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ARTICLE

Comparison of Beef Palatability Characteristics between *Longissimus Thoracis* and *Vastus Lateralis* Muscles from Different Grades during Postmortem Aging

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Abstract   The objectives of this study was to compare palatability changes of the *longissimus thoracis* (LT) and *vastus lateralis* (VL) muscles of Hanwoo steers from different beef quality grades (1^+ and 1) during 28 d of wet-aging in order to improve the utilization of the VL muscle as a steak. The VL muscle showed a higher collagen content and a lower intramuscular fat content than the LT muscle ($p<0.05$). As expected, the Warner-Bratzler shear force value was greater in the LT 1 grade (LT-1) muscle than the LT-1^+ muscle ($p<0.05$); whereas no difference was observed between the grades in the VL muscle at 24 h postmortem. Compared to 0 d of aging, tenderness scores significantly increased after 14 and 21 d of aging in the LT and VL muscles, respectively ($p<0.05$). Additionally, there was no difference in tenderness score between the VL-1^+ aged for 21 d and the LT-1 at 24 h postmortem, although tenderness score was greater in the LT than the VL at each period ($p<0.05$). Moreover, the VL-1^+ steak exhibited a higher tenderness score than the VL-1 steak at 21 and 28 d of aging ($p<0.05$). On the other hand, the effect of aging time on juiciness and flavor in the VL muscle was somewhat limited unlike the LT muscle. Taken together, the VL muscle requires a longer aging time than the LT muscle to improve consumer preference. Considering the tenderness, using a higher quality grade for aging is more useful in the VL muscle.

Keywords   sensory quality, *longissimus thoracis* muscle, *vastus lateralis* muscle, beef quality grade, wet-aging

Introduction

With the development of economy and society, the interest of many consumers has been more focused on food quality especially eating quality characteristics. Among the eating quality characteristics, which include tenderness, juiciness, and flavor of meat and meat products, tenderness has been considered as the most important determinant

of sensory quality traits (Hulankova et al., 2018). Thus, numerous researchers have studied the most frequently about factors that influencing tenderness variation of cooked beef in order to improve tenderness and to ensure the consistency of eating quality (Hulankova et al., 2018; Koohmaraie et al., 2002; Lee et al., 2018).

The extent of marbling or intramuscular fat (IMF) content is one of the pivotal factors that influence tenderness variation (Lee et al., 2019; Smith et al., 1988). Lee et al. (2018) reported the Korean beef quality grades mainly assessed by the extent of marbling was positively correlated with sensory tenderness, and the 1^{++} grade (marbling scores 8 and 9) loin was tenderer than the 1^{+} (marbling scores 6 and 7) and 1 grade (marbling scores 4 and 5) loins. Additionally, considerable variations in sensory tenderness and Warner-Bratzler shear force (WBS) value exist among beef steaks from different muscles (Nair et al., 2019). It is well known that round muscles, including the *vastus lateralis* (VL) muscle, are primarily responsible for locomotion (Nair et al., 2019). Thus, beef steaks from round muscles tend to exhibit tougher and inconsistent tenderness, resulting in a lower consumer acceptability compared to steaks from the *longissimus thoracis* (LT) muscle (Kolle et al., 2004). In this sense, the meat industry is consistently striving to improve tenderness of beef round in order to make a higher-valued cut, like loin and rib (Anderson et al., 2012).

Postmortem aging is a common industrial method to improve sensory quality characteristics, especially tenderness. Wet-aging, whereby beef cuts are aged in a vacuum sealed plastic pouch at refrigeration temperature, is the most common approach in the meat industry, especially in the USA and Australia, although steaks from wet-aged beef exhibited lower scores of sensory tenderness and flavor intensity compared to steaks from dry-aged beef (Berger et al., 2018). Huff-Lonergan and Lonergan (2005) and Nair et al. (2019) suggested that during the wet-aging process, beef steaks from the LT muscle exhibited a dramatic improvement in palatability, especially tenderness. This improvement in sensory quality was associated with biochemical and structural changes of the LT muscle during postmortem aging period, and these changes in the LT muscle are well-characterized (Huff-Lonergan and Lonergan, 2005; Nair et al., 2019). However, there is a lack of precise information on when and how the sensory quality traits of beef round, especially the VL muscle, are significantly changed during the aging period, although a lower consumer preference for the VL muscle could be improved through postmortem aging as a higher-valued cut.

