ARTICLE

Evaluation of sensory attributes of Hanwoo *Longissimus dorsi* muscle and its relationships with intramuscular fat, shear force, and environmental factors

Chandima Gajaweera, Ki Yong Chung, Eung Gi Kwon, In Ho Hwang, Soo Hyun Cho, and Seung Hwan Lee

Abstract: We examined the relationship of Hanwoo (*Bos taurus coreana*) beef sensory attributes with intramuscular fat (IMF), Warner–Bratzler shear force (WBSF), and other environmental factors. Samples of 458 beef carcasses including 32 cows, 34 steers, and 392 bulls were analyzed for IMF percentage, WBSF, and important sensory attributes (tenderness, juiciness, and flavour-likeness). Results revealed that steer beef had significantly higher scores for all three sensory attributes than beef from cows and bulls. While juiciness and flavour-likeness differed ($p < 0.05$) among bulls and cows, they were not associated an effect on tenderness. All sensory attributes and WBSF were correlated ($p < 0.001$) with IMF; the highest correlation coefficient was for tenderness (0.55) while a negative coefficient (−0.39) was found for WBSF. The influence of IMF level on all three sensory attributes of bull beef significantly increased with IMF level. All sensory attributes of steer and bull beef showed negative relationship ($p < 0.01$) with WBSF, where highest correlation coefficient (−0.8) found for steer beef tenderness. Furthermore, tenderness and flavour-likeness showed lower ranks for meats slaughtered during the winter season; however, juiciness did not differ ($p < 0.05$) among seasons.

Key words: sensory attributes, intramuscular fat, shear force, season, Hanwoo.

Résumé : Nous avons examiné les relations entre les attributs sensoriels du bœuf Hanwoo (*Bos taurus coreana*) et le gras intramusculaire (IMF — « intramuscular fat »), les forces de cisaillement de Warner–Bratzler (WBSF — « Warner–Bratzler shear force ») et autres facteurs environnementaux. Des échantillons de 458 carcasses de bœuf incluant 32 vaches, 34 bouvillons et 392 taureaux ont été analysés pour leurs pourcentages d'IMF, WBSF et les attributs sensoriels importants (tendreté, jutosité et appréciation de saveur). Les résultats ont révélé que le bœuf des bouvillons avait des cotes significativement plus élevées pour les trois attributs sensoriels que le bœuf provenant des vaches et des taureaux. Tandis que la jutosité et l'appréciation de saveur différaient ($p < 0,05$) entre les taureaux et les vaches, elles n'étaient pas associées à un effet sur la tendreté. Il y avait une corrélation ($p < 0,001$) entre l'IMF et tous les attributs sensoriels et le WBSF; le plus grand coefficient de corrélation était pour la tendreté (0,55) tandis qu'un coefficient négatif (−0,39) a été trouvé pour le WBSF. L'influence du taux d'IMF sur les trois attributs sensoriels du bœuf de taureaux augmentait significativement avec le taux d'IMF. Tous les attributs sensoriels du bœuf des bouvillons et des taureaux ont montré une relation négative ($p < 0,01$) avec le WBSF, où le plus grand coefficient de corrélation (−0,8) a été trouvé pour la tendreté du bœuf de bouvillon. De plus, la tendreté et l'appréciation de saveur montraient des cotes plus faibles pour les viandes abattues pendant la saison hivernale; par contre, la jutosité ne différait pas ($p < 0,05$) entre les saisons. [Traduit par la Rédaction]

Mots-clés : attributs sensoriels, gras intramusculaire, force de cisaillement, saison, Hanwoo.

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Introduction

Hanwoo, Korean native cattle (*Bos taurus coreana*), is a hybrid of *Bos Taurus* × *Bos zebu.* Historically, Hanwoo cattle were draft animals that migrated to the Korean peninsula over 5000 yr ago. Through a long-term strategic pure-breeding program, the Hanwoo breed has been significantly improved for economically important production traits and has maintained stable traits over the last 30 yr (Han 1996; Lee et al. 2014). Consequently, Hanwoo beef has acquired a greater market share than cheaper imported beef in the Korean market due to its palatable taste, texture, and high nutritional value (Rhee et al. 2002). Despite its higher price, Hanwoo beef is positioned as a premium beef in the Korean meat market. Moreover, the revenue of farmers is mainly determined by the quality of meat grades, with the uppermost Hanwoo beef grade costing 2.5 times more than the lowest grade (Jo et al. 2012).

In 2016, approximately 2.7 million Hanwoo cattle were raised in Korea, and nearly 738 867 were slaughtered, including 363 332 steers, 20 264 bulls, and 353 880 cows [Korea Institute of Animal Products Quality Evaluation (KAPE) 2017; Korea Meat Trade Association (KMTA) 2017]. Korea is an emerging beef producer, accounting for less than 1% of the global production (Ryan and Cheetham 2017). Hanwoo beef has been recently introduced to world market as an initially recognized potential market; 46 MT was exported to Hong Kong in the last year (2016) (KMTA 2017). However, high marbling Korean beef will be expected to rival with the Japanese Wagyu beef, especially in the East Asian market. Average intramuscular fat (IMF) content of quality grade 1++ Hanwoo *Longissimus thoracis* muscle is substantially higher (approximately 28%) than Australian Angus (5.7%), while high marbling Japanese black cattle (Wagyu) developed an extraordinary amount of more than 40% (Cho et al. 2005; Horii et al. 2009; Hwang and Joo 2016).

Meat is a highly heterogeneous product with physicochemical and sensory properties dependent on pre-slaughter factors including breed, age, weight, sex, environment, and postmortem factors such as storage time and temperature (Prieto et al. 2009). A superior beef taste results from a balance between tenderness, juiciness, and flavour. A consistent great taste is fundamentally important to consumer decisions to purchase beef for a pleasurable dining experience (Tatum 2015). Kim et al. (2008) suggested that IMF content and tenderness are considered the most important factors determining meat quality and consumer taste preferences. Therefore, the marbling score for IMF and Warner–Bratzler shear force (WBSF) for meat tenderness are considered determinants for the market value of beef carcasses.

Marbling is one of the important traits determining overall meat quality (Cheng et al. 2015), which is visually observed as white flecks of fat present within the lean in the *Longissimus dorsi* (LD) muscle and is derived from the distribution of fat among muscle bundles from a cross-section of muscles (Yamada et al. 2009; Oler et al. 2015). Tenderness is the force required to bite through a piece of beef and is considered the most important qualitative characteristic determining overall acceptance (Guerrero et al. 2013). Since tenderness is associated with several texture parameters including hardness, firmness, cohesiveness, and ease of fragmentation, beef tenderness is characterized as a multiparameter attribute (Font-I-Furnols et al. 2015). Flavour is a complex attribute resulting from a combination of sensations such as odor, taste, pressure, and cutaneous sensations. Raw meat has a mainly bloody taste with flavour developing during the cooking process. A complex mixture of volatile compounds derived from lipid degradation during cooking determines the characteristic meaty aromas (Mottram 1998). Flavour preferences are widely associated with previous experiences and cultural backgrounds. Juiciness is the perception of meat moistness and is derived from the amount of juice released via successive mastication, which depends on the amount of moisture retained after cooking. Juiciness also helps to soften the meat and stimulates saliva production; consequently, making mastication easier [Szczesniak 2002; Food and Agriculture Organization of the United Nation (FAO) 2017].

