Fatty Acid Profiles, Meat Quality, and Sensory Palatability of Grain-fed and Grass-fed Beef from Hanwoo, American, and Australian Crossbred Cattle

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Abstract

Fatty acid profiles in relation to meat quality traits and sensory palatability of grain-fed and grass-fed beef from Hanwoo, American, and Australian crossbred cattle were examined in this study. There were significant \((p<0.001)\) differences in fat content and fatty acid compositions between grain-fed and grass-fed beef. Grain-fed Hanwoo had significantly \((p<0.001)\) lower saturated fatty acid (SFA) proportion but higher monounsaturated fatty acid (MUFA) proportion compared to grass-fed cattle. The proportion of oleic acid in grain-fed Hanwoo was significantly \((p<0.001)\) higher than that in grass-fed Hanwoo, Australian crossbred, or American crossbred cattle. Grain-fed Hanwoo had significantly \((p<0.001)\) lower percentages of drip loss and cooking loss compared to other cattle. Overall palatability panel scores of grain-fed cattle were significantly \((p<0.001)\) higher than those of grass-fed cattle. Consequently, sensory overall palatability was negatively correlated with proportions of SFA and polyunsaturated fatty acid (PUFA), but positively correlated with the proportion of MUFA. In particular, the proportion of oleic acid was strongly and positively correlated with fat content \((r=0.91, p<0.001)\) and overall palatability \((r=0.92, p<0.001)\). These results implied that high-concentrate grain-fed could increase intramuscular fat (IMF) content and the proportion of oleic acid, thus increasing the sensory palatability of Hanwoo beef.

Keywords fatty acid profile, grain-fed, grass-fed, hanwoo beef, intramuscular fat, oleic acid

Introduction

It is well-known that marbling plays an important role in meat quality and sensory palatability of beef. For this reason, the value of beef carcasses is determined by meat quality grade with marbling as the most important determinant in many countries. High content of intramuscular fat (IMF) can improve the texture and juiciness of beef, thus increasing its acceptability. Our previous studies have demonstrated that an increase in crude fat content in Hanwoo beef can increase the flavor, juiciness, tenderness, and overall palatability (Hwang and Joo, 2016; Jung et al., 2016). Numerous studies have demonstrated that marbling can positively influence eating quality traits including flavor, juiciness, and tenderness of meat (Frank et al., 2016a, Frank et al., 2016b; Hocquette et al., 2014; Legako et al., 2016). However, the relationship between fatty acids and sensory palatability remains largely unknown. A better understanding of breed-, origin-, and diet-related sensory differences in proportions of fatty acids would be useful.

The sensory palatability of beef is not only affected by the amount of IMF, but
also affected by fatty acid composition of IMF (Frank et al., 2016a; Hwang and Joo, 2016; Pavan and Duckett, 2013). In general, lipid fraction in beef varies from 4-15% on fresh basis depending on several factors, including genotype, muscle type, and feeding regime (Mapiye et al., 2013). Fatty acid compositions are different depending on breeds (Smith et al., 2006). It has been reported that animals fed with high-grain diet have muscles containing higher concentrations of n-6 polyunsaturated fatty acid (PUFA) while those fed with grass diets have muscles with increased n-3 PUFA concentrations (Daley et al., 2010; Wood et al., 2008). Smith et al. (2006) have reported that a higher percentage of monounsaturated fatty acid (MUFA) can lead to a lower fat-melting point which contributes to the softness of beef fat and favorable beef flavor. In a recent study on grilled beef from three different production types (grass-fed Wagyu, grass-fed Angus, and grain-fed Angus), a trained sensory panel has shown that most flavor-related attributes are significantly correlated with the level of IMF (Frank et al., 2016a). In this regard, it can be easily anticipated that fatty acid composition of beef is affected by cattle breeds and origins, resulting in different sensory palatability. However, not many research studies have been performed on Hanwoo and imported beef in relation to grain-fed and grass-fed. Therefore, the objective of this study was to evaluate fatty acid profiles of Hanwoo (grain-fed and grass-fed) and imported beef (grain-fed American cross-breed and grass-fed Australian crossbred) in relation to sensory palatability. 