According to Lepper-Blilie et al. (2016), the aging time for the improvement of sensory tenderness can vary depending on the bovine marbling score and beef quality grade based on the USDA grading system. In Hanwoo steer, little is known regarding the effect of beef quality grade on sensory quality characteristics of wet-aged steaks from the LT and VL muscles. Therefore, the this study aimed to investigate and compare the palatability changes of VL muscle from different quality grades (1^{+} and 1) during 28 d of postmortem wet-aging with the well-characterized LT muscle of Hanwoo steer in order to improve the utilization of the VL muscle as a steak.

Materials and Methods

Muscle samples and preparation

A total of 10 LT and 10 VL muscles from a total of 10 Hanwoo steers (1^{+} quality grade, n=5; 1 quality grade, n=5) were used in this study. At 24 h postmortem, muscle samples were removed from the left side of Hanwoo steers after carcass quality grading by the Korea Institute of Animal Products Quality Evaluation (KAPE, 2017). The KAPE provided the marbling scores and beef quality grades of each carcass. The LT and VL muscles of each animal were cut into six sections (one section for the meat quality measurements; five sections for the aging experiments), respectively. Each section within

each muscle was randomly assigned to one of the five aging periods (0, 7, 14, 21, and 28 d) and meat quality measurements. A total of 80 muscle sections for wet-aging (10 animals×2 muscles×4 aging periods; except of 0 d) were placed individually in nylon-polyethylene bags (thickness 90 μm, oxygen transmission rate 50 cm^3/m^2/24 h). Muscle sections were then packaged using a vacuum packaging machine (Leepack, Hanguk Electronics, Incheon, Korea), and the vacuum level was 2.5 kPa. Muscle sections were then wet-aged at 2°C for 7, 14, 21, and 28 d. At each aging period, sections were removed from the vacuum package and cut into three steak-size cuts of 1.5 cm thick (one cut for cooking loss and WBS analysis; two cuts for sensory quality analysis), and then were frozen and stored at –20°C.

Meat quality measurements and chemical analysis

Ultimate muscle pH was measured at 24 h postmortem in the middle part of the LT and VL muscles using a portable pH- and temperature-measuring instrument with a penetration probe (Testo 206-pH2, Testo AG, Lenzkirch, Germany). At 24 h postmortem, muscle surfaces were allowed to bloom at 4°C in a cold room for 30 min, and then meat color values were recorded using a chromameter (CR-400, Minolta Camera Co., Osaka, Japan). The color values, including lightness (L*), redness (a*), and yellowness (b*), were expressed according to the recommendations of the Commission Internationale de l'Eclairage (1978).

The IMF, collagen, and myoglobin contents were measured using samples from the LT and VL muscles at 24 h postmortem. The IMF content was determined by the Soxhlet method (AOAC, 2012) using a solvent extraction system. The collagen content in muscle samples was measured using the hydroxyproline content as a calibration curve (Cross et al., 1973). The myoglobin content was calculated based on the absorbance value (Tang et al., 2004).

Cooking loss and WBS analysis

At each aging period, cooking loss and WBS were measured based on Honikel (1998). Cooked sample preparation for cooking loss and WBS analysis was the same. Samples of the LT and VL muscles were first placed inside a thin polyethylene bag and then placed in a continuously heated water-bath until the final internal temperature reached 71°C. Beef samples were weighed before and after cooking to calculate the percentage of cooking loss (Honikel, 1998). For analysis of WBS, six to ten cores (1.27 cm^2 diameter) were used. The WBS force was measured using an Instron Universal Testing Machine (Model 1011; Instron Corp., Canton, USA) equipped with a Warner-Bratzler blade operating at load capacity 10 kN with a crosshead speed of 200 mm/min (American Meat Science Association, 1995).