The IMF content of the Hanwoo breed has increased by more than 30% over the last two decades (Smith and Johnson 2014). After the establishment of Korean carcass grading system in 1992, two new quality grades have been reintroduced in 1997 and 2004 to cater the emergence of highly marbled Hanwoo beef (KAPE 2017), and it is assumed that another new quality grade will be introduced within next few years. As IMF of Hanwoo beef significantly correlated with the sensory attributes (Moon et al. 2006; Jung et al. 2016), it is important to have frequent studies on sensory attributes related to the increasing IMF. In addition, three-sex types of Hanwoo beef are available in Korean market including steers and bulls slaughtered around 30 mo of age and cows no longer used for reproduction (approximately 5-yr-old). Therefore, it is a timely need to analyse the sensory attributes of Hanwoo beef considering the sex types available in the market to better understand the consumer perception. Cho et al. (2010) has suggested that the overall palatability of Hanwoo beef in the Korean market is primarily determined by the three sensory qualities, tenderness, flavour, and juiciness with importance weights for 55%, 27%, and 18%, respectively. Therefore, the objective of this study was to evaluate the sensory attributes (tenderness, juiciness, and flavour-likeness) of Hanwoo LD muscle and their relationship with IMF, shear force (SF), and other environmental factors.

Table 1. Experimental groups according to the intramuscular fat (IMF) percentage.

	Steers			Bulls			Cows		
IMF group	1	2	3	1	2	3	1	2	3
IMF concentration in loin[a]	<10%	10–15%	>15%	<5%	5%–10%	>10%	<5%	5%–10%	>10%
Number of animals	5	15	13	176	159	56	10	16	4
Mean IMF %	7.86	12.88	18.19	3.18	7.28	13.6	3.71	6.95	11.94

[a]Intramuscular fat percentage in loin (wet-basis).

Materials and Methods

Sample preparation

This study was conducted at Hanwoo Research Institute of the National Institute of Animal Science (NIAS), Pyeongchang-gun, Gangwon-do, Republic of Korea. This is a high mountain area with a temperate climate, with cold and rainy conditions. The area has four distinct seasons including clear and dry spring from March to May (average temperature 5.8 °C), hot and humid summer from June to August (average temperature 18.2 °C), cool and dry fall from September to November (average temperature 8.7 °C), and very cold and dry winter from December to February (average temperature −5.2 °C). The average annual precipitation is 1082 mm. The 458 beef carcass samples used in this study included 32 cows, 34 steers, and 392 bulls that were obtained from the Hanwoo Research Institute's beef feedlots. All animals were reared under the same environmental and management conditions, and were slaughtered following standard procedures (KAPE 2017).

All the experimental animals were fed a similar ration over the last 5 mo before slaughtering, as they were prepared for the market. Therefore, during the last fattening stage, more concentrates were introduced while reducing roughage (rice straw supply was reduced up to 1.5–2 kg^{-1} d^{-1} animal^{-1}). The rate of concentrate was raised to 90% and only 10% of rice straw was provided to maximize the IMF deposition and the resulting increase in the marbling scores. Concentrate feed contained 72%–73% total digestible nutrients and 11%–12% crude protein. Animals had ad libitum access to fresh water. The data were divided into four discrete seasons referring to time of slaughter. The summary statistics are shown in Table 2. However, due to the inadequate number of steers and cows slaughtered during the summer, fall, and winter (Table 2), only bulls were used to evaluate the seasonal effect.

Determination of IMF and SF

After 24 h of post-slaughter chilling at 4 °C, carcasses were ribbed between 13th rib and the 1st lumbar vertebrae. Subsequently, the cold carcass weight, meat quality, and yield grades were evaluated with reference to the Korean grading standard (KAPE 2017). The LD muscles were removed between 12th and 13th rib and transferred at temperature 0–5 °C to Meat Science

Laboratories for further evaluation. The IMF in ground samples of LD muscle was analyzed using a microwave solvent extraction method according to the procedures of the Association of Official Analytical Chemists [Association of Official Analytical Chemists (AOAC) 1996; Silva et al. 2015]. IMF was measured as a continuous variable, then classified into discrete IMF groups for analysis. As shown in Table 1, three IMF groups were determined on the basis of variability in IMF percentage in corresponding sex groups.

The WBSF of cooked steaks (LD muscle) was measured according to the method described by Wheeler et al. (2000). Approximately 80 g of 2.5 cm thick meat steaks were placed in polyethylene bags and cooked in a preheated water bath for approximately 40 min until the internal temperature reached 70 °C. Subsequently, samples were cooled in running water (approximately 18 °C) at room temperature (below 30 °C) for 30 min. At least six representative cores samples (1.27 cm diameter) were removed from the center of each steak, parallel to the muscle fiber orientation. WBSF values were determined using an Instron Universal Testing machine (Model 3344, Canton, MA, USA) with a Warner–Bratzler shear device with a load cell of 50 kg and crosshead speed of 200 mm min^{-1}. The mean force required to shear each set of cores was considered to be the WBSF value (Kragten and Gil 2015).

Determination of sensory attributes

Longissimus dorsi muscles were cut into 75 mm × 20 mm × 4 mm slices parallel to the fiber orientation, then vacuum packed and stored at −20 °C until analysis. For sensory evaluation, the samples were thawed to approximately 4 °C and then cooked by placing on a tin plate equipped with a water jacket at approximately 245–255 °C. Strips were turned at the first pooling of liquid on the surface of the sample or at the start of shrinkage. Cooked samples were labeled with three-digit random numbers and immediately served to each panelist for evaluation. Seven to nine trained panelists were used for each sensory evaluation session and were asked to score the samples for tenderness, juiciness, and flavour-likeness based on a nine-point hedonic scale with the following standards: tenderness = very tough (0) to very tender (9), juiciness = very dry (0) to very juicy (9), and flavour-likeness = extreme dislike (0)

to extreme like (9). Each and every sample was separately evaluated by each panelist and scores were averaged over the different panelists for each animal (Dang et al. 2014; Belk et al. 2015; Font-I-Furnols et al. 2015; Cho et al. 2016).

