Korean Journal for Food Science of Animal Resources

pISSN 1225-8563
eISSN 2234-246X

Korean J. Food Sci. An. 37(2): 153~161 (2017)
DOI https://doi.org/10.5851/kosfa.2017.37.2.153

ARTICLE

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

Young-Hwa Hwang[1] and Seon-Tea Joo*

Division of Applied Life Science (BK21+), Gyeongsang National University, Jinju 52852, Korea
[1]Institute of Agriculture & Life Science, Gyeongsang National University, Jinju 52852, Korea

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

Received February 20, 2017
Revised March 3, 2017
Accepted March 3, 2017

*Corresponding author
Seon-Tea Joo
Meat Science Laboratory, Department of Animal Science, Collage of Agriculture & Life Science, Gyeongsang National University, Jinju 52852, Korea
Tel: +82-55-772-1943
Fax: +82-55-772-1949
E-mail: stjoo@gnu.ac.kr

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 crossbreed 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 (Chaekeut 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 stirred 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_2O = 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 methanolic 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(C14:0) + 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_2SO_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, 29% v/v 1-ptopanol, pH 6.0). Samples were vortexed and left at room temperature for 20 min before adding 1 mL of color regent (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 from a standard curve (1.2, 2.4, 3.6, and 4.8 μg hydroxyproline per ml of H_2O). 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=0.3132, 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

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^{A}	5.94±0.54^{C}	10.22±0.79^{B}	5.15±0.47^{C}
Crude protein	16.62±0.76^{C}	20.42±0.60^{AB}	19.95±0.56^{B}	20.89±0.19^{A}
Moisture	56.89±0.81^{C}	72.52±0.13^{A}	68.63±0.36^{B}	72.84±0.36^{A}
Ash	1.05±0.07	1.05±0.02	1.02±0.04	1.05±0.05

$^{A-C}$Means±SD with different superscripts in the same row are significantly different ($p<0.001$).

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 beef

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 marbling 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

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

Fatty acids	Hanwoo Beef (grain-fed)	Hanwoo Beef (grass-fed)	American Beef (grain-fed)	Australian Beef (grass-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^{B}	0.07±0.00^{A}	0.05±0.01^{B}	0.07±0.01^{A}
C14:0	2.43±0.13^{B}	2.62±0.10^{A}	2.56±0.06^{AB}	2.67±0.08^{A}
C15:0	0.35±0.03^{B}	0.37±0.04^{B}	0.35±0.05^{B}	0.50±0.04^{A}
C16:0	26.22±0.66^{D}	29.29±0.57^{B}	27.55±0.69^{C}	30.57±0.73^{A}
C17:0	1.31±0.04^{AB}	1.31±0.15^{AB}	1.19±0.10^{B}	1.36±0.07^{A}
C18:0	8.98±0.35^{C}	13.32±1.67^{B}	14.31±0.64^{B}	15.73±0.87^{A}
C20:0	0.11±0.02^{C}	0.14±0.02^{B}	0.12±0.01^{BC}	0.17±0.02^{A}
C21:0	0.11±0.03^{A}	0.02±0.01^{B}	0.05±0.02^{B}	0.02±0.01^{B}
C22:0	0.04±0.01^{A}	0.01±0.01^{C}	0.03±0.01^{AB}	0.03±0.01^{B}
C14:1	0.60±0.06^{A}	0.45±0.09^{B}	0.50±0.06^{AB}	0.43±0.08^{B}
C15:1	0.05±0.01^{AB}	0.04±0.01^{AB}	0.05±0.01^{A}	0.04±0.01^{B}
C16:1	4.40±0.19^{A}	3.47±0.36^{B}	4.42±0.05^{A}	3.54±0.38^{B}
C17:1	1.12±0.04^{A}	0.98±0.10^{AB}	0.96±0.19^{AB}	0.86±0.16^{B}
C18:1 (n-9)	50.62±1.01^{A}	43.75±1.36^{B}	44.15±1.21^{B}	40.09±1.26^{C}
C20:1	0.28±0.07^{A}	0.32±0.02^{A}	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^{A}	1.93±0.24^{B}	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^{A}	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}
SFA[1]	39.66±1.07^{C}	47.23±2.04^{B}	46.28±1.05^{B}	51.20±1.06^{A}
MUFA[2]	57.11±0.85^{A}	49.07±1.82^{B}	50.34±1.15^{B}	45.28±1.05^{C}
PUFA[3]	3.22±0.23^{B}	3.70±0.33^{A}	3.38±0.17^{AB}	3.52±0.17^{AB}
Σn-6	2.95±0.15^{A}	2.48±0.37^{B}	2.82±0.17^{A}	2.41±0.15^{B}
Σn-3	0.27±0.10^{C}	1.22±0.10^{A}	0.56±0.10^{B}	1.11±0.06^{A}
AI[4]	0.60±0.03^{D}	0.76±0.03^{B}	0.71±0.02^{C}	0.84±0.03^{A}