Trained sensory panel analysis

For the sensory quality analysis, a total of 200 beef samples were evaluated (10 animals×2 muscles×5 aging periods×2 replicates) during 34 sessions (5 to 6 samples for 1 session). All panel training sessions and sensory evaluations were performed at Kyungpook National University (KNU), and the human ethics approval was granted by the Bioethics Committee of KNU (protocol number: 2019-0027). Eleven panelists were trained according to previously published procedures (American Meat Science Association, 1995; Meilgaard et al., 1991). Each panelist evaluated the cooked beef samples of each muscle, quality grade, and aging time for tenderness (1 to 9; not at all tender to extremely tender), juiciness (1 to 9; extremely dry to extremely juicy), and flavor intensity (1 to 9; no beef flavor to full beef flavor) using a 9-point hedonic scale.

Statistical analysis

In order to compare meat quality, chemical traits, and sensory quality between muscle locations, beef quality grades, and aging time, the general linear model (GLM) procedure in SAS software (2014) was performed to elucidate any associations. Significant differences in the least squares means (LSM) of investigated parameters between the groups were compared by the probability difference (PDIFF) option at p≤0.05. All data were presented as LSM and standard errors.

Results

Comparison of meat quality and chemical characteristics

Table 1 shows the comparison of meat quality and chemical characteristics between the LT and VL muscles from different quality grades at 24 h postmortem. The LT muscle showed a lower muscle pH compared with the VL muscle (p<0.05), although no significant difference was observed between the LT muscle from 1^+ grade (LT-1^+) carcass and the VL muscle from 1^+ grade (VL-1^+) carcass (5.36 vs. 5.47, respectively). Lightness value was higher in the LT-1^+ compared to the other groups (p<0.05) possibly due to a higher number of smaller marbling fleck in the LT-1^+ (Lee et al., 2019), whereas there were no differences in redness and yellowness among the groups (p>0.05). As expected, the LT-1^+ grade group showed the highest IMF content compared to the other groups (p<0.05) and no difference was detected between the two grades within the VL muscle (10.8% vs. 11.1%, p>0.05). Collagen (0.31% vs. 0.18%, p<0.05) and myoglobin (6.97 vs. 6.39 mg/g, p<0.05) contents were higher in the VL-1 group than the LT-1^+ group.

Comparison of cooking loss and WBS value during postmortem aging

The cooking loss values in the LT and VL muscles from different quality grades during postmortem wet-aging are shown in Table 2. At each aging period, the LT muscle exhibited a lower cooking loss compared to the VL muscle (p<0.05). Noticeable differences were observed between the LT-1^+ and VL-1^+ groups aged 0 (14.9% vs. 28.7%, p<0.05) and 14 (18.3% vs. 31.8%, p<0.05) d. After aging for 14 d, a significant increase was observed within the LT-1^+ muscle (p<0.05), and the LT-1^+ samples

Table 1. Comparison of meat quality and chemical characteristics between *longissimus thoracis* (LT) and *vastus lateralis* (VL) muscles from different quality grades (1+ and 1) at 24 h postmortem

Muscle	LT muscle		VL muscle		SEM	Level of significance		
Grade	1^+	1	1^+	1		M	G	M×G
Muscle pH$_u$	5.36[b]	5.37[b]	5.47[ab]	5.50[a]	0.10	*	NS	NS
Lightness (L*)	41.1[a]	39.2[b]	36.6[c]	37.1[c]	0.57	***	NS	*
Redness (a*)	22.3	22.1	23.5	23.1	0.60	NS	NS	NS
Yellowness (b*)	10.6	9.94	9.98	9.73	0.37	NS	NS	NS
Chemical analysis								
Intramuscular fat (%)	19.8[a]	15.9[b]	10.8[c]	11.1[c]	1.52	***	NS	NS
Collagen (%)	0.18[b]	0.13[b]	0.39[a]	0.31[a]	0.05	***	NS	NS
Myoglobin (mg/g)	6.39[b]	6.29[b]	6.84[a]	6.97[a]	0.28	*	NS	NS

[a-c] Different superscripts in the same row represent significant differences (p<0.05).
* p<0.05, *** p<0.001.
M, muscle; G, grade; NS, not significant.