Materials and Methods

Animals and samples

A total of 10 Hanwoo steer (5 grain-fed and 5 grass-fed) carcasses were selected at commercial plants. Quality grade (QG) 1++ indicating highly marbled carcasses were selected for grain-fed Hanwoo. Grass-fed Hanwoo carcasses had QG 2 indicating low marbled. Sirloin cuts (Cheakeut in Korean name, Longissimus lumborum) were removed from carcasses, vacuum packaged, and stored at 1°C cold room for 7 d prior to analysis for meat quality traits, fatty acid composition, and sensory palatability. A total of 10 imported sirloin cuts from USA (5 grain-fed American crossbreed beef, Choice grade) and Australia (5 grass-fed Australian crossbreed beef) were purchased from a commercial meat market in Korea. All imported sirloin cuts were vacuum packaged and sampled within one month from slaughtering date.

Chemical compositions and fatty acid composition

Moisture, crude protein, and ash contents were determined according to the method described by AOAC (2000). Fat content was determined using the method described by Folch et al. (1957) with slight modification. Briefly, lipid was extracted from 3 g of homogenized meat sample with 30 mL of Folch solution I (chloroform : methanol = 2:1, v/v). The homogenate was filtered with Whatman No.1 filter paper. The filtered solution was stripped with 0.88% of NaCl and allowed to separate into two layers. After washing the wall of measuring cylinder with 10 mL of Folch solution II (chloroform : methanol : H$_2$O = 3:47:50), the final volume of the lower layer was recorded. The upper layer (methanol and water layer) was removed using an aspirator. Then, 10 mL of the lower layer (chloroform containing lipid extract) was transferred to a dish to dry at 50°C. The weight of the dish was measured before and after drying. Fat content was computed from weight difference of the dish before and after drying.

After extracting intramuscular lipids, lipid methyl esters were prepared via saponification with 1.0 N m ethanolic NaOH and subsequently methylated with boron trifluoride in methanol. Fatty acid methyl esters (FAME) were analyzed using a HP6890N (Hewlett-Packard, USA) gas chromatograph equipped with a HP7683 (Hewlett-Packard) automatic sampler. FAME separations were accomplished using a 100 m SP2560 (Supelco, USA) capillary column (0.25 mm of i.d. and 0.20 μm of film thickness). For the separation of FAME from samples, the following temperature program was applied using nitrogen as a carrier gas at a flow rate of 1 mL per min. Column oven temperature was increased from 50 to 180°C at 10°C per min, from 180 to 220°C at 5°C per min, from 220 to 240°C at 2°C per min, and then held at 240°C for 20 min. The injector and detector were maintained at 250°C. Sample injection volume was 1 μL. The analysis was performed in duplicates. Individual fatty acids were identified by comparison with retention times of standards (Supelco 37 components FAME Mix, USA). Results were expressed as percentage of total fatty acid detected based on the total peak area. Atherogenic indices were calculated as content ratio of saturated fatty acid (SFA)/unsaturated fatty acid using the following formula proposed by Ulbricht and Southgate (1991): AI (atherogenic index) = [C12:0 + 4(C 14:0) + C16:0] / [MUFA + PUFA].
Collagen content was determined according to the method described by AOAC (2000). Total collagen was determined in duplicates for approximated 4 g of minced meat sample. Then 30 mL of H$_2$SO$_4$ was added to the sample followed by subsequent hydrolysis at 105°C for 16 h. After hydrolysis, water was added to the sample to reach a total volume of 500 mL. Then, 5 mL of filtered solution after passing through a filter paper was diluted to 100 mL. Hydroxyproline content was measured using 2 mL diluted solution after adding 1 mL of oxidant solution (50 mM of chloramine-T hydrate, 156 mM citric acid, 375 mM NaOH, 661 mM sodium acetate trihydrate, 392% v/v 1-propanol, pH 6.0). Samples were vortexed and left at room temperature for 20 min before adding 1 mL of color reagent (246 mM of 4-dimethylaminobenzaldehyde, 35% v/v perchloric acid, and 65% v/v 2-propanol). Samples were vortexed, covered with foil, and then placed in a 60 °C water bath for 15 min. Samples were cooled in running water for 3 min before measuring its absorbance at wavelength 558 nm. Hydroxyproline content was calculated based on the standard curve (1.2, 2.4, 3.6, and 4.8 μg hydroxyproline per ml of H$_2$O). Results were calculated using the following equation: Total collagen = Hydroxyproline × 8. Results were expressed as mg/g of meat.