Statistical analysis

Sensory attributes and SF were analyzed using the following linear models to identify the factors influencing the response.

$$Y_{ijklmn} = \mu + IM_i + A_j + Y_k + S_l + Sx_m$$
$$+ (IM * Sx)_n + e_{ijklmn}$$

Where Y_{ijklmn} indicates sensory attributes or SF, μ is overall mean, IM_i is IMF group, A_j is age, Y_k is slaughter year, S_l is slaughter season, Sx_m is sex group, $(IM*Sx)_n$ is the interaction of IMF group by sex, and e_{ijklmn} is the random residual effect (Fortin et al. 2005).

The statistical significance of differences between data were analyzed with analysis of variance, followed by Tukey's honestly significant difference test at a significance level of 0.05. In addition, Pearson product-moment correlation coefficients were used to investigate the relationship between sensory attributes, SF, and IMF. All data were analyzed using the statistical software package R (R Core Team 2016).

Results and Discussion

Summary statistics

Selected descriptive statistics are shown in Table 2. This experiment used 458 animals including 34 steers, 392 bulls, and 32 cows. Steers and bulls were slaughtered at a comparatively younger age, 27.98 ± 2.01 and 25.127 ± 1.16 mo on average, respectively, than cows. Since the objective of rearing cows is reproduction purpose, cows were slaughtered at a mean age of 144.75 mo (range of 109.8–192.2) after their production cycle. Most of the animals were slaughtered during the spring and summer.

Effect of sex (steer, bull, and cow) on sensory attributes of Hanwoo beef

Figure 1 shows the relationships between sensory attributes (juiciness, tenderness, and flavour-likeness) of Hanwoo beef by sex (steer, bull, and cow). Steer beef has significantly higher scores for all three sensory attributes than cow beef. Although bulls (24–29.6 mo) and steers (24.4–30.6 mo) belong to a similar age group, steer beef had greater values ($p < 0.05$) for all sensory attributes than bull beef. Significantly lower scores were found for juiciness and flavour-likeness of cow beef than for bulls; however, there was no effect ($p < 0.05$) on tenderness between these two sex groups. Furthermore, a comparison between SF and sex type indicated that SF was significantly different among the three-sex groups, i.e., highest in cows followed by bulls and steers. Steers

Table 2. Selected descriptive statistics based on sex.

	Steers	Bull	Cow
Number	34	392	32
Age at slaughtering (months)			
Mean	27.97	25.13	144.75
Standard deviation	2.01	1.16	22.47
Minimum to maximum	24.4–30.6	24–29.6	109.8–192.2
Carcass weight (kg)			
Mean	400.89	386.99	263.53
Standard deviation	44.10	50.92	35.41
Minimum to maximum	307–481	228–523	198–347
Number of animals slaughter at different season			
Spring	24	175	20
Summer	3	154	7
Fall	3	40	2
Winter	1	20	1

Fig. 1. Effect of sex (steers, bulls, and cows) on sensory attributes of Hanwoo beef. Different letters indicate significant differences ($p < 0.05$) between sex.
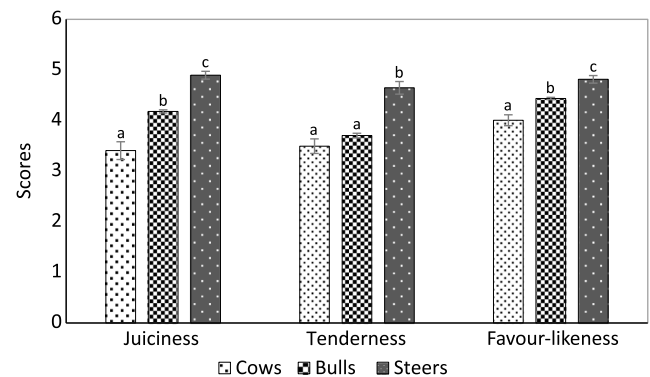
showed higher IMF levels (average 14.21 ± 4.13, $p < 0.05$) than the other two sex groups, while there was no difference ($p < 0.05$) between IMF percentage for bulls and cows.

The sex of the animal has a vital effect on the physico-chemical properties of the meat, especially on tenderness, IMF deposition, moisture content, pH, lightness, and hydroxyproline content (Panjono et al. 2009; Zhang et al. 2010). Fritsche and Steinhart (1998) and Panjono et al. (2009) reported that the hormonal profile of an animal changes based on their sex, and this is associated with meat quality parameters such as fat and protein distribution and tenderness. Also, Prior et al. (1983) suggested that it is possible to change the process of lipid metabolism by manipulating the sex hormone profile of cattle. Testosterone hormone has anabolic effects on collagen synthesis and increase the thermal stability of collagen. In addition, testosterone plays a major role in the maturation of collagen by decreasing the collagen degradation rate and increasing the hydroxyproline

content in bulls (Cross et al. 1984; Gerrard et al. 1987; Destefanis et al. 2003). Therefore, sex is an important antemortem factor contributing to variation in beef sensory parameters (Nielsen and Thamsborg 2005; Choat et al. 2006).

Similar to our results, Panjono et al. (2009) indicated that all important carcass traits were significantly different between steers, bulls, and cows, with steers showing significantly higher carcass quality grades than bulls and cows. Destefanis et al. (2003) explained that castration affects the chemical composition of muscles including decreasing water and increasing fat content. In this study, cow beef showed inferior palatability characteristics to bull beef, which might be due to cows being slaughtered at a mature age after their production cycle (mean 144.75 + 22.46 mo). Research conducted to examine the relationship of physiological maturity and meat quality traits of Hanwoo females has shown that maturity could negatively influence beef qualities and carcass traits with old animals that showed lower scores for flavour, tenderness, and overall acceptability than young and intermediate age animals (Moon et al. 2006). According to Du Plessis and Hoffman (2007), sensory quality characteristics of Simmentaler crossbreed beef decreased with chronological age. In addition, physiological maturity was negatively correlated (-0.108, $p < 0.01$) with the carcass quality grade of Hanwoo steers (Panjono et al. 2009).

Effects of IMF level on sensory attributes of Hanwoo beef

Table 3 presents the different parameters of the linear relationship between Hanwoo beef sensory qualities and WBSF with IMF percentage. All attributes were significantly correlated ($p < 0.001$) with IMF percentage. The highest correlation coefficient was obtained for tenderness (0.55) while average SF had a negative coefficient (-0.39). The relationship between average SF and IMF is further illustrated in Fig. 2.

Figure 3 presents the effect of IMF level on sensory attributes of Hanwoo beef related to sex (bulls, cows, and steers). Juiciness and flavour-likeness did not differ ($p < 0.05$) among the IMF groups for steer meat; however, there was a significant difference between low (<10) and high IMF groups for tenderness. The level of IMF in the loin (<10%, 10–15%, and >15%) did not have an effect ($p < 0.05$) on sensory attributes of cow meat samples. However, the influence of IMF level (<5%, 5–10%, and >10%) on all three sensory attributes of bull beef were significantly increased by IMF level. Furthermore, a positive relationship between IMF level and sensory attributes for all three-sex groups were observed (Fig. 3). This agrees with the moderate correlation for juiciness, flavour-likeness, and tenderness with IMF percentage shown in Table 3.