Table 2. Comparison of cooking loss between *longissimus thoracis* (LT) and *vastus lateralis* (VL) muscles from different quality grades (1⁺ and 1) during postmortem wet-aging

Aging period	LT muscle		VL muscle		SEM
	1+	1	1+	1	
0	14.9^{bx}	16.7^{by}	28.7^{ay}	29.5^{az}	0.80
7	16.4^{bx}	18.6^{by}	25.0^{ax}	24.5^{ay}	0.90
14	18.3^{dy}	22.4^{cz}	31.8^{az}	29.2^{bz}	0.81
21	20.7^{bz}	21.4^{bz}	26.7^{axy}	24.2^{ay}	0.98
28	21.6^{bz}	22.2^{bz}	28.4^{ay}	28.5^{az}	1.00

[a–d] Different superscripts in the same row represent significant differences (p<0.05).
[x–z] Different superscripts in the same column represent significant differences (p<0.05).

at 7 d of aging showed a lower cooking loss compared to the samples at 14 and 28 d of aging (16.4%, 18.3%, and 21.6%, respectively). Moreover, the cooking loss result of the LT-1 samples at different aging periods exhibited a similar tendency as the LT-1⁺ samples. Unlike the LT muscle, the VL muscle did not exhibit an increase in cooking loss with increasing aging time although a significant difference was observed within the 1⁺ or 1 sample in the VL muscle (p<0.05).

Within the LT muscle at each aging period, the 1 grade showed a higher WBS value compared to the 1⁺ grade (p<0.05) except on 28 d, and no significant difference was observed at 28 d of aging between the grades (39.4 vs. 36.5 N, respectively) (Fig. 1). Within the LT-1⁺, the WBS value at 0 d of aging was higher than value at 14 d of aging (56.5 vs. 35.5 N, p<0.05) and there was a no difference within the 1⁺ grade of LT muscle after 14 d of aging (p>0.05). Additionally, WBS value of the LT-1 group at 0 d of aging was a higher than that of the LT-1 group at 21 d of aging (68.4 vs. 51.7 N, p<0.05). Within the VL muscle, there were no differences between the grades at each aging period (p>0.05). The WBS value of the VL-1 group at 0 d of aging was a higher than that of the VL-1 group after 21 d of aging (p<0.05), and similar tendency was observed in the VL-
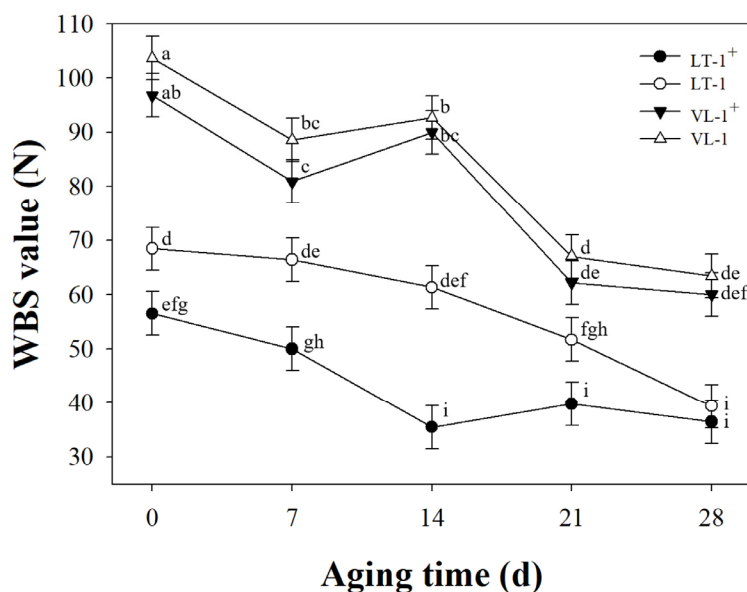

Fig. 1. Comparison of Warner-Bratzler shear force (WBS) value between *longissimus thoracis* (LT) and *vastus lateralis* (VL) muscles from different quality grades (1⁺ and 1) during postmortem wet-aging. Bars indicate standard errors of means. [a–i] Different superscripts represent significant differences (p<0.05).

1^+ group. Moreover, no significant differences were observed in the WBS value among samples from the LT-1 group at 0 d of aging and samples from the VL muscles after 21 d of aging.