Meat quality traits

Muscle pH was measured for homogenates of 3 g sample in 27 mL of deionized water using a pH-meter (MP 230, Mettler Toledo, Switzerland). Meat color (CIE L*a*b*) was measured on the muscle surface using a Minolta Chromameter (CR-300, Minolta Co., Japan) that was standardized with a white plate (Y=93.5, x=0.313, y=0.3198). The average value from five random locations of the sample surface was used for statistical analysis.

Drip loss was measured as the weight loss during the suspension of a standardized sample (2 cm in diameter × 2 cm in thickness) in a plastic box (18 × 15 × 10 cm) at 4°C for 24 h (Joo et al., 2002). Drip loss was computed from the weight of the drip and the weight of the sample. It was then expressed as percentage loss based on the initial weight of the sample. Cooking loss was determined by weight loss during cooking. The sample (2 cm in diameter × 2 cm in thickness) was placed in a plastic bag and broiled in a water bath at temperature of 90°C for 30 min. Samples were then surface dried and weighed. Cooking loss was calculated using the following equation: Cooking loss (%) = cooked weight/uncooked weight × 100.

Mechanical tenderness was measured as Warner-Bratzler shear force (WBSF, kg/cm$^2$) using Instron Universal Testing Machine Model 3343 with a V-shaped shear blade. From each of six samples, cross sectional areas as close as possible to 0.5 cm × 4.0 cm (approximately 2.0 cm$^2$) were cut across fibers to measure cutting force. Samples were placed at right angles to the blade. Crosshead speed was set at 100 mm/min. Full scale load was 50 kg.

Sensory evaluation

Samples from each treatment were evaluated by an 8-member trained expert descriptive attribute sensory panel in the Meat Science Laboratory at Gyeongsang National University. Panelists evaluated these samples for tenderness, juiciness, flavor, and overall palatability using a 9-point hedonic scale. Evaluation was performed on a single sheet. Four lines for sensory traits were marked with the following parameters: flavor, dislike extremely (0) to like extremely (9); juiciness, very dry (0) to very juicy (9); tenderness, very tough (0) to very tender (9); overall palatability, very bad (0) to very good (9).

Statistical analysis

Data from three replicates were analyzed by analysis of variance (ANOVA) using statistical analysis systems (SAS, 2002). ANOVA was performed for the mathematical model using SAS 9.2 (SAS Institute, Inc., USA). Duncan’s multiple range tests were used to determine significance among means. Correlation analysis was performed using CORR procedure of SAS to evaluate the correlation between individual fatty acid and sensory panel traits or meat quality traits.

Results and Discussion

Chemical compositions of grain-fed and grass-fed cattle beef

There were significant ($p<0.001$) differences in chemical compositions among grain-fed and grass-fed beef from Hanwoo, American, and Australian crossbred cattle (Table 1). In particular, the fat content of sirloin from grain-fed Hanwoo was significantly ($p<0.001$) higher than that of grass-fed Hanwoo, grass-fed Australian crossbred, and grain-fed American crossbred. This was expected because QG 1++ carcasses which were highly marbled were selected for grain-fed Hanwoo. The fat content of sirloin from QG 1++ grain-fed Hanwoo was 25.4%, which was similar to that reported in our previous studies (Hwang...
and Joo, 2016; Jung et al., 2015). Also, fat contents of imported sirloins from American and Australian crossbred were 10.2% and 5.1%, respectively, which were similar to other reports (Cho et al., 2005; Kim et al., 1999; Kwon and Choi, 2015).

**Fatty acid compositions of grain-fed and grass-fed cattle**

Fatty acid profiles of sirloins from Hanwoo (grain-fed and grass-fed), American crossbred (grain-fed) and Australian crossbred (grass-fed) cattle are summarized in Table 2. The proportion of SFA was significantly (p<0.05) different between grain-fed Hanwoo and grass-fed Australian crossbred cattle, although there was no significant (p>0.05) difference in SFA proportion between grass-fed Hanwoo and grain-fed American crossbred cattle. These differences in SFA proportions among the four cattle groups were due to differences in proportions of two majority SFAs: palmitic acid (C16:0) and stearic acid (C18:0) (Daley et al., 2010; Frank et al., 2016). Proportions of these SFAs in grain-fed Hanwoo were significantly (p<0.05) lower than those in other cattle. However, there was no significant (p>0.05) difference in the proportion of palmitic acid or stearic acid between grass-fed Hanwoo and grain-fed American crossbred cattle.

