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

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<td>GAJAWEERA, CHANDIMA; Division of Animal and Dairy Science, ; Department of Animal Science, Faculty of Agriculture Chung, Ki Yong ; Hanwoo Experiment Station, National Institute of Animal Science, RDA Kwon, Eung Gi; Hanwoo Experiment Station, National Institute of Animal Science, RDA Hwang, In Ho ; Department of Animal Science, Chonbuk National University Cho, Soo Hyun ; Division of Animal Production, National Institute of animal Science, RDA Lee, Seung Hwan ; Division of Animal and Dairy Science, Chungnam National University</td>
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Evaluation of sensory attributes of Hanwoo *Longissimus dorsi* muscle and its relationships with intramuscular fat, shear force and environmental factors

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**Abbreviations**: IMF, intramuscular fat; LD, *Longissimus dorsi*; SF, shear force; WBSF, Warner-Bratzler shear force.
Evaluation of sensory attributes of Hanwoo *Longissimus dorsi* muscle and its relationships with intramuscular fat, shear force and environmental factors

Abstract

We examined the relationships 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.

*Keywords*: Sensory attributes, IMF, Shear force, season, Hanwoo
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 years 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 years (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 slaughtered nearly 738,867 including 363,332 steers, 20,264 bulls and 353,880 cows (Korea Meat Trade Association (KMTA) 2017; Korea Institute of Animal Products Quality Evaluation (KAPE) 2017). Korea is an emerging beef producer, accounting for less than 1 percent 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 last year (2016) (KMTA 2017). However, high marbling Korean beef will be expected to rivalry with the Japanese Wagyu beef especially in the East Asian market. Average 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; Hwang and Joo, 2016; Horii et al. 2009)
Meat is a highly heterogeneous product with physicochemical and sensory properties dependent on pre-slaughter factors including breed, age, weight, sex, environment and post-mortem 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 intramuscular fat (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 LD muscle and is derived from the distribution of fat among muscle bundles from a cross section of muscles (Oler et al. 2015; Yamada et al. 2009). 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 multi-parameter 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 (Food and Agriculture Organization of the United Nation (FAO) 2017; Szczesniak 2002).

The IMF content of the Hanwoo breed has increased by more than 30% over the last two decades (Smith et al. 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, assume that another new quality grade will be introduced within next few years. As IMF of Hanwoo beef significantly correlated with the sensory attributes (Jung et al. 2016; Moon et al. 2006) 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 months of age and cows no longer used for reproduction (approximately 5 years old). Therefore, it is a timely need to analysis 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, flavor 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.
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 1,082 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 five months 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 to 2kg/ day/ animal). The rate of concentrate was raised to 90% and only 10% of rice straw was provided to maximize the intramuscular fat deposition and the resulting increase in the marbling scores. Concentrate feed contained 72-73% TDN and 11-12% CP. 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 Shear force (SF)**

After 24 hours 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 were 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 pre-heated water bath for approximately 40 minutes 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 minutes. 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. 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**

LD muscles were cut into 75×20×4 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. (Cho et al. 2016; Dang et al. 2014; Belk et al. 2015; Font-I-Furnols et al. 2015).

**Statistical analysis**

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

\[ Y_{ijklmn} = \mu + IM_i + A_j + Y_k + S_l + Sx_m + (IM \ast Sx)_n + e_{ijklmn} \]
Where $Y_{ijklmn}$ indicates sensory attributes or SF, $\mu$ 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 ANOVA, followed by Tukey’s honestly significant difference (HSD) 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 months on average, respectively, than cows. Since the objective of rearing cows is reproduction purpose, cows were slaughtered at a mean age of 144.75 months (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 months) and steers (24.4-30.6 months) 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 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 physicochemical properties of the meat, especially on tenderness, IMF deposition, moisture content, pH, lightness, and hydroxyproline content (Zhang et al. 2010; Panjono et al. 2009). 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 play a major role in the maturation of collagen by decreasing the collagen degradation rate and increased the hydroxyproline content in bulls (Destefanis et al. 2003; Cross et al. 1984; Gerrard et al. 1987). Therefore, sex is an important antemortem factor contributing to variation in beef sensory parameters (Choat et al. 2006; Nielsen and Thamsborg 2005).

