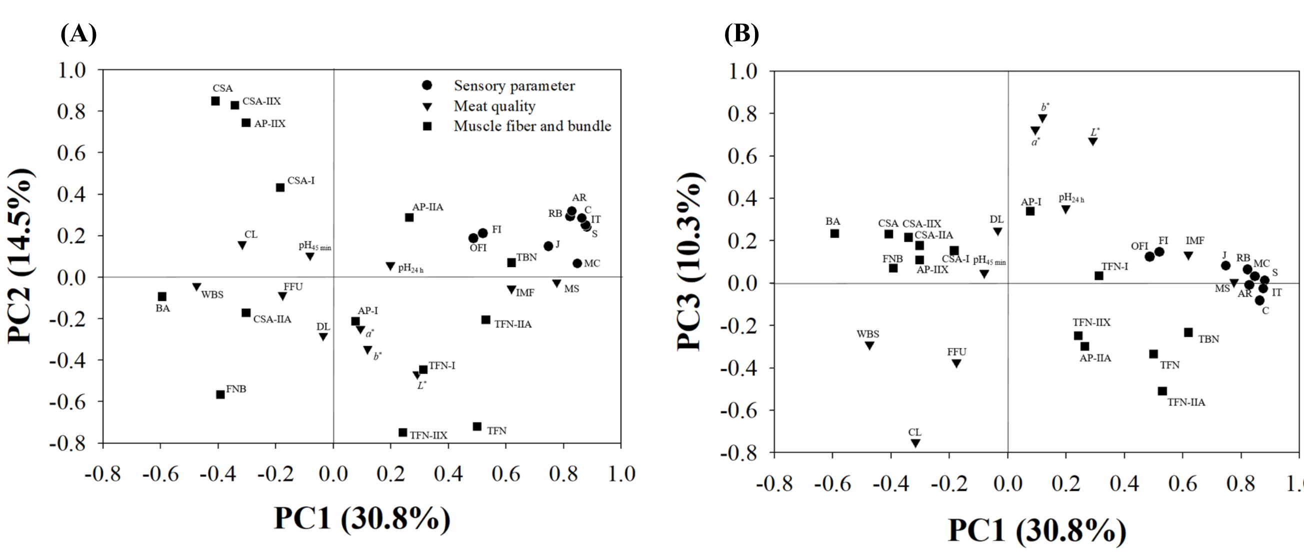


**Fig. 1. Principal component analysis (PCA) plots for PC1 versus PC2 (A) and PC1 versus PC3 (B).** The percentage variance explained by the three PCs was 55.6%. S, softness; IT, initial tenderness; C, chewiness; RB, rate of breakdown; AR, amount of perceptible residue; J, juiciness; FI, flavor intensity; OFI, Off flavor intensity; MC, mouth coating; DL, drip loss; FFU, filter-paper fluid uptake; CL, cooking loss; WBS, Warner-Bratzler shear force; MS, marbling score; IMF, intramuscular fat content; CSA, muscle fiber cross-sectional area; CSA-I, type I fiber CSA; CSA-IIA, type IIA fiber CSA; CSA-IIX, type IIX fiber CSA; TFN, total fiber number; TFN-I, TFN of type I fiber; TFN-IIA, TFN of type IIA fiber; TFN-IIX, TFN of type IIX fiber; AP-I, area percentage of type I fiber; AP-IIA, AP of type IIA fiber; AP-IIX, AP of type IIX fiber; BA, bundle area; FNB, fiber number per bundle; TBN, total bundle number.

positive loading of PC1 and PC2 (Fig. 1A). In Fig. 1B, initial tenderness, chewiness and AR were distributed in the area with negative loading of PC3. All tenderness attributes were located close to one another indicating that they were positively correlated with each. The IMF content, marbling, and total number of bundle were distinguishable by the positive loading of PC1, while WBS, bundle size, and fiber number per bundle showed the negative loading of PC1. However, IMF content, bundle size, and fiber number per bundle were distributed in the area with negative loading of PC2, but positive loading of PC3.

## Discussion

Eating quality characteristics of cooked beef are associated with the quality characteristics of fresh meat. Muscle pH at the early postmortem period is an important indicator of the postmortem glycolytic rate, and the ultimate pH can influence the meat tenderness (Marsh et al., 1987). Lomiwes et al. (2013), showed that beef with a higher ultimate pH ($\geq$6.2) showed higher scores for sensory tenderness and lower values of WBS than beef with normal (6.19 to 5.8) or lower pH ($\leq$5.79), which might be attributable to the extent of myofibril structural degradation by endoprotease, and activities of endoprotease were greater at higher pH due to their isoelectric point (Pulford et al., 2008). However, in the present study, no significant correlation was observed between sensory quality traits and muscle pH, a discrepancy which might arise due to the curvilinear relationship between the ultimate pH and sensory tenderness (Silva et al., 1999). Furthermore, muscle pH can influence the development of meat color (Jeong et al., 2010). In the current study, muscle $pH_{45\ min}$ was significantly correlated with lightness (r=–0.23; data not shown), and values of softness (r=0.34), initial tenderness (r=0.31) and AR (r=0.29) were positively correlated with lightness. Generally, the WHC of meat is positively correlated with tenderness. Gil et al. (2008) reported that drip loss is correlated with hardness and juiciness. Porcine muscles with lower drip loss were previously shown to exhibit lower values of WBS compared to those with higher drip loss (Jeong et al., 2010). Results from the present study corroborate with this observation; low cooking loss was associated with tender and juicy beef. As expected, the WBS positively correlated with the tenderness attributes as well as juiciness and flavor intensity ($p<0.05$).