Comparison of sensory quality characteristics during postmortem aging

Sensory quality characteristics, including tenderness, juiciness, and flavor intensity, in the LT and VL muscles from different quality grades during postmortem wet-aging are shown in Fig. 2. Within the LT muscle, the 1 grade showed a lower value of tenderness compared to the 1^+ grade at each aging period ($p<0.05$) except on 28 d. After 14 d of aging, the 1^+ or 1 grades displayed higher sensory tenderness scores compared to the 1^+ (7.41 vs. 6.23, $p<0.05$) or 1 (6.42 vs. 5.21, $p<0.05$) grades at 0 d of aging, respectively. For the VL muscle, no differences were detected in tenderness scores between the grades from 0 to 14 d of aging ($p>0.05$). Higher tenderness scores were observed within each grade in the same muscle ($p<0.05$) aged 21 d compared to 0 d. On the contrary, steaks from the LT-1 at 0 d of aging showed a similar tenderness score compared to steaks from the VL-1^+ after both 21 and 28 d of aging (5.21, 4.89, and 4.84, $p>0.05$). Like sensory tenderness, the 1 grade showed a lower juiciness score compared to the 1^+ grade at each aging period from 0 to 21 d in the LT muscle ($p<0.05$). After 21 d of aging, juiciness was higher than at 0 d of aging in the LT-1 muscle ($p<0.05$); whereas, no differences were found between the grades within the VL muscle at each aging period ($p>0.05$). Moreover, there was no significant difference between at 0 and 28 d of aging in the VL-1^+ group (3.33 vs. 3.67), although the VL-1 at 28 d showed a higher score than the VL-1 at 0 d (3.84 vs. 2.59, $p<0.05$). For flavor intensity, the LT-1^+ group at 14 d of aging had a higher score compared to the same group at 0 d of aging (6.71 vs. 5.67, $p<0.05$), and similar tendency was observed in the LT-1 group. In the VL-1^+ group, no difference was observed between aging periods ($p>0.05$). Conversely, the flavor intensity score of the LT-1group at 0 d of aging was similar to that assigned to the VL-1^+ group at 7 d of aging (4.78 vs. 4.26, $p>0.05$).

Discussion

The distinct differences between muscles from the same animal possibly by not only in the contractile behavior but also in the biochemical and morphological characteristics of muscle fiber (Nair et al., 2019). These muscle specificities can contribute to variations in quality of fresh meat and palatability of cooked meat (Lee et al., 2018). The VL muscle is part of the *quadriceps femoris* muscle group, which includes the VL, *vastus medialis*, *vastus intermedius*, and *rectus femoris* muscles (King et al., 2009). This muscle has a variety of functionally different fiber types and pronounced changes in exercise intensity (Staron et al., 2000). Due to functional characteristics of the VL muscle, higher composition of type I fiber, collagen, and myoglobin were observed compared to the LT muscle (Kolle et al., 2004) or the other muscles (Stolowski et al., 2006). In the current study, the VL muscle exhibited a lower IMF content and higher collagen content compared to the LT muscle at 24 h postmortem. Especially, the collagen content of the VL-1^+ muscle was approximately 2.2 times greater than that of the LT-1^+ muscle ($p<0.05$). Additionally, the 1^+ and 1 grades from VL muscle showed a darker cut-surface and higher myoglobin content compared to the LT muscle ($p<0.05$). These finding highlight the distinct biochemical characteristics between these muscles, especially in the contents of IMF and collagen, and it is possible that these muscles respond differently to wet-aging.

Water holding capacity (WHC) may not be improved by postmortem aging (Modzelewska-Kapitula et al., 2015). In this study, the cooking loss of steaks from the LT muscle tended to increase gradually from 0 to 28 d of aging. A comparable trend of cooking loss changes during postmortem aging was published by Wyrwisz et al. (2016). Anderson et al. (2012)