In general, fatty acid compositions of adipose tissue affect its firmness because different fatty acids have different melting points. Fatty acids and their composites of meat will melt between about 25°C and 50°C. SFAs melt at higher temperature while PUFAs melt at lower temperature (Wood, 1984). According to Smith et al. (1998), palmitic acid and stearic acid, the two majority SFAs, contribute substantially to the overall fatty acid composition of beef and beef fat. Both of them can increase the hardness of fat. In particular, the concentration of stearic acid has a crucial effect on lipid melting points of adipose tissue from beef carcasses (Turk and Smith, 2009). Stearic acid has a melting point at around 70°C, whereas MUFAs have melting points below room temperature at around 20°C (Smith, 2016). In this respect, the lower proportion of SFA, especially stearic acid and palmitic acid, in grain-fed Hanwoo is certainly related to decreased melting point and decreased firmness and toughness of meat (Kwon and Choi, 2015).

Unsurprisingly, proportions of MUFA were also significantly (p<0.05) different between grain-fed and grass-fed cattle, although there was no significant (p>0.05) difference in MUFA proportion between grass-fed Hanwoo and grain-fed American crossbred cattle. Especially, grain-fed Hanwoo had significantly (p<0.05) higher MUFA proportion than grass-fed Hanwoo, grass-fed Australian crossbred, and grain-fed American crossbred. The higher proportion of MUFA in grain-fed Hanwoo was due to the higher proportion of oleic acid (C18:1 n9c) comprising the majority of MUFA. Since MUFAs have low melting points (Smith, 2016; Woods et al., 2008), sirloin from grain-fed Hanwoo is arguably soft due to the high proportion of oleic acid.

In this study, oleic acid was the most abundant fatty acid within IMF, consistent with results of previous studies (Cho et al., 2005; Hwang and Joo, 2016; Kwon and Choi, 2015). The high proportion of oleic acid might be due to the feeding of Hanwoo cattle with high-grain diets. Fat depots of cattle fed with grain-based finishing diets typically display a general decrease in SFA with age and a concomitant increase in MUFA (Huerta-Leidenz et al., 1996). The slaughter age of Hanwoo is often extended beyond 24 mon to further increase its marble fat content. The marketing age of Hanwoo has been commonly extended to an average of 31 mon. In addition, the amount of IMF content and the proportion of MUFA can increase spectacularly in grain-fed cattle with time on feed in relation to the activity of stearoyl-CoA desaturase (SCD) (Smith et al., 2016). It is certainly possible that high-concentrate grain-fed Hanwoo cattle can stimulate the activity of adipose tissue SCD, resulting in the accumulation of oleic acid and MUFA due to higher SCD activity (Wang et al., 2005). Consequently, this might have contributed to

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**Table 1. Chemical compositions (%) of grain-fed and grass-fed beef from Hanwoo, American, and Australian crossbred cattle**

|                | Hanwoo Beef (grain-fed) | Hanwoo Beef (grass-fed) | American Beef (grain-fed) | Australian Beef (grass-fed) |
|----------------|-------------------------|-------------------------|---------------------------|-----------------------------|
| Crude fat      | 25.39±1.47              | 5.94±0.54               | 10.22±0.79                | 5.15±0.47                   |
| Crude protein  | 16.62±0.76              | 20.42±0.60              | 19.95±0.56                | 20.89±0.19                 |
| Moisture       | 56.89±0.81              | 72.52±0.13              | 68.63±0.36                | 72.84±0.36                 |
| Ash            | 1.05±0.07               | 1.05±0.02               | 1.02±0.04                 | 1.05±0.05                  |

ACMeans±SD with different superscripts in the same row are significantly different (p<0.001).
The high oleic acid seen in Hanwoo beef compared to that in imported beef from USA or Australia.

Early studies have clearly shown that beef from grain-fed cattle have higher concentrations of n-6 PUFAs while grass-fed beef have higher concentrations of n-3 PUFAs (Kemp et al., 1981; Larick and Turner, 1990). This was confirmed in the present study. The proportion of PUFA in grass-fed Hanwoo was higher compared to that in grain-fed Hanwoo. Both grain-fed Hanwoo and American crossbred cattle had higher proportions of n-6 PUFA, especially linoleic acid (C18:2 n-6), compared to grass-fed Hanwoo and Australian crossbred cattle. On the other hand, proportions of n-3 PUFA, especially α-linolenic acid (C18:3 n-3), were higher in grass-fed Hanwoo and Australian crossbred cattle compared to those in grain-fed cattle. This was in agreement with results of Wood et al. (1999) showing that the ratios of C18:2/C18:3 were higher in grain-fed ruminants compared to those in grass-fed animals. Results of the present study suggested that these different proportions of n-3 and n-6 PUFAs might be associated with flavor perception as suggested by Mitchell et al. (1991). Our results also suggest that the lower AI values in grain-fed cattle compared to those in grass-fed cattle might potential have human health benefits.