Health concerns associated with the red meat such as major chronic diseases, such as cardiovascular disease, colon cancer, and obesity, has driven a negative force

Table 3. Different parameters of the linear relationships between sensory attributes and shear force with the intramuscular fat (IMF) percentage.

Attributes	Linear relationship		Pearson correlation coefficient
	a	b	
Shear force	7.31***	−0.20***	−0.39***
Juiciness	3.67***	0.07***	0.47***
Tenderness	2.98***	0.11***	0.55***
Flavour-likeness	4.09***	0.05***	0.47***

**Note:** *** $p < 0.001$, [Attribute (Y) = $a + b$ * IMF].

on purchasing of high fat meat in global market (McAfee et al. 2010). However, Korean consumers are willing to pay more for their premium Hanwoo beef regardless of its high marbling fat content. IMF develops among muscle bundles during growth; however, IMF formation continues even after muscle development is completed (Bennett 2013). Approximately 80% of fat is deposited in muscle adipocytes found between fibers and fiber bundles with the rest (5%–20%) stored as intracellular lipids in lipid droplets within myofibers in the cytoplasm. IMF consists of structural lipids, phospholipids, and triglycerides (Essén-Gustavsson and Fjelkner-Modig 1985). Marbling is one of the important traits determining overall meat quality (Cheng et al. 2015). The IMF percentage varies due to a large number of factors including species, age, sex, maturity, breed, feeding management and nutrition, slaughter weight, muscle localization, and myofiber type (Cheng et al. 2015; Silva et al. 2015). The desired marbling content of meat depends on the country, consumer, and processing technology; therefore, different countries have developed their own standards for evaluating the marbling degree of meat based on demand associated with marbling content. Consequently, there is a very high correlation between marbling score and the market price of meat (Cheng et al. 2015).

Intramuscular fat deposition mainly takes place in the perimysium between fiber bundles and subsequently disorganizes the metrix of intramuscular connective tissues. Therefore, increasing IMF content reduces meat toughness, which contributes to enhancing tenderness (Wheeler et al. 1994; Nishimura 2015). Li et al. (2006) have shown that the development of marbling results in a change in the collagen content and its solubility, mechanical strength of intramuscular connective tissue, fiber diameter, avoidance of sarcomere shortening, and disorganization of the perimysia, which accounts for the improvement in beef tenderness. Also, Li et al. (2006) suggested that beef with a high marbling score should be positioning for higher grade for important sensory attributes (juiciness, tenderness, and flavour-likeness) by consumers.

Fig. 2. Relationship between average shear force and intramuscular fat (IMF) percentage of Hanwoo beef.
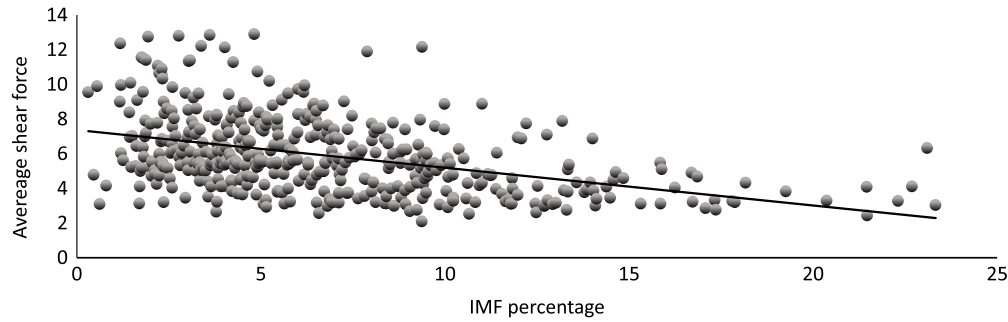
Fig. 3. Effect of the level of intramuscular fat (IMF) on sensory attributes (juiciness, tenderness, and flavour-likeness) of Hanwoo beef related to sex (bulls, cows, and steers). Different letters indicate significant differences ($p < 0.05$) between IMF groups.
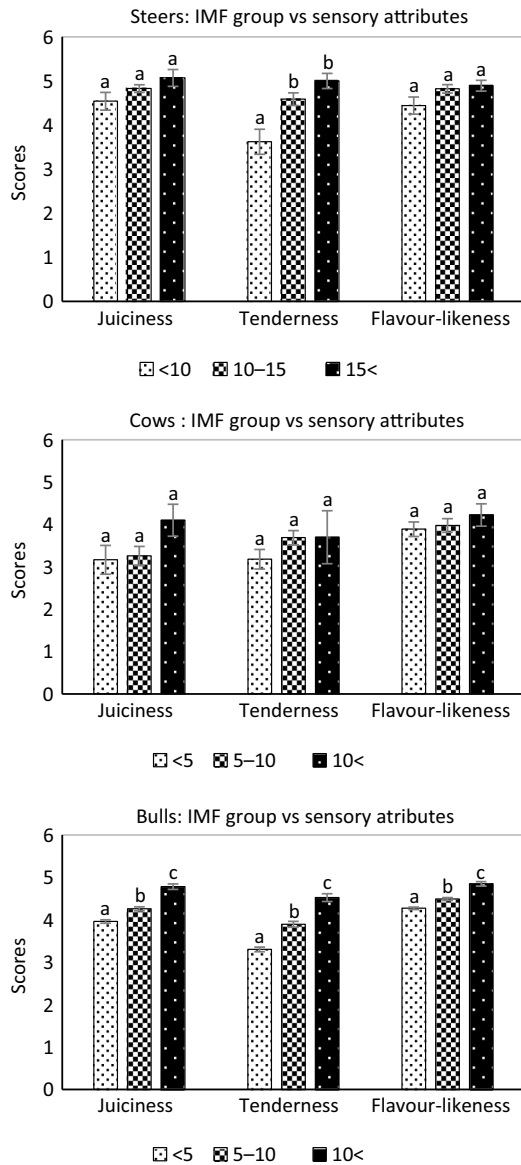
Table 4. Correlation coefficient between sensory attributes and Warner–Bratzler shear force.

	Bulls	Cows	Steers
Tenderness	−0.49**	−0.45*	−0.80**
Juiciness	−0.29**	−0.41*	−0.62**
Flavour-likeness	−0.32**	−0.35	−0.62**

Note: ** $p < 0.01$ (correlation is significant at 0.01 level). * $p < 0.05$ (correlation is significant at 0.05 level).