$^{A\text{-}D}$Means±SD with different superscripts in the same row are significantly different ($p<0.05$).
[1]SFA, Saturated fatty acids; [2]MUFA, Monounsaturated fatty acids; [3]PUFA, Polyunsaturated fatty acids; [4]AI, Atherogenic index.

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 (C 18:3 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.

Meat quality traits of grain-fed and grass-fed cattle beef

Meat quality traits of grain-fed and grass-fed cattle are shown in Table 3. Meat quality traits were affected by different contents and fatty acid compositions of IMF in sirloins 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 the 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 positive 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	$5.60±0.06^{B}$	$5.69±0.05^{AB}$	$5.65±0.12^{AB}$	$5.72±0.07^{A}$
CIE L*	$41.64±2.52^{A}$	$34.01±2.00^{B}$	$35.05±0.96^{B}$	$35.37±1.08^{B}$
CIE a*	$23.33±0.99^{A}$	$20.39±1.55^{B}$	$24.40±1.70^{A}$	$22.04±3.00^{AB}$
CIE b*	$5.73±1.03^{AB}$	$7.44±0.61^{A}$	$6.24±0.97^{A}$	$4.30±2.02^{B}$
Chroma	$24.03±1.20^{AB}$	$21.70±1.62^{B}$	$25.19±1.87^{A}$	$22.49±3.30^{AB}$
Hue	$13.66±1.85^{B}$	$19.96±1.04^{A}$	$14.18±1.29^{B}$	$10.54±3.85^{C}$
Drip loss (%)	$0.72±0.21^{C}$	$1.68±0.27^{AB}$	$1.57±0.28^{B}$	$1.98±0.2^{A}$
Cooking loss (%)	$20.16±1.37^{B}$	$23.01±2.87^{A}$	$22.32±1.21^{AB}$	$23.84±1.23^{A}$
Shear force (kg/cm^2)	$2.01±0.42^{B}$	$4.11±1.03^{A}$	$3.92±0.87^{A}$	$4.97±0.60^{A}$
Collagen (g/100g)	$0.89±0.21^{C}$	$1.27±0.20^{B}$	$1.34±0.16^{B}$	$1.86±0.15^{A}$

$^{A-C}$Means±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	$7.38±0.38^{A}$	$6.72±0.22^{B}$	$5.80±0.16^{C}$	$5.89±0.19^{C}$
Juiciness	$8.12±0.09^{A}$	$4.58±0.21^{C}$	$7.07±0.22^{B}$	$4.14±0.17^{D}$
Tenderness	$7.12±0.17^{A}$	$4.74±0.33^{C}$	$6.43±0.34^{B}$	$3.83±0.21^{D}$
Overall palatability	$7.78±0.18^{A}$	$4.94±0.23^{C}$	$6.22±0.25^{B}$	$4.09±0.22^{D}$

$^{A-D}$Means±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[1]	-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*
Σn-3	-0.86***	0.60**	0.69**	0.70***	-0.35	-0.96***	-0.91***	-0.91***
Σn-6	0.65**	-0.49*	-0.52*	-0.44	0.34	0.75***	0.71***	0.75***

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

[1]SFA, 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 PUFAs 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.