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 months). 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 negative 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 Figure 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%, >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%, >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 (Figure 3). This agrees with the moderate correlation for juiciness, flavour-likeness and tenderness with IMF percentage showed in Table 3.

Health concerns associated with the red meat such as major chronic diseases; cardiovascular disease, colon cancer and obesity driven a negative force 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 (Silva et al. 2015; Cheng 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).

IMF 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 (Nishimura 2015; Wheeler et al. 1994). 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. The sensory quality evaluation done by Nishimura et al. (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 Figure 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%; 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, while bulls and cows have moderate correlations of -0.49 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 2007).

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 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).

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tenderness classes to tenderness of gluteus medius, semimembranosus, and biceps

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polymorphisms in the endothelial differentiation sphingolipid G-protein-coupled
216.

### Table 1. Experimental groups according to the IMF percentage

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<th>Steers</th>
<th>Bulls</th>
<th>Cows</th>
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<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
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<tr>
<td>IMF</td>
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<tr>
<td>concentration</td>
<td>&lt;10%</td>
<td>10 - 15%</td>
<td>&gt;15%</td>
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<tr>
<td>Number of Animals</td>
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<td>13</td>
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<tr>
<td>Mean IMF %</td>
<td>7.86</td>
<td>12.88</td>
<td>18.19</td>
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**Note:** IMF percentage in loin (wet basis).
Table 2. Selected descriptive statistics based on sex.

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<td><strong>Number</strong></td>
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<td>392</td>
<td>32</td>
</tr>
<tr>
<td><strong>Age at slaughtering</strong> (months)</td>
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<td>Mean</td>
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<td>Winter</td>
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Table 3. Different parameters of the linear relationships between sensory attributes and SF with the IMF percentage.

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<th>Attributes</th>
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<td></td>
<td>a</td>
<td>b</td>
</tr>
<tr>
<td>Shear force</td>
<td>7.31***</td>
<td>-0.20***</td>
</tr>
<tr>
<td>Juiciness</td>
<td>3.67***</td>
<td>0.07***</td>
</tr>
<tr>
<td>Tenderness</td>
<td>2.98***</td>
<td>0.11***</td>
</tr>
<tr>
<td>Flavour-likeness</td>
<td>4.09***</td>
<td>0.05***</td>
</tr>
</tbody>
</table>

Note: *** P<0.001, [Attribute(Y) = a + b *IMF]
Table 4. Correlation coefficient between sensory attributes and WBSF

<table>
<thead>
<tr>
<th></th>
<th>Bulls</th>
<th>Cows</th>
<th>Steers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tenderness</td>
<td>-0.49</td>
<td>**</td>
<td>-0.80</td>
</tr>
<tr>
<td>Juiciness</td>
<td>-0.29</td>
<td>**</td>
<td>-0.62</td>
</tr>
<tr>
<td>Flavour-likeness</td>
<td>-0.32</td>
<td>**</td>
<td>-0.62</td>
</tr>
</tbody>
</table>

Note: ** P<0.01 (Correlation is significant at 0.01 level)

* P<0.05 (Correlation is significant at 0.05 level)
Figure 1. Effect of sex (steers, bulls and cows) on sensory attributes of Hanwoo beef. Different letters indicate significant differences (p<0.05) between sex.
Figure 2. Relationship between average SF and IMF percentage of Hanwoo beef.
Figure 3. Effect of the level of 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.
Figure 4. Effect of slaughtering season on sensory quality of Hanwoo bull beef. Different letters indicate significant differences (p<0.05) between the seasons.