### Table 2. Fatty acid compositions (%) of grain-fed and grass-fed beef from Hanwoo, American, and Australian crossbred cattle

| Fatty acids | Hanwoo Beef (grass-fed) | Hanwoo Beef (grain-fed) | American Beef (grass-fed) | American Beef (grain-fed) | Australian Beef (grass-fed) | Australian Beef (grain-fed) |
|-------------|--------------------------|--------------------------|---------------------------|---------------------------|-----------------------------|-----------------------------|
| C10:0       | 0.06±0.00                | 0.07±0.00                | 0.06±0.01                 | 0.07±0.02                 |
| C12:0       | 0.06±0.01                 | 0.07±0.00                | 0.05±0.01                 | 0.07±0.01                 |
| C14:0       | 2.43±0.13                 | 2.62±0.10                | 2.56±0.06B                | 2.67±0.08B                |
| C15:0       | 0.35±0.03                 | 0.37±0.04                 | 0.35±0.05B                | 0.50±0.04                 |
| C16:0       | 26.22±0.60               | 29.29±0.57               | 27.55±0.60D               | 30.57±0.73A               |
| C17:0       | 1.31±0.04                 | 1.31±0.15                 | 1.19±0.10B                | 1.36±0.07                 |
| C18:0       | 8.98±0.35                 | 13.32±1.67               | 14.31±0.64B               | 15.73±0.87A               |
| C18:1       | 0.11±0.02                 | 0.14±0.02                 | 0.12±0.01BC               | 0.17±0.02                 |
| C20:0       | 0.11±0.03                 | 0.02±0.01                 | 0.05±0.02B                | 0.02±0.01                 |
| C22:0       | 0.04±0.01                 | 0.01±0.01                 | 0.03±0.01AB               | 0.03±0.01                 |
| C14:1       | 0.60±0.06                 | 0.45±0.09                 | 0.50±0.06AB               | 0.43±0.08                 |
| C15:1       | 0.05±0.01                 | 0.04±0.01                 | 0.05±0.01A                | 0.04±0.01                 |
| C16:1       | 4.40±0.19                 | 3.47±0.36                 | 4.42±0.05A                | 3.54±0.38                 |
| C17:1       | 1.12±0.04                 | 0.98±0.10                 | 0.96±0.19A                | 0.86±0.16                 |
| C18:1(n-9)  | 50.62±1.01\(^A\)         | 43.75±1.36\(^A\)         | 44.15±1.21\(^B\)          | 40.09±1.26\(^C\)          |
| C20:1       | 0.28±0.07                 | 0.32±0.02                 | 0.20±0.01\(^B\)          | 0.27±0.03\(^A\)          |
| C22:1(n-9)  | 0.05±0.02                 | 0.06±0.01                 | 0.05±0.01                 | 0.04±0.01                 |
| C18:2(n-6)  | 2.25±0.06                 | 1.93±0.24                 | 2.08±0.09\(^AB\)         | 1.69±0.11\(^C\)          |
| C20:2(n-6)  | 0.19±0.05                 | 0.19±0.08                 | 0.19±0.04                 | 0.22±0.03                 |
| C18:3(n-3)  | 0.17±0.07\(^C\)         | 0.97±0.06                 | 0.47±0.09\(^B\)          | 0.91±0.08\(^A\)          |
| C18:3(n-6)  | 0.12±0.03\(^A\)         | 0.05±0.01\(^B\)         | 0.12±0.01\(^A\)          | 0.13±0.02\(^A\)          |
| C20:3(n-3)  | 0.02±0.01\(^B\)         | 0.05±0.01\(^A\)         | 0.03±0.01\(^B\)          | 0.05±0.01\(^A\)          |
| C20:3(n-6)  | 0.18±0.05\(^AB\)       | 0.14±0.04\(^B\)         | 0.20±0.02\(^A\)          | 0.15±0.02\(^B\)          |
| C20:4(n-6)  | 0.21±0.06                 | 0.17±0.10                 | 0.22±0.06                 | 0.22±0.04                 |
| C20:5(n-3)  | 0.05±0.02\(^BC\)       | 0.12±0.03\(^A\)         | 0.02±0.01\(^C\)          | 0.07±0.01\(^B\)          |
| C22:6(n-3)  | 0.03±0.02\(^B\)         | 0.08±0.01\(^A\)         | 0.05±0.01\(^B\)          | 0.08±0.01\(^A\)          |

\(^A\)-\(^D\)Means±SD with different superscripts in the same row are significantly different (p<0.05).