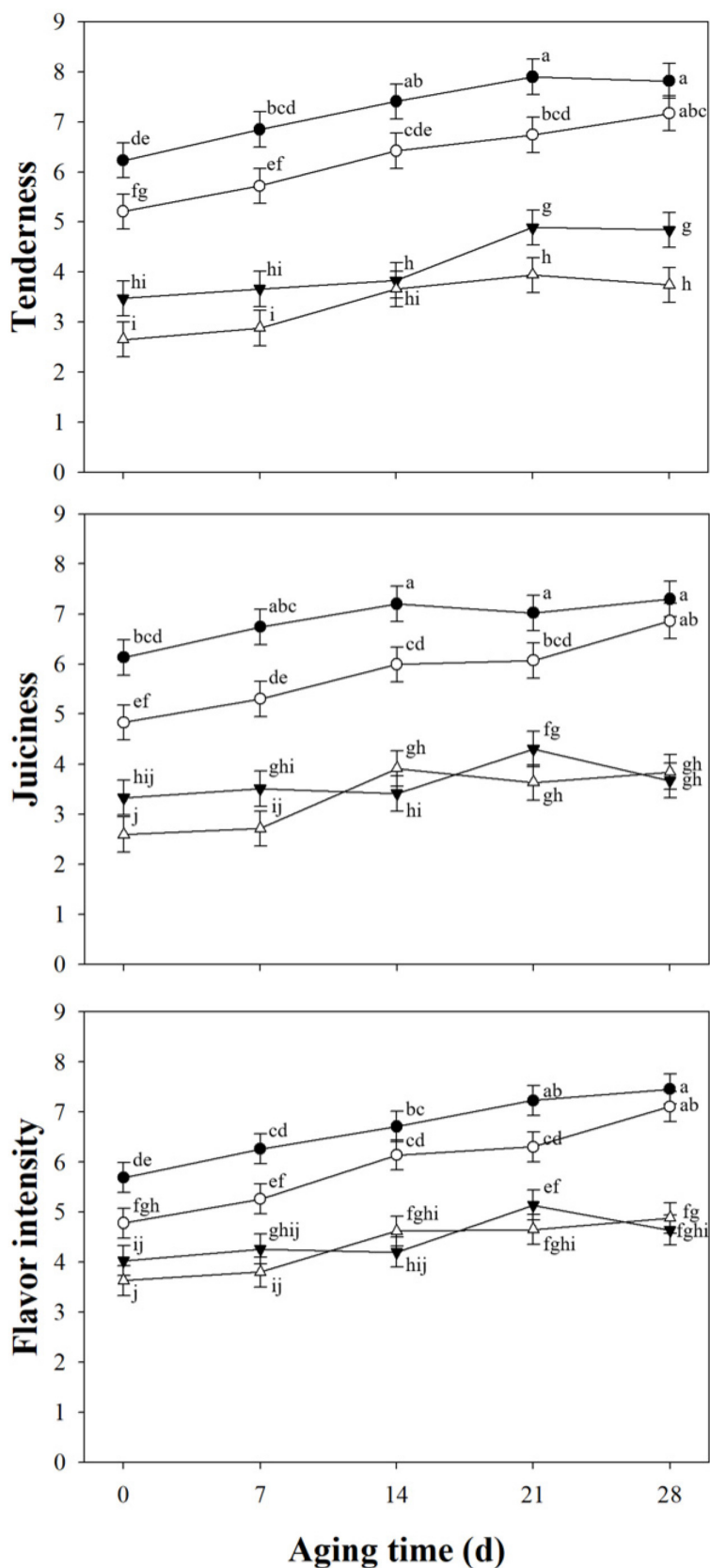**Fig. 2. Comparison of palatability characteristics, including tenderness, juiciness, and flavor intensity, between *longissimus thoracis* (LT and *vastus lateralis* (VL) muscles from different quality grades (1+ and 1) during postmortem wet-aging.** Bars indicate standard errors of means. [a–j] Different superscripts represent significant differences (p<0.05).

reported no significant changes in cooking loss of the VL and *vastus intermedius* muscles during 1 to 14 d of aging. Similarly, in the current study, there was no significant difference in the VL muscles between 0 and 28 d of aging. On the other contrary, the VL muscle with a higher collagen content showed a greater cooking loss during the aging period in comparison to the LT muscle with lower collagen content. This result is justified because the collagen concentration is negatively correlated with the WHC in bovine muscle (Modzelewska-Kapitula et al., 2015). However, the effect of quality grade on cooking loss was somewhat limited in the LT or VL muscle.