The sensory quality evaluation done by Nishimura (2015) indicated that high IMF content improves the texture, tenderness, and juiciness of beef and, thereby, its overall acceptability. Thompson (2004) described IMF's important impacts on both juiciness and flavour by enhancing lubrication during chewing. Also, Thompson showed a positive curvilinear relationship between flavour and juiciness scores with IMF percentage. Moon et al. (2006) showed that sensory scores were highest ($p < 0.05$) for tenderness, flavour, and overall acceptability in a high-marbling group, with maximum WBSF for the low-marbling group. The results shown in Fig. 2 and Table 3 reveal that there is a negative correlation (−0.39, $p < 0.001$) between WBSF and IMF. Moreover, a recent study has shown significantly higher juiciness, tenderness, and overall acceptance scores with increasing IMF level (low, <14%; medium, 14%–17%; and high, >17%) in Hanwoo beef (Jo et al. 2013).

Relationship between WBSF and sensory attributes of Hanwoo beef

Table 4 shows the relationship between sensory attributes and WBSF for Hanwoo beef of different sexes, illustrating that all of the sensory attributes of the three different sexes have a negative relationship with WBSF. The highest correlation coefficient (−0.8, $p < 0.01$) was found for steers' tenderness with WBSF, whereas bulls and cows have moderate correlations of −0.49

Fig. 4. Effect of slaughtering season on sensory quality of Hanwoo bull beef. Different letters indicate significant differences ($p < 0.05$) between the seasons.
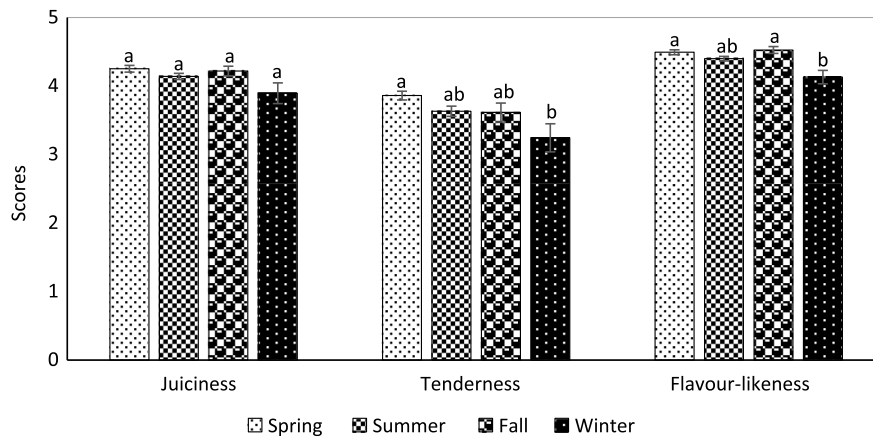
and −0.45, respectively. Juiciness and flavour-likeness showed a similar correlation (−0.62, $p < 0.01$) with WBSF for steers. While the correlation coefficient between flavour-likeness and WBSF was not significant, there was a significant negative correlation ($p < 0.05$) for cow beef juiciness. The lowest correlation coefficient ($p < 0.01$) between juiciness and WBSF was found for the bull group.

Hanwoo beef contains comparatively lean muscle fibers and less connective tissues (Jo et al. 2013). Intramuscular connective tissue plays an important role in determining meat texture, especially since collagen is responsible for regulating meat tenderness (Nishimura et al. 1999; Weston et al. 2002). Furthermore, Torrescano et al. (2003) reported a high positive correlation between raw meat collagen content and SF. In this investigation (Table 4), the high correlation between sensory attributes of beef of Hanwoo steers might be due to their superior IMF content. As discussed earlier, WBSF was lower with higher IMF, and there were positive correlations for flavour-likeness and juiciness with IMF. Corresponding to the present study, Destefanis et al. (2008) reported a −0.72 correlation coefficient for WBSF with sensory tenderness score and Pearson (1963) reported correlations of WBSF with the sensory assessment of beef tenderness vary in a range from −0.60 to −0.85. In addition, mean tenderness ratings and mean SF values for different beef muscles had a −0.85 correlation ($p < 0.001$) (Calkins and Sullivan 2011).

Similar to our results, an evaluation of beef top loin steak palatability with WBSF showed a difference ($p < 0.05$) between lower and higher SF groups; consumers also gave higher ($p < 0.05$) juiciness and flavour ratings to lower SF than higher SF beef steaks (Boleman et al. 1997). In the same way, Shackelford et al. (2001) showed a higher rating ($p < 0.001$) for all consumer traits (i.e., tenderness, juiciness, and beef flavour intensity) by lower SF than higher SF groups. Comparable to the present results, research conducted with Canada 1 yield grade beef carcasses indicated that WBSF had negative correlations ($p < 0.05$) with the juiciness (−0.13), flavour intensity (−0.22), and overall tenderness (−0.6) of beef rib steaks (Caine et al. 2003). Miller et al. (2001) observed a high degree of consumer acceptability and higher tenderness ratings in beef steaks with lower WBSF values ($p < 0.05$). Furthermore, Jung et al. (2016) evaluated the relationship between meat quality traits and palatability of different primal cuts of Hanwoo beef, illustrating that SF was significantly correlated with tenderness and overall palatability −0.66 ($p < 0.001$) and −0.54 ($p < 0.01$), respectively, suggesting that overall palatability of Hanwoo beef is mainly determined by fat content and SF.

Influence of slaughtering season on sensory quality of Hanwoo beef

Environmental factors including air temperature, relative humidity, solar radiation, air movement, and atmospheric pressure adversely affect animal performance such as production, reproduction, and health (Hahn et al. 2003; Ski et al. 2016). Several studies have indicated that an adverse seasonal environment is a stress for animals and negatively affects meat quality traits of ruminants, with animals showing dramatic responses to seasonal change (Grandin 1996; Guerrero et al. 2013). The present study shows that season had a low impact on juiciness since there was no difference ($p < 0.05$) among the seasons. However, tenderness of beef from cattle slaughtered during winter was significantly lower than spring. Figure 4 indicates that flavour-likeness of Hanwoo beef of cattle slaughtered during winter was lower ($p < 0.05$) than fall and spring. Kadim et al. (2008) reported that inclement weather (e.g., heat) caused physiological stress in beef cattle that led to the depletion of muscle glycogen reserves, which might raise the meat's ultimate pH values, possibly affecting the associated beef quality characteristics. The

start of acclimatization to heat stress changes the physiological state of the animal including modifying the hormonal profile of the body, subsequently altering energy, lipid and protein metabolism, and nutrient partitioning, as well as the glucose-sparing mechanism (Bernabucci et al. 2010). Kadim et al. (2004) showed that the hot season increased ($p < 0.001$) pH values of meat with significantly lower SF compared to meat samples slaughtered during the cool season. Accordingly, due to the higher tenderization rate with increasing pH, meat tenderness was enhanced. Similar to the present results, beef juiciness for Hanwoo steer was not different ($p < 0.05$) among the winter and summer slaughter seasons; however, the sensory panel's rankings for tenderness and aroma of Hanwoo meat from summer slaughter were higher ($p < 0.05$) than meat slaughtered during winter (Panjono et al. 2011).