\(^A\)SFA, Saturated fatty acids; \(^B\)MUFA, Monounsaturated fatty acids; \(^C\)PUFA, Polynsaturated fatty acids; \(^D\)AI, Atherogenic index.
loins from grain-fed and grass-fed cattle. Muscle pH of grass-fed Australian crossbred cattle was significantly \((p<0.001)\) higher than that of grain-fed Hanwoo. Contrarily, the lightness (CIE L*) value of grain-fed Hanwoo was significantly \((p<0.001)\) higher than that of grass-fed Australian crossbred cattle. Higher CIE L* value of grain-fed Hanwoo was definitely related to its abundant white fat content. Interestingly, Chroma values of grain-fed cattle were significantly \((p<0.001)\) higher than those of grass-fed cattle. Grass-fed cattle also had higher percentages of drip loss and cooking loss compared to grain-fed cattle. Especially, grain-fed Hanwoo had significantly \((p<0.001)\) lower percentages of drip loss and cooking loss compared to other cattle. These results are consistent with those of an earlier study showing that highly marbled meat has less drip loss. Therefore, increased IMF content could improve the water-holding capacity of meat (Joo et al., 2002).

In our previous studies, lower drip and cooking loss percentages in grain-fed Hanwoo have been found to be closely related to high IMF content (Hwang and Joo, 2016; Jung et al., 2015; Jung et al., 2016). In general, water-holding capacity and chemical composition of meat are influenced by IMF. As IMF is increased from 6.6% to 21.5%, moisture content is declined (Cho et al., 2005). Consequently, drip loss and water lost during cooking are lower in meat with high IMF (Frank et al., 2016b). Results of the present study clearly showed that shear force value and collagen content of grain-fed Hanwoo were significantly \((p<0.001)\) lower than those of other cattle. These results confirm that IMF can affect tenderness, although there has been extensive debate about the contribution of IMF to the tenderness of meat (Joo et al., 2013).

### Sensory panel scores of grain-fed and grass-fed cattle beef

As expected, sensory panel traits were strongly and positively influenced by IMF content and fatty acid compositions of sirloins from grain-fed and grass-fed cattle. Sensory panel scores of beef from Hanwoo (grain-fed), Hanwoo (grass-fed), American crossbred (grain-fed), and Australian crossbred (grass-fed) are shown in Table 4. Sensory flavor scores of grain-fed cattle were significantly \((p<0.001)\) higher than those of grass-fed cattle, although grass-fed Hanwoo beef had significantly \((p<0.001)\) higher flavor scores compared to grain-fed American crossbred beef. Also, juiciness and tenderness scores of grain-fed Hanwoo and American crossbred beef were significantly \((p<0.001)\) higher than those of grass-fed Hanwoo and Australian crossbred beef. Consequently, overall palatability scores of grain-fed cattle were significantly \((p<0.001)\) higher than those of grass-fed cattle.

### Table 3. Meat quality traits of grain-fed and grass-fed beef from Hanwoo, American, and Australian crossbred cattle

|                | Hanwoo Beef (grain-fed) | Hanwoo Beef (grass-fed) | American Beef (grain-fed) | Australian Beef (grass-fed) |
|----------------|-------------------------|-------------------------|---------------------------|-----------------------------|
| Muscle pH      | 5.60±0.06               | 5.69±0.05**             | 5.65±0.12**               | 5.72±0.07                  |
| CIE L*         | 41.64±2.52              | 34.01±2.00              | 35.05±0.96                | 35.37±1.08                 |
| CIE a*         | 23.33±1.99              | 20.39±1.55              | 24.40±1.70                | 22.04±3.00                 |
| CIE b*         | 5.73±1.03               | 7.44±0.61               | 6.24±0.97                 | 4.30±2.02                  |
| Chroma         | 24.03±1.20              | 21.70±1.62              | 25.19±1.87                | 22.49±3.30                 |
| Hue            | 13.66±1.85              | 19.96±1.04              | 14.18±1.29                | 10.54±3.85                 |
| Drip loss (%)  | 0.72±0.21               | 1.68±0.25               | 1.57±0.28                 | 1.98±0.2                  |
| Cooking loss (%)| 20.16±1.37              | 23.01±2.87              | 22.32±1.21                | 23.84±1.23                 |
| Shear force (kg/cm²) | 2.01±0.42         | 4.11±1.03               | 3.92±0.87                 | 4.97±0.60                 |
| Collagen (g/100g) | 0.89±0.21              | 1.27±0.20               | 1.34±0.16                 | 1.86±0.15                 |