The LT-1^{+} muscle harboring a higher IMF content exhibited a lower WBS value and a higher tenderness score compared to the LT-1 muscle harboring a lower IMF content at 24 h postmortem (p<0.05). However, difference of the IMF content between the grades in the LT muscles showed a tendency distinct from the VL muscle, and so similar IMF contents were observed between the quality grades in the VL muscle (p>0.05). For this reason, no differences were observed in the WBS and sensory tenderness between the grades in the VL muscle at 0 d of aging. During wet-aging, steaks from the LT and VL muscles demonstrated significant improvements in tenderness. In the LT muscle, sensory tenderness improved from 0 to 14 d of aging. In the VL muscle, improved values of WBS and sensory tenderness were observed after 21 d of aging when compared with the corresponding values at 0 d of aging, although the changes in WBS and tenderness were not linear and consistent. However, wet-aging beyond 14 and 21 d did not improve sensory tenderness of the LT and VL muscles, respectively. These results on required aging time for tenderness improvement corroborate previous studies (Anderson et al., 2012; Nair et al., 2019; Stolowski et al., 2006) that steaks from the *longissimus lumborum* muscle generally needed a shorter aging time to improve tenderness compared to steaks from the other muscles. Stolowski et al. (2006) demonstrated that a longer aging time was required for the VL muscle compared to the *longissimus dorsi* and *semimembranosus* muscles. These differences between muscles during aging is mainly due to variations in the connective tissue protein content, IMF content, and postmortem proteolysis (Nair et al., 2019). Especially, greater collagen content in the VL muscle than in the other muscles is the most important factor contributing to the variations in tenderness during the aging period (King et al., 2009). On the other hand, Bratcher et al. (2005) suggested that beef loins of lower quality grade needed longer aging times compared to beef loins of upper quality grades in the USA. In the current study, there was no marked difference between the 1[+] and 1 grades in aging time required for sensory tenderness within each muscle in Hanwoo steer. Additionally, the VL-1^{+} steaks aged for 21 d and the LT-1 steaks at 24 h postmortem exhibited similar tenderness score and WBS value to each other.

Considerable improvements in juiciness and flavor can also occur during wet-aging period possibly due to structural changes of muscles through the action of endogenous proteases (Huff-Lonergan and Lonergan, 2005). In the current study, juiciness and flavor improved significantly in the LT steaks from 0 to 14 d of aging like sensory tenderness. Conversely, steaks from the VL-1^{+} muscle received similar scores in juiciness and flavor between 0 and 28 d of aging although these traits slightly improve in the VL-1 steak from 0 to 28 d of aging. A result reported by Anderson et al. (2012) proved similar tendencies for juiciness and flavor in the VL muscle and no differences were detected during aging periods. Thus, the effect of aging time on juiciness and flavor in the VL muscle is somewhat limited unlike tenderness.

Conclusion

In the current study, the sensory tenderness of cooked beef improved as aging time increased, and the required times to improve tenderness were 14 d of aging in the LT muscle. Additionally, trained panelists did not distinguish the difference in tenderness between the VL-1^{+} steaks aged for 21 d and the LT-1 steaks at 24 h postmortem, although the LT steaks were

tenderer compared to the VL steaks at each aging period due to a higher concentration of collagen in the VL muscle. Moreover, the VL-1$^+$ steak was tenderer than the VL-1 steak after 21 d of aging, whereas no differences were detected between the quality grades at 24 h postmortem. Taken together, our results indicated that the VL muscle should be aged for at least 21 d to improve consumer preference and utilization of this muscle. Considering the tenderness, using a higher quality grade for aging is also more useful in the VL muscle unlike the LT muscle.

Conflict of Interest

The authors declare no potential conflict of interest.

Acknowledgement

Author Contributions

Conceptualization: Yun Y, Kwon K, Kang S. Data curation: Yun Y, Choi YM. Formal analysis: Yun Y. Methodology: Lee B. Validation: Choi YM. Investigation: Lee B. Writing - original draft: Yun Y, Lee B, Choi YM. Writing - review & editing: Yun Y, Lee B, Kwon K, Kang S, Oh E, Choi YM.

Ethics Approval

The human ethics approval was granted by Bioethics Committee of Kyungpook National University (protocol number: 2019-0027).

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