Acknowledgments

References

Association of Official Analytical Chemists (AOAC). 1996. Official methods of analysis. 16th ed. Association of Official Analytical Chemists, Washington, DC.

Belk, K.E., Dikeman, M.E., Calkins, C.R., Andy King, D., Shackelford, S.D., Hale, D., and Laird, H. 2015. Research guidelines for cookery, sensory evaluation, and instrumental tenderness measurements of meat. American Meat Science Association, Champaign, IL. pp. 6–104.

Bennett, S. 2013. Intramuscular fat deposition (marbling) in beef including Wagyu, Wagyu International. [Online]. Available from http://www.wagyuinternational.com/marbling.php [28 Dec. 2016].

Bernabucci, U., Lacetera, N., Baumgard, L.H., Rhoads, R.P., Ronchi, B., and Nardone, A. 2010. Metabolic and hormonal acclimation to heat stress in domesticated ruminants. Animal, 4(7): 1167–1183. doi:10.1017/S175173111000090X. PMID:22444615.

Boleman, S.J., Boleman, S.L., Miller, R.K., Taylor, J.F., Cross, H.R., Wheeler, T.L., Koohmaraie, M., Shackelford, S.D., Miller, M.F., West, R.L., Johnson, D.D., and Savell, J.W. 1997. Consumer evaluation of beef of known categories of tenderness. J. Anim. Sci. 75: 1521–1524. doi:10.2527/1997.7561521x. PMID:9250512.

Caine, W., Aalhus, J., Best, D., Dugan, M.E., and Jeremiah, L. 2003. Relationship of texture profile analysis and Warner–Bratzler shear force with sensory characteristics of beef rib steaks. Meat Sci. 64: 333–339. doi:10.1016/S0309-1740(02)00110-9. PMID:22063112.

Calkins, C.R., and Sullivan, G. 2011. Ranking of beef muscles for tenderness the significance of tenderness. J. Food Qual. 34: 195–203. doi:10.1111/j.1745-4557.2011.00386.x.

Cheng, W., Cheng, J.-H., Sun, D.-W., and Pu, H. 2015. Marbling analysis for evaluating meat quality: methods and techniques. Compr. Rev. Food Sci. Food Saf. 14: 523–535. doi:10.1111/1541-4337.12149.

Cho, S.H., Park, B.Y., Kim, J.H., Hwang, I.H., Kim, J.H., and Lee, J.M. 2005. Fatty acid profiles and sensory properties of *Longissimus dorsi*, *Triceps brachii*, and semimembranosus muscles from Hanwoo and Australian Angus beef. Asian-Australas. J. Anim. Sci. 18: 1786–1793. doi:10.5713/ajas.2005.1786.

Cho, S.H., Kim, J., Park, B.Y., Seong, P.N., Kang, G.H., Kim, J.H., Jung, S.G., Im, S.K., and Kim, D.H. 2010. Assessment of meat quality properties and development of a palatability prediction model for Korean Hanwoo steer beef. Meat Sci. 86: 236–242. doi:10.1016/j.meatsci.2010.05.011. PMID:20584575.

Cho, S., Kang, S.M., Seong, P., Kang, G., Kim, Y., Kim, J., Lee, S., and Kim, S. 2016. Effect of aging time on physicochemical meat quality and sensory property of Hanwoo bull beef. Korean J. Food Sci. Anim. Resour. 36: 68–76. doi:10.5851/kosfa.2016.36.1.68.

Choat, W.T., Paterson, J.A., Rainey, B.M., King, M.C., Smith, G.C., Belk, K.E., and Lipsey, R.J. 2006. The effects of cattle sex on carcass characteristics and longissimus muscle palatability. J. Anim. Sci. 84: 1820–1826. doi:10.2527/jas.2004-418. PMID:16775066.

Cross, H.R., Schanbacher, B.D., and Crouse, J.D. 1984. Sex, age and breed related changes in bovine testosterone and intramuscular collagen. Meat sci. 10(3): 187–195. doi:10.1016/0309-1740(84)90021-4. PMID:22054433.

Dang, C.G., Cho, S.H., Sharma, A., Kim, H.C., Jeon, G.J., Yeon, S.H., Hong, S.K., Park, B.Y., Kang, H.S., and Lee, S.H. 2014. Genome-wide association study for Warner–Bratzler shear force and sensory traits in Hanwoo (Korean Cattle). Asian-Australas. J. Anim. Sci. 27(9): 1328–1335. doi:10.5713/ajas.2013.13690.

Destefanis, G., Brugiapaglia, A., Barge, M.T., and Lazzaroni, C. 2003. Effect of castration on meat quality in Piemontese cattle. Meat Sci. 64: 215–218. doi:10.1016/S0309-1740(02)00184-5. PMID:22062869.

Destefanis, G., Brugiapaglia, A., Barge, M.T., and Dal Molin, E. 2008. Relationship between beef consumer tenderness perception and Warner–Bratzler shear force. Meat Sci. 78: 153–156. doi:10.1016/j.meatsci.2007.05.031. PMID:22062265.

Du Plessis, I., and Hoffman, L.C. 2007. Effect of slaughter age and breed on the carcass traits and meat quality of beef steers finished on natural pastures in the arid subtropics of South Africa. S. Afr. J. Anim. Sci. 37: 143–1853. doi:10.4314/sajas.v37i3.4084.

Essén-Gustavsson, B., and Fjelkner-Modig, S. 1985. Skeletal muscle characteristics in different breeds of pigs in relation to sensory properties of meat. Meat Sci. 13: 33–47. doi:10.1016/S0309-1740(85)80003-6.

Food and Agriculture Organization of the United Nation (FAO). 2017. Meat quality, quality and safety. Animal Production and Health, Agriculture and Consumer Protection Department. [Online]. Available from http://www.fao.org/ag/AGAInfo/themes/en/meat/quality_meat.html [21 July 2017].

Font-I-Furnols, M., Núria Panella, R., and Karlsson, A. 2015. Chapter 7 Reference measurement for sensory attributes: tenderness, juiciness, flavour and taint. Pages 66–77 in M. Font-I-Furnols, M. Čandek-Potokar, C. Maltin, and M. Prevolnik Povše, eds. A handbook of reference methods for meat quality assessment. SRUC, European Cooperation in Science and Technology. Kings Buildings, West Mains Road, Edinburgh, Scotland.

Fortin, A., Robertson, W.M., and Tong, A.K.W. 2005. The eating quality of Canadian pork and its relationship with intramuscular fat. Meat Sci. 69: 297–305. doi:10.1016/j.meatsci.2004.07.011. PMID:22062822.

Fritsche, S., and Steinhart, H. 1998. Differences in natural steroid hormone patterns of beef from bulls and steers. J. Anim. Sci. 76: 1621–1625. doi:10.2527/1998.7661621x. PMID:9655582.