\(\text{A-CMeans±SD with different superscripts in the same row are significantly different (}\ p<0.001).\)

### Table 4. Sensory panel scores of grain-fed and grass-fed beef from Hanwoo, American, and Australian crossbred cattle

|                | Hanwoo Beef (grain-fed) | Hanwoo Beef (grass-fed) | American Beef (grain-fed) | Australian Beef (grass-fed) |
|----------------|-------------------------|-------------------------|---------------------------|-----------------------------|
| Flavor         | 7.38±0.38               | 6.72±0.22               | 5.80±0.16                 | 5.89±0.19                  |
| Juiciness      | 8.12±0.09               | 4.58±0.21               | 7.07±0.22                 | 4.14±0.17                  |
| Tenderness     | 7.12±0.17               | 4.74±0.33               | 6.43±0.34                 | 3.83±0.21                  |
| Overall palatability | 7.78±0.18           | 4.94±0.23               | 6.22±0.25                 | 4.09±0.22                  |

\(\text{A-DMeans±SD with different superscripts in the same row are significantly different (}\ p<0.001).\)
These results are consistent with previous reports showing that increasing IMF content in beef through high grain-fed can increase flavor intensity and juiciness of beef (Frank et al., 2016a; Smith, 2016). According to Wood et al. (2008), total lipid content of muscle (IMF) has a role in the tenderness and juiciness of cooked meat, although the strength of the correlation varies considerably between studies. Nowadays, it is generally accepted that increasing levels of marbling correspond to more acceptable flavor, juiciness, and overall liking (Corbin et al., 2015; Frank et al., 2016a; Hunt et al., 2014; Legako et al., 2016). Higher fat content in the meat also results in higher initial and sustained juiciness scores based on consumers and trained panelists (Frank et al., 2016a). In a study on grilled beef from three different production types (grass-fed Wagyu, grass-fed Angus, and grain-fed Angus), a trained sensory panel has shown that most flavor-related attributes are significantly correlated with the level of IMF (Frank et al., 2016a). Thus, it is possible that the palatability of beef can be improved by increasing IMF content through high-concentrated grain-fed, thus increasing sensory flavor, juiciness, and tenderness.

**Relationship between fatty acid compositions and meat quality or sensory traits**

Results of correlations between fatty acid proportions and meat quality traits or sensory panel scores are presented in Table 5. The majority of SFAs such as palmitic acid and stearic acid were negatively correlated with fat content, but positively correlated with collagen content (p <0.001). These SFAs were also positively correlated with drip loss and shear force, but negatively correlated with sensory juiciness and tenderness scores (p<0.01). Results of the present study clearly showed that the majority of SFAs had negative correlations with overall palatability, although they were positively correlated with sensory flavor score. In contrast, oleic acid, the most abundant fatty acid in IMF of beef, was positively correlated with fat content (r=0.91, p<0.001), but negatively correlated with collagen content (r=-0.79, p<0.001), drip loss (r=-0.88, p<0.001), and shear force (r=-0.78, p<0.001). Oleic acid was also strongly and positively correlated with all sensory panel scores, including flavor (r=0.76, p<0.001), juiciness (r=0.82, p<0.001), tenderness (r=0.84, p<0.001), and overall palatability (r=0.92, p<0.001). In addition, linoleic acid and α-linolenic acid had opposite correlations with meat quality traits and sensory panel scores. Linoleic acid, the majority of omega-6 fatty acid, had negative correlation with fat content. However, omega-3 fatty acids such as α-linolenic acid and docosahexaenoic acid (C22:6 n-3, DHA) had positive correlation with fat content. Also, linoleic acid was positively correlated with all sensory panel scores while α-linolenic acid was negatively correlated with all sensory panel scores. Consequently, sensory panel scores were negatively correlated with SFA and PUFA, but positively correlated with MUFA.