The extent of marbling plays a key role in determining organoleptic characteristics (Hocquette et al., 2010; Lee et al., 2019). Similar to Japanese Black cattle (Albrecht et al., 2011), Hanwoo cattle are genetically predisposed to depositing a higher content of IMF than German Angus and Galloway (Albrecht et al., 2006; Cho et al., 2010). The IMF content of the *longissimus thoracis* muscle at the 13$^{th}$ thoracic vertebra ranges from approximately 5% to 21% with marbling scores from 1 to 9 (Cho et al., 2010; KAPE 2017). In the present study, the IMF content and marbling score of the *longissimus thoracis* muscle ranged from 6.63% to 22.8% and 2 to 9, respectively (data not shown). The tenderness attributes of cooked beef correlated with the IMF content and marbling score ($p<0.05$). A similar result has been reported by Nishimura (2015), who suggested that the IMF content was strongly related to tenderness evaluated by sensory panel in Japanese Black steer, as the consumers in Japan preferred a well-marbled beef.

It is well known that type I fiber is predominantly energized by the oxidative metabolism, and therefore lipids and fatty acids are mainly used as sources of metabolic fuel in living animals (Schiaffino and Reggiani, 1996). However, in the present study, no significant correlations were found between area percentage of type I fiber and IMF content in this study ($p>0.05$), as a higher IMF content is achieved by long-term feedlot programs with high energy in well-marbled beef (Cho et al., 2010; Hocquette et al., 2010). On the other hand, the metabolic and contractile characteristics of muscle are associated with sensory quality, especially meat tenderness (Choi et al., 2013; Picard et al., 2014). According to Jeong et al. (2010), the fiber mean

CSA and type I fiber CSA were positively correlated with sensory tenderness of cooked pork. Several studies have investigated the effects of fiber characteristics on sensory quality traits of cooked beef. However, collectively, researchers are divided on whether fiber characteristics affect the sensory quality traits of cooked beef. For instance, some studies showed a negative correlation between fiber area and tenderness of cooked beef (Seideman et al., 1986), while others reported no correlation between these two attributes (Vestergaard et al., 2000; Wegner et al., 2000). In the present study, a limited correlation was observed between the morphological characteristics of muscle fiber and the sensory quality traits of the cooked beef. On the contrary, the tenderness attributes, except the RB and AR, were positively correlated with the area percentage of type I fiber ($p<0.05$).

A muscle bundle is a group of muscle fibers enveloped by connective tissue layer (known as the perimysium) and can be classified into primary and secondary bundles (Purslow, 2005). Muscle fascicle and perimysium maintain passive stiffness of the muscle for accurate contraction and prevent overstretching of muscle fibers in living animal (Schleip et al., 2006). Thus, muscle bundle area is related to the graininess of muscle surface, which can be observed in carcasses (Lee et al., 2018b; Purslow, 2005). Although the bundle CSA increases with in advanced maturity, significant differences in bundle characteristics, including bundle CSA, have been observed in various cattle breeds of similar age (Albrecht et al., 2006). Cooper et al. (1968) reported that the bundle area positively correlated with WBS value ($r=0.39$, $p<0.01$), and negatively with the sensory tenderness ($r=-0.30$, $p<0.05$) in the bovine *longissimus* muscle, in accordance with the results of the present study. Muscles with s smaller bundle area and lower fiber number per bundle exhibited lower initial force to penetrate beef, easily to break into fragments, and leave lower amount of residue compared to muscles with larger bundle area and higher fiber number per bundle ($p<0.05$).

In the PCA, the first seven and ten PCs were extracted explaining 81.5% and 91.9% of the total variance (data not shown). The first two and three PCs described 45.3% and 55.6% of the total variance in the 34 variables, as there were many variables in this study. Mwove et al. (2018) extracted the first seven PCs explaining 95.5% of the total variance in the 24 beef quality characteristics, including sensory quality, WBS and proximate composition, and Liu et al. (2004) reported that the first two and seven PCs accounted for 36.8% and 69.2%, respectively, of the total variance for 24 variables including sensory quality traits, color and physical characteristics of chicken breast. In the current study, sensory quality characteristics, especially tenderness attributes, were positively correlated with marbling score, IMF content and total bundle number. On the other hand, tenderness attributes were negatively correlated with WBS, total bundle number and bundle area, which were located on the opposite quadrant.

## Conclusion

The present study found that bovine muscles with smaller bundle size exhibited more tender after initial compression and less chewing force than bovine muscles with larger bundle size. As expected, the IMF content showed a positive effect on tenderness attributes. Therefore, the characteristics of muscle bundle can influence the tenderness attributes of cooked beef as the IMF content.

## Conflict of Interest

The authors declare no potential conflict of interest.

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## Author Contributions

Conceptualization: Choi YM. Data curation: Choi YM, Garcia LG, Lee K. Formal analysis: Choi YM. Methodology: Choi YM. Software: Choi YM. Validation: Choi YM, Garcia LG, Lee K. Investigation: Choi YM. Writing - original draft: Choi YM, Garcia LG, Lee K. Writing - review & editing: Choi YM, Garcia LG, Lee K.

## Ethics Approval

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

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