Acknowledgements

This research was supported by Korean Institute of Planning and Evaluation for Technology in Food, Agriculture, Forestry and Fisheries (IPET) through Agri-Bio-industry Technology Development Program, funded by Ministry of Agriculture, Food and Rural Affairs (MAFRA) (Project No. 315017-05-1-SB-140).

References

1. 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 Korean Hanwoo and Australian Angus beef. *Asian-Aust. J. Anim. Sci.* **18**, 1786-1793
2. Corbin, C. H., O'Quinn, T. G., Garmyn, A. J., Legako, J. F., Hunt, M. R., Dinh, T. T. N., Rathmann, R. J., Brooks, J. C., and Miller, M. F. (2015) Sensory evaluation of tender beef strip loin steaks of varying marbling levels and quality treatments. *Meat Sci.* **100**, 24-31.
3. Daley, C., Abbott, A., Doyle, P., Nader, G., and Larson, S. (2010) A review of fatty acid profiles and antioxidant content in grass-fed and grain-fed beef. *Nutr. J.* **9**, 10.
4. Fernandez, X., Monin, G., Talnamt, A., Mourot, J., and Lebret, B. (1999) Influence of intramuscular fat content on the quality of pig meat - 2. Consumer acceptability of m. longissimus lumborum. *Meat Sci*. **53**, 67-72.
5. Folch, J., Lees, M., and Sloane-Stanley, G. H. (1957) A simple method for the isolation and purification of total lipids from animal tissues. *J. Biol. Chem*. **226**, 497-509.
6. Frank, D., Ball, A., Hughes, J., Krishnamurthy, R., Piyasiri, U., Stark, J., Watkins, P., and Warner, R. (2016a) Sensory and flavor chemistry characteristics of Australian beef: Influence of intramuscular fat, feed and breed. *J. Agric. Food Chem*. **64**, 4299-4311.
7. Frank, D., Joo, S. T., and Warner, R. (2016b) Consumer acceptability of intramuscular fat. *Korean J. Food Sci. An*. **36**, 699-708.
8. Hocquette, J. F., Van Wezemael, L., Chriki, S., Legrand, I., Verbeke, W., Farmer, L., and Pethick, D. W. (2014) Modelling of beef sensory quality for a better prediction of palatability. *Meat Sci*. **97**, 316-322.
9. Huerta-Leidenz, N. O., Cross, H. R., Savell, J. W., Kunt, D. K., Baker, J. F., and Smith, S. B. (1996) Fatty acid composition of subcutaneous adipose tissue from male calves at different stages of growth. *J. Anim. Sci*. **74**, 1256-1260
10. Hunt, M. R., Garmyn, A. J., O'Quinn, T. G., Corbin, C. H., Legako, J. F., Rathmann, R. J., Brooks, J. C., & Miller, M. F. (2014) Consumer assessment of beef palatability from four beef muscles from USDA Choice and Select graded carcasses. *Meat Sci.* **98**, 1-8.
11. 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 steers. *Korean J. Food Sci. An*. **36**, 679-688.
12. Joo, S. T., Kim, G. D., Hwang, Y. H., and Ryu, Y. C. (2013) Control of fresh meat quality through manipulation of muscle fiber characteristics. *Meat Sci*. **95**, 828-836.
13. Joo, S. T., Lee, J. I., Ha, Y. L., and Park, G. B. (2002) Effects of dietary conjugated linoleic acid on fatty acid composition, lipid oxidation, color, and water-holding capacity of pork loin. *J. Anim. Sci.* **80,** 108-112.
14. Jung, E. Y., Hwang, Y. H., and Joo, S. T. (2015) Chemical components and meat quality traits related to palatability of ten primal cuts from Hanwoo carcasses. *Korean J. Food Sci. An*. **35**, 859-866.
15. Jung, E. Y., Hwang, Y. H., and Joo, S. T. (2016) The relationship between chemical compostions, meat quality, and palatability of the 10 primal cuts from Hanwoo steer. *Korean J. Food Sci. An*. **36**, 137-143.