Previously, our study has shown that highly marbled Hanwoo beef have different amounts of IMF and meat

### Table 5. Correlation coefficients between fatty acids and meat quality traits or sensory panel scores

|                | Fat content | Collagen content | Drip loss | Shear Force | Flavor | Juiciness | Tenderness | Overall palatability |
|----------------|-------------|------------------|-----------|-------------|--------|-----------|------------|----------------------|
| C12:0          | -0.52*      | 0.45*            | 0.37      | 0.27        | -0.10  | -0.75***  | -0.71***   | -0.65***             |
| C14:0          | -0.69***    | 0.50*            | 0.59**    | 0.72***     | -0.50* | -0.67**   | -0.64**    | -0.72***             |
| C16:0          | -0.84***    | 0.77***          | 0.83**    | 0.74***     | 0.77***| -0.51*    | -0.91***   | -0.90***             |
| C18:0          | -0.87***    | 0.75**           | 0.83**    | 0.69***     | -0.83***| -0.71***  | -0.73***   | -0.83***             |
| C21:0          | 0.90***     | -0.62***         | -0.75***  | -0.71***    | 0.63** | 0.81***   | 0.74***    | 0.83***              |
| C18:1 (n-9)    | 0.91***     | -0.79***         | -0.88***  | -0.78***    | 0.76** | 0.82***   | 0.84***    | 0.92***              |
| C18:2 (n-6)    | 0.72***     | -0.63**          | -0.58**   | -0.73***    | 0.54*  | 0.81***   | 0.81***    | 0.84***              |
| C18:3 (n-3)    | -0.89***    | 0.62**           | 0.73***   | 0.75***     | -0.40  | -0.96***  | -0.91***   | -0.92***             |
| C20:3 (n-6)    | -0.68**     | 0.55*            | 0.57**    | 0.54*       | -0.17  | -0.87***  | -0.83***   | -0.78***             |
| C22:6 (n-3)    | -0.76***    | 0.66**           | 0.67**    | 0.59**      | -0.39  | -0.88***  | -0.84***   | -0.84***             |
| SFA*           | -0.90***    | 0.80***          | 0.87***   | 0.76***     | -0.73***| -0.84***  | -0.86***   | -0.93***             |
| MUFA           | 0.92***     | -0.80***         | -0.88***  | -0.77***    | 0.73***| 0.86***   | 0.87***    | 0.94***              |
| PUFA           | -0.53*      | 0.33             | 0.42      | 0.53*       | -0.13  | -0.56*    | -0.53*     | -0.49*               |
| 2n-3           | -0.86***    | 0.60**           | 0.69**    | 0.70***     | -0.35  | -0.96***  | -0.91***   | -0.91***             |
| 2n-6           | 0.65*       | -0.49*           | -0.52*    | -0.44       | 0.34   | 0.75***   | 0.71***    | 0.75***              |

*p<0.05, **p<0.01, ***p<0.001.

1SFA, Saturated fatty acids; MUFA, Monounsaturated fatty acids; PUFA, Polyunsaturated fatty acids.
quality traits as well as sensory properties (Hwang and Joo, 2016). A high-concentrate grain-fed is suggested to increase the IMF content in Hanwoo beef because overall palatability of beef could be improved by increasing fat content. In this study, differences in fatty acid compositions between grain-fed and grass-fed beef were confirmed (Table 2). Correlations between fatty acid compositions and meat quality traits or sensory panel scores were also observed (Table 5). Variations in the amount of marbling fat and fatty acid compositions between grain-fed and grass-fed cattle might have contributed to the differences in meat quality and sensory palatability between domestic Hanwoo beef and imported beef from USA and Australia.

Results of the present study clearly showed that the proportion of SFA was negatively correlated with sensory panel scores while the proportion of MUFA was positively correlated with sensory panel scores. These results were not similar to those of Cho et al. (2005) and Hwang and Joo (2016) showing positive correlations between SFAs and all sensory traits but negative correlations between PUFA and all sensory traits. The positive correlation between oleic acid and sensory panel scores was also expected because an increased level of IMF was reported to have positive influence on sensory qualities (Fernandez et al., 1999). Larick and Turner (1990) have also reported a positive correlation between cooked beef fat flavor and oleic acid, the main fatty acid in the IMF of cattle. Thus, high-concentrate grain-fed should be greatly emphasized to increase IMF content and the proportion of oleic acid in Hanwoo beef. This might be one of the best ways to differentiate domestic Hanwoo beef from imported American and Australian beef.

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