Grandin, T. 1996. Factors that impede animal movement at slaughter plants. J. Am. Vet. Med. Assoc. 209: 757–759. PMID:8756875

Gerrard, D.E., Jones, S.J., Aberle, E.D., Lemenager, R.P., Diekman, M.A., and Judge, M.D. 1987. Collagen stability, testosterone secretion and meat tenderness in growing bulls and steers. J. Anim. Sci. **65**(5): 1236–1242. doi:10.2527/jas1987.6551236x. PMID:3693150.

Guerrero, A., Valero, M.V., Campo, M.M., and Sañudo, C. 2013. Some factors that affect ruminant meat quality: from the farm to the fork. Rev. Acta Sci. Anim. Sci. **35**: 335–347.

Han, S.Y. 1996. Breeds of cattle. Pages 53–55 in S.Y. Han, ed. Animal breeds. Sunjin Publishing Company, Seoul, South Korea.

Hahn, G.L., Mader, T.L., and Eigenberg, R.A. 2003. Perspective on development of thermal indices for animal studies and management. Pages 31–44 in Interactions between climate and animal production (EAAP Proceedings, Technical Series 7). Wageningen Academic Publishers, Wageningen, the Netherlands.

Horii, H., Sakurai, Y., Kanbe, Y., Kasai, K., Ono, K., Asada, T., Mori, T., Kobayashi, M., Iguchi, A., Yamada, M., Hayashi, M., and Hodate, K. 2009. Relationship between Japanese beef marbling standard numbers and intramuscular lipid in *M. longissimus thoracis* of Japanese Black steers from 1996 to 2004. Nihon Chikusan Gakkaiho, **80**: 55–61. doi:10.2508/chikusan.80.55.

Hwang, Y.H., and Joo, S.T. 2016. Fatty acid profiles of ten muscles from high and low marbled (quality grade 1^{++} and 2) Hanwoo beef. Korean J. Food Sci. Anim. Resour. **36**: 679–688. doi:10.5851/kosfa.2016.36.5.679. PMID:27857545.

Jo, C., Cho, S.H., Chang, J., and Nam, K.C. 2012. Keys to production and processing of Hanwoo beef: a perspective of tradition and science. Anim. Front. **2**: 32–38. doi:10.2527/af.2012-0060.

Jo, C., Jayasena, D.D., Lim, D.G., Lee, K.H., Kim, J.J., Cha, J.S., and Nam, K.C. 2013. Effect of intramuscular fat content on the meat quality and antioxidative dipeptides of Hanwoo beef. Korean J. Food Nutr. **26**: 117–124. doi:10.9799/ksfan.2013.26.1.117.

Jung, E.-Y., Hwang, Y.-H., and Joo, S.-T. 2016. The Relationship between chemical compositions, meat quality, and palatability of the 10 primal cuts from Hanwoo steer. Korean J. Food Sci. Anim. Resour. **36**: 145–151. doi:10.5851/kosfa.2016.36.2.145. PMID:27194921.

Kadim, I.T., Mahgoub, O., Al-Ajmi, D.S., Al-Maqbaly, R.S., Al-Mugheiry, S.M., and Bartolome, D.Y. 2004. The influence of season on quality characteristics of hot-boned beef *m. longissimus thoracis*. Meat Sci. **66**: 831–836. doi:10.1016/j.meatsci.2003.08.001. PMID:22061015.

Kadim, I.T., Mahgoub, O., Al-Marzooqi, W., Al-Ajmi, D.S., Al-Maqbali, R.S., and Al-Lawati, S.M. 2008. The influence of seasonal temperatures on meat quality characteristics of hot-boned, *m. psoas major* and *minor*, from goats and sheep. Meat Sci. **80**: 210–215. doi:10.1016/j.meatsci.2007.11.022. PMID:22063324.

Kim, N.K., Cho, S., Lee, S.H., Park, H.R., Lee, C.S., Cho, Y.M., Choy, Y.H., Yoon, D., Im, S.K., and Park, E.W. 2008. Proteins in longissimus muscle of Korean native cattle and their relationship to meat quality. Meat Sci. **80**: 1068–1073. doi:10.1016/j.meatsci.2008.04.027. PMID:22063838.

Korea Institute of Animal Products Quality Evaluation (KAPE). 2017. The beef carcass grading. [Online]. Available from http://www.ekapepia.com/user/distribution/distDetail.do?nd93763 [28 July 2017] [in Korean].

Korea Meat Trade Association (KMTA). 2017. Information and data of agricultural statistics of Korea. [Online]. Available from http://www.kmta.or.kr/ [23 July 2017] [in Korean].

Kragten, S.A., and Gil, M. 2015. Chapter 5 Instrumental tenderness—shear force. Pages 45–54 in M. Font-I-Furnols, M. Čandek-Potokar, C. Maltin, and M. Prevolnik Povše, eds.

A handbook of reference methods for meat quality assessment. SRUC, European Cooperation in Science and Technology. Kings Buildings, West Mains Road, Edinburgh, Scotland.

Lee, S.H., Park, B.H., Sharma, A., Dang, C.G., Lee, S.S., Choi, T.J., Choy, Y.H., Kim, H.C., Jeon, K.J., Kim, S.D., Yeon, S.H., Park, S.B., and Kang, H.S. 2014. Hanwoo cattle: origin, domestication, breeding strategies and genomic selection. J. Anim. Sci. Technol. **56**(2): 1–8. doi:10.1186/2055-0391-56-2.

Li, C., Zhou, G., Xu, X., Zhang, J., Xu, S., and Ji, Y. 2006. Effects of marbling on meat quality characteristics and intramuscular connective tissue of beef longissimus muscle. Asian-Australas. J. Anim. Sci. **19**: 1799–1808. doi:10.5713/ajas.2006.1799.

McAfee, A.J., McSorley, E.M., Cuskelly, G.J., Moss, B.W., Wallace, J.M., Bonham, M.P., and Fearon, A.M. 2010. Red meat consumption: an overview of the risks and benefits. Meat sci. **84**(1): 1–13. doi:10.1016/j.meatsci.2009.08.029. PMID:20374748.

Miller, M.F., Carr, M.A., Ramsey, C.B., Crockett, K.L., and Hoover, L.C. 2001. Consumer thresholds for establishing the value of beef tenderness. J. Anim. Sci. **79**: 3062–3068. doi:10.2527/2001.79123062x. PMID:11811460.

Moon, S.S., Yang, H.S., Park, G.B., and Joo, S.T. 2006. The relationship of physiological maturity and marbling judged according to Korean grading system to meat quality traits of Hanwoo beef females. Meat Sci. **74**: 516–521. doi:10.1016/j.meatsci.2006.04.027. PMID:22063056.