16. Kemp, J. D., Mahyuddin, L., Ely, D. J., Fox, J. D., and Moody, W. G. (1981) Effect of feeding systems, slaughter weight and sex on organoleptic properties and fatty acid composition of lamb. *J. Anim. Sci*. **51**, 321-330.
17. Kim, I. S., Lee, S. O., Kang, S. N., Byun, J. S., and Lee, M. (1999) The physiochemical, microbial and sensory characteristics of Hanwoo and imported chilled beef. *Korean J. Food Sci. An*. **19**, 331-338.
18. Kwon, H. N. and Choi, C. B. (2015) Comparison of lipid content and monounsaturated fatty acid composition of beef by country of origin and marbling score. *J. Korean Soc. Food Sci. Nutr.* **44,** 1806-1812.
19. Larick, D. K. and Turner, B. E. (1990) Head space volatiles and sensory characteristics of ground beef from forage- and grain fed heifers. *J. Food Sci*. **54**, 649-654.
20. Legako, J. F., Dinh, T. T. N., Miller, M. F., Adhikari, K., and Brooks, J. C. (2016) Consumer palatability scores, sensory descriptive attributes, and volatile compounds of grilled beef steaks from three USDA Quality Grades. *Meat Sci.* **112**, 77-85.
21. Mapiye, C., Aalhus, J. L., Turner, T. D., Rolland, D. C., Basarab, J. A., Baron, V. S., and Dugan, M. E. R. (2013) Effects of feeding flaxseed or sunflower-seed in high-forage diets on beef production, quality and fatty acid composition. *Meat Sci*. **95**, 98-109.
22. Mitchell, G. E., Reed, A. W., and Rogers, S. A. (1991) Influence of feeding regimen on the sensory qualities and fatty acid contents of beef steaks. *J. Food Sci*. **56**, 1101-1103.
23. SAS (2002) *SAS/STAT software for PC*. Cary: SAS Institute Inc.
24. Smith, S. B. (2016) Marbling and its nutritional impact on risk factors for cardiovascular disease. *Korean J. Food Sci. An*. **36**, 435-444.
25. Smith, S. B., Lunt, D. K., Chung, K. Y., Choi, C. B., Tume, R. K., and Zembayashi, M. (2006) Adiposity, fatty acid composition, and delta-9 desaturase activity during growth in beef cattle. *Anim. Sci. J.* **77**, 478-486.
26. Smith, S. B., Yang, A., Larsen, T. W., and Tume, R. K. (1998) Positional analysis of triacrylglycerols from bovine adipose tissue lipids varying in degree of unsaturation. *Lipids.* **33**, 197-207.
27. Turk, S. N. and Smith, S. B. (2009) Carcass fatty acid mapping. *Meat Sci*. **81**, 658-663.
28. Ulbricht, T. L. V. and Southgate, D. A. T. (1991) Coronary heart disease: Seven dietary factors. *Lancet*. **338**, 985-992.
29. Wang, Y. H., Revertter, A., Mannen, H., Taniguchi, M., Haper, G. S., Oyama, K. Byrne, K. A., Oka, A., Tsuji, S., and Lehnert, S. A. (2005) Transcriptional profiling of muscle tissue in growing Japanese Black cattle to identify genes involved with the development of intramuscular fat. *Aust. J. Exp. Agr*. **45**, 809-820.
30. Wood, J. D. (1984) Fat deposition and the quality of fat tissue in meat animals. In: Fats in animal nutrition. Wiseman, J. (ed) Butterworths, London, pp. 407-435.
31. Wood, J. D., Enser, M., Fisher, A. V., Nute, G. R., Richardson, R. I., and Sheard, P. R. (1999) Manipulating meat quality and composition. *Proc. Nutr. Soc*. **58**, 1-8.
32. Wood, J. D., Enser, M., Fisher, A. V., Nute, G. R., Sheard, P. R., Richardson, R. I., Hughes, S. I., and Whittington, F. M. (2008) Fat deposition, fatty acid composition and meat quality: A review. *Meat Sci*. **78**, 343-358.