Mottram, D.S. 1998. Flavour formation in meat and meat products: a review. Food Chem. **62**: 415–424. doi:10.1016/S0308-8146(98)00076-4.

Nielsen, B.K., and Thamsborg, S.M. 2005. Welfare, health and product quality in organic beef production: a Danish perspective. Livest. Prod. Sci. **94**: 41–50. doi:10.1016/j.livprodsci.2004.11.023.

Nishimura, T. 2015. Role of extracellular matrix in development of skeletal muscle and postmortem aging of meat. Meat Sci. **109**: 48–55. doi:10.1016/j.meatsci.2015.05.015. PMID:26141816.

Nishimura, T., Hattori, A., and Takahashi, K. 1999. Structural changes in intramuscular connective tissue during the fattening of Japanese black cattle: effect of marbling on beef tenderization. J. Anim. Sci. **77**: 93–104. doi:10.2527/1999.77193x. PMID:10064032.

Oler, A., Głowí Nska, B., Młynek, K., and Głowiska, B. 2015. Slaughter and carcass characteristics, chemical composition and physical properties of longissimus lumborum muscle of heifers as related to marbling class. Arch. Anim. Breed. **58**: 145–150. doi:10.5194/aab-58-145-2015.

Panjono, Moon Kang, S., Sun Lee, I., Kim, Y.-J., and Ki Lee, S. 2009. Relationship of slaughter age and carcass traits of Hanwoo cattle. Korean J. Food Sci. Anim. Resour. **29**: 550–556. doi:10.5851/kosfa.2009.29.5.550.

Panjono, Kang, S.M., Lee, I.S., and Lee, S.K. 2011. The quality characteristics of *M. longissimus* from Hanwoo (Korean cattle) steer with different raising altitudes and slaughter seasons. Livest. Sci. **136**: 240–246. doi:10.1016/j.livsci.2010.09.015.

Pearson, A.M., 1963. Objective and subjective measurements for meat tenderness. Proc. Meat Tenderness Symposium, Camden, NJ. Campbell Soup Co. pp. 135–160.

Prieto, N., Roehe, R., Lavín, P., Batten, G., and Andrés, S. 2009. Application of near infrared reflectance spectroscopy to predict meat and meat products quality: a review. Meat Sci. **83**: 175–186. doi:10.1016/j.meatsci.2009.04.016. PMID:20416766.

Prior, R.L., Smith, S.B., Schanbacher, R.D., and Mersmann, H.J. 1983. Lipid metabolism in finishing bulls and steers implanted with oestradiol-17 β-dipropionate. Anim. Prod. **37**(1): 81–88. doi:10.1017/S0003356100001562.

R Core Team. 2016. R: A language and environment for statistical computing. R Foundation for Statistical Computing,

Vienna, Austria. [Online]. Available from http://www.R-project.org/.

Rhee, M.S., Ryu, Y.C., and Kim, B.C. 2002. Comparative studies on metabolic rate and calpain/calpastatin activity between Hanwoo and Holstein beef. Asian-Australas. J. Anim. Sci. **15**: 1747–1753. doi:10.5713/ajas.2002.1747.

Ryan, T., and Cheetham, A. 2017. The Korean beef market: insights and prospects from an Australian perspective. Meat & Livestock Australia Market Information Report 6: 11.

Shackelford, S.D., Wheeler, T.L., Meade, M.K., Reagan, J.O., Byrnes, B.L., and Koohmaraie, M. 2001. Consumer impressions of Tender Select beef. J. Anim. Sci. **79**: 2605–2614. doi:10.2527/2001.79102605x. PMID:11721839.

Silva, S., Teixeira, A., and Font-I-Furnols, M. 2015. Chapter 2 Intramuscular fat and marbling. Pages 12–21 in M. Font-I-Furnols, M. Čandek-Potokar, C. Maltin, and M. Prevolnik Povše, eds. A handbook of reference methods for meat quality assessment. SRUC, European Cooperation in Science and Technology. Kings Buildings, West Mains Road, Edinburgh, Scotland.

Ski, V., Srividya, G., Naidu, G., Sekhar, C., and Vasantha, S.K. 2016. Heat stress and its mitigation strategies: a review. J. Vet. Sci. Res. **1**(1): 000102.

Smith, S.S., and Johnson, B.J. 2014. Marbling: management of cattle to maximize the deposition of intramuscular adipose tissue. White paper: product quality. Cattleman's Beef Board and National Cattlemen's Association, Centennial, CO. 1 pp.

Szczesniak, A.S. 2002. Texture is a sensory property. Food Qual. Prefer. **13**: 215–225. doi:10.1016/S0950-3293(01)00039-8.

Tatum, J.D. 2015. Recent trends: beef quality, value and price. Colorado State University, Fort Collins, CO. pp. 1–14.

Thompson, J.M. 2004. The effects of marbling on flavour and juiciness scores of cooked beef, after adjusting to a constant tenderness. Aust. J. Exp. Agric. **44**: 645–652. doi:10.1071/EA02171.

Torrescano, G., Sánchez-Escalante, A., Giménez, B., Roncalés, P., and Beltrán, J.A. 2003. Shear values of raw samples of 14 bovine muscles and their relation to muscle collagen characteristics. Meat Sci. **64**: 85–91. doi:10.1016/S0309-1740(02)00165-1. PMID:22062666.

Weston, A.R., Rogers, R.W., and Althen, T.G. 2002. Review: the role of collagen in meat tenderness. Prof. Anim. Sci. **18**: 107–111.

Wheeler, T.L., Cundiff, L.V., and Koch, R.M. 1994. Effect of marbling degree on beef palatability in Bos taurus and Bos indicus cattle. J. Anim. Sci. **72**: 3145–3151. doi:10.2527/1994.72123145x. PMID:7759364.

Wheeler, T.L., Shackelford, S.D., and Koohmaraie, M. 2000. Relationship of beef longissimus tenderness classes to tenderness of gluteus medius, semimembranosus, and biceps femoris. J. Anim. Sci. **78**: 2856–2861. doi:10.2527/2000.78112856x. PMID:11063309.

Yamada, T., Itoh, M., Nishimura, S., Taniguchi, Y., Miyake, T., Sasaki, S., Yoshioka, S., Fujita, T., Shiga, K., Morita, M., and Sasaki, Y. 2009. Association of single nucleotide polymorphisms in the endothelial differentiation sphingolipid G-protein-coupled receptor 1 gene with marbling in Japanese Black beef cattle. Anim. Genet. **40**(2): 209–216. doi:10.1111/j.1365-2052.2008.01822.x. PMID:19133939.

Zhang, Y.Y., Zan, L.S., Wang, H.B., Xin, Y.P., Adoligbe, C.M., and Ujan, J.A. 2010. Effect of sex on meat quality characteristics of Qinchuan cattle. Afr. J. Biotechnol. **9**: 8215–8221. doi:10.5897/AJB